# ON THE VALUE OF DEMAND INFORMATION DISSEMINATION

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# On The Value of Demand Information Dissemination

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Zhongyuan HAO (Name of student)

# Abstract

The importance of information can never be overstated. In the industrial world, more and more firms have deployed information systems to collect market data. Those firms who have symmetric information availabilities can choose to share their signals with each other, which is called horizontal information sharing. For the supply chain, however, the firms often have asymmetric information availabilities. The downstream firms, due to their market proximity and IT investment, usually have exclusive access to market demand. To be proactive with market savvy, more and more of upstream firms have taken the initiatives to strengthen the connection with the downstream firms and acquire information from them. The main purpose of this study is to explore the incentives for horizontal information sharing and vertical information acquisition among firms facing uncertain demand.

We first investigate information flow in two-tier supply chains, where retailers order products from suppliers and sell in a market with uncertain demand. The retailers each have access to a demand signal. They can exchange signals (horizontal information sharing), while the suppliers can offer them payments to acquire signals (vertical information acquisition). We establish the impacts of channel structure, signal structure, and market competition on information dissemination, and the strategic interplay between horizontal information sharing and vertical information acquisition. We find that the retailer competition provides a necessary condition to sustain information flow of any form while supplier competition excludes vertical information acquisition. Furthermore, facing horizontal competition, the retailers can have an incentive to share signals if competition is not too intense; and this incentive is stronger when they order from independent suppliers than when they order from the same supplier. In the latter situation, once the retailers exchange signals, the supplier will acquire signals from them both. If the retailers forfeit this option, the supplier will have an incentive to acquire signals if the signals are sufficiently correlated.

We then study information flow in the particular system where a supplier sells to two retailers that serve a market with uncertain demand. We examine the incentives for the retailers to share signals, and for the supplier to solicit signals from the retailers, together with the procedure it should follow. On the basis of the outcomes thus obtained, we demonstrate that vertical information acquisition by the supplier and horizontal information sharing between the retailers are strategic complements. System-wide information transparency, under which the demand signals at the retailers are visible throughout the entire

supply chain, is attainable through information flow. Moreover, we show that incentive-driven demand information dissemination can be egalitarian to benefit each and every individual party.

Furthermore, we consider unintentional information leakage in the above system, in which case the supplier learns a retailer's signal and utilizes it in wholesale pricing, the other retailer can infer the signal from the adjusted wholesale prices and use the signal in making order decision. We show that, with indirect signal divulgence, the retailers will forfeit horizontal information sharing, and information transparency is attainable through a combination of information acquisition by the supplier and unintentional information leakage to the retailers.

# Publications Arising from the Thesis

1. "Incentive-driven Information Dissemination in Two-tier Supply Chains", with Li Jiang, accepted by *Manufacturing & Service Operations Management*.
2. "On Strategic Demand Information Dissemination", with Li Jiang, under review.
3. "Strategic Demand Information Dissemination under Unintentional Information Leakage", with Li Jiang, under review.

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# Table of Contents

# List of Figures

# List of Tables

# Chapter 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 can utilize the data to update demand forecasts and tailor their decisions to fit market conditions. They 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, airlines have formed alliances and sharing of consumer data is common among partners. As stated in Delta Air Lines' privacy policy, they "*routinely*" share consumer information with SkyMiles partners (Lazarus, 2015). This allows airlines to jointly track passengers' flyer statuses to 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 conduct data sharing.

On the other hand, data communication between firms with market access, particularly those in the downstream supply chain, 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 data 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 have a lack of 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 establish information links for their benefit.

In reality, horizontal data sharing and vertical data acquisition can coexist to transmit the demand signals at downstream firms to other supply chain parties. CVS, Kmart, and WalMart initiated an alliance in 2001 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 OM literature, by treating horizontal and vertical information sharing separately, produces a rather gloomy picture on the sustainability of information flow. It has been shown that neither form of information flow is sustainable under such practical assumptions as linear production costs at the suppliers, price-only contracts, and quantity competition between the firms with market access (please refer to the literature review where we describe the existing results and position this paper). This gap between academic literature and industry reality motivates us to investigate information flow by adding more elements into the existing framework. We strive to gain a better understanding of: 1) the factors that influence the incentives for supply chain parties to engage in horizontal and vertical information sharing in practical settings; and 2) the impacts of incentive-driven information flow on the profit performance 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 analyze horizontal data sharing and vertical data acquisition in two-tier supply chains in this paper, in which suppliers sell through retailers in a common market with uncertain demand. The supplier incurs a linear production cost. Price-only contracts govern the relationships between the supplier and retailers. The retailers each have access to an unbiased demand signal that distorts the actual market condition by a noise term. The retailers can exchange signals (horizontal information sharing) and the suppliers can offer them possibly different payments to acquire the retailer's 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 to make responsive decisions. As such, 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, can interplay to influence the performance of individual parties.

Vertical information acquisition and horizontal information sharing have respective effects on the suppliers and retailers. After learning a retailer's signal, a supplier can make responsive wholesale price decision and the variance of the retailer's order quantity will decrease. We refer to this as the direct effect of information acquisition, the extent of which depends on channel structure and the establishment of other information links. Regardless, this direct effect benefits the supplier, hurts the retailer by limiting its flexibility in responsive ordering, and lowers their total profit. When a monopolist retailer orders from two independent suppliers, after revealing its signal to a supplier, the retailer will strengthen its signal utilization and be more flexible in ordering from the other supplier. With retailer competition, signal acquisition by a supplier from a retailer can affect the other retailer. Specifically, when the retailers order from the same supplier, the supplier's responsive wholesale pricing will force the other retailer to adjust its order policy and limit its flexibility in ordering as well. When the retailers order from independent suppliers, product substitutability will make the other retailer more flexible in responsive ordering. We refer to all this as the indirect effect of information acquisition.

Horizontal information sharing has a pooling effect on the retailers and this effect is modulated by market competition. When market competition is weak, the retailers' quantity decisions are not much correlated and signal exchange grants them each more flexibility in utilizing the signals at both retailers. As competition intensifies, a retailer's quantity will have a stronger impact on the demand at the other retailer. While signal exchange grants access to more signals to the retailers, the high pressure of quantity interaction will force them to limit signal utilization and their order responsiveness will suffer. This is particularly the case when the signals are strongly correlated. As a consequence, the pooling effect has a positive influence on the retailers for enhanced responsiveness and more flexibility in ordering only in a less competitive market. Under the circumstance when the two forms of information flow coexist, the direct and indirect effects of information acquisition and the pooling effect of information exchange will superimpose on one another to affect the profits of the suppliers and retailers.

In Chapter 2, we assume that the signals available to the retailers are correlated. This makes our work differ from the literature that assumes signal independency. We characterize the information structures sustainable in four representative channel structures that are differentiated by the existence of horizontal competition in either one or both tiers. The new features of demand correlation and the combination of the two forms of information flow allow us to reveal substantially new findings relating to information sharing and provide concrete insights into the issues of interest. Channel structure, market competition, and signal structure are crucial in the sustainability of incentive-driven information flow.

With a monopolist retailer, vertical information acquisition is unsustainable. This is because once a supplier acquires signal from the retailer, the direct effect of information acquisition will always dominate the indirect effect to make the retailer suffer a profit loss that is more than what the supplier can compensate by its profit gain. With retailer competition, information acquisition is not sustainable when the retailers order from independent suppliers. This can be attributed to the dominant role by the direct effect in lowering the retailers' profits and unilateral decision making by the suppliers that deprives them of the incentives to acquire signals. In this situation, however, the retailers have an incentive to exchange signals when competition is less intense so that the pooling effect functions to improve their profits.

The sustainable pattern of information flow is richer when two retailers that sell substitutable products order from the same supplier. If the retailers forfeit signal exchange, the supplier will acquire signals when they are sufficiently correlated. To acquire one signal, the supplier will compensate this retailer just enough for its loss due to the direct effect of information acquisition, leaving the other retailer suffering a net profit loss due to the indirect effect. To acquire both signals, the supplier will use its first-mover advantage to offer the retailers differential payments to trap them in a Prisoner's Dilemma type of situation for signal disclosure. It will acquire 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 the 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 the interactions among parties. The retailers' profit losses from signal disclosure will reduce, enabling the supplier to afford more signals. If the retailers exchange signals, the supplier will always solicit signals from them both. Vertical signal acquisition then complements horizontal signal exchange to equip every party with the same signal availability. Signal exchange, by granting the retailers access to the same signals, can diminish the effects of information acquisition by the supplier. This makes signal acquisition more affordable to the supplier, which however still has to offer them differential payments to manipulate the retailers' incentives for signal disclosure.

To engage in horizontal information sharing, the retailers have to each earn a higher profit from signal exchange than if they forfeit this option, by taking into account the supplier's signal solicitation and weighing the resulting direct and indirect effects against the pooling effect. A necessary condition to sustain horizontal competition is that market competition is not too intense so that the pooling effect is positive on the retailer's profits. Once they share signals, the supplier will acquire signals from them both so that the retailers' signals are made available to all parties. Under this circumstance, the direct effect of information acquisition will be strong to make the suppliers better off but the customers worse off. The retailers will suffer profit losses in general as their losses from signal acquisition outweigh their gain from signal exchange. But they can be better off when signal correlation is weak, in which case the streamlined system-wide decision making resulting from information flow will be dominant to improve system profit and the retailers are able to earn higher profits, even though the supplier exploits part of their profit gain.

In Chapter 3, we study further information sharing in system RC when two retailers order from the same supplier. The issues of particular academic interest of this chapter are: 1) the incentive by the supplier to solicit signals from the retailers and the procedure it should follow; 2) the strategic interplay between horizontal and vertical information flow; and 3) the attainability of system-wide information transparency so that the demand signals are made visible to each and every party through incentive-driven information flow.

To address these issues, we assume that the supplier and the retailers adopt the following sequence to settle the information structure. The retailers first choose to disclose signals to each other, and the supplier then selects a procedure to acquire their signals. Under simultaneous signal acquisition, the supplier approaches the retailers at the same time and offers payments to acquire signals from them, who make unilateral decisions to accept the offers and disclose signals to the supplier. Under sequential signal acquisition, the supplier follows a sequence to approach the retailers, who take turns to decide whether to accept the offers and grant signal access to the supplier. The status of horizontal (vertical, resp.) information flow enhances as more horizontal (vertical, resp.) information links are built. The information agreement is reached before the demand signals are received. After receiving the demand signals, the retailers will disclose them horizontally and vertically according to the agreement, and the signal-triggered operation decisions will then follow.

Our complete analysis for the situation in which only one retailer horizontally discloses signal to the other retailer and the supplier sequentially solicits signals from the retailers allows us to investigate, to substantial depth, the strategic interplay between the two forms of information flow. Our results shed light on the strategic issues that motivate our study. We find that the supplier always prefers to sequentialize the process to approach the retailers to gain signal access. A higher status of horizontal information flow, with more retailers horizontally disclosing signals, can stimulate the supplier to set up more vertical information links and profit more from vertical signal access, particularly when signal quality is low. From the perspective of building information flow, vertical information acquisition by the supplier functions as a strategic complement to horizontal information sharing between the retailers. Importantly, we demonstrate that it can be incentive compatible for the demand signals at the retailers to be made accessible to all the supply chain parties. The system-wide information transparency thus results will always benefit the supplier, while the retailers and the system can be better off as well, compared with when information flow does not occur. This makes the communication of demand information an egalitarian instrument to bring a profit gain to each and every party.

One issue that we have not sufficiently explored in Chapter 2 and Chapter 3 is indirect signal divulgence. Since the supplier's signal-triggered wholesale price policy structure is publicly known, one retailer can infer the signal that the other retailer has disclosed to the supplier from the wholesale price adjustment by the latter. The indirect signal divulgence takes its root in channel structure and common knowledge of the decision policy structure. Indirect signal divulgence may significantly influence the sustainable pattern of information flow.

Thus, in Chapter 4, we consider the possibility that the retailers can further use the signal inferred through indirect signal divulgence to adjust operation decisions. We show that, with information leakage, vertical information acquisition is still a strategic complement to horizontal information sharing in establishing information flow, but this complementarity deprives the retailers of the incentives to horizontally disclose signals. However, information transparency is still attainable through a combination of information acquisition by the supplier and unintentional information leakage to the retailers.

All this contributes to the literature by a comprehensive investigation into incentive-driven demand information communication, to justify both horizontal and vertical information sharing.

## *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.

Clarke (1983) considers an oligopoly model in which firms engage in Cournot competition to sell perfect substitutes and shows 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 when the signals are uncorrelated. 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 suboptimal. 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 themIn this paper, we treat horizontal information sharing as a cooperative ex-ante decision by the retailers and identify the associated pooling effect. With respect to this literature, we demonstrate that firms can benefit from sharing signals with each other when they engage in quantity competition, irrespective of product substitutability. We also show that pooling effect alone can benefit the retailers when market competition is less intense given that the retailers engage in quantity competition.

Li (2002) considers a manufacturer selling to multiple retailers that have demand information and sell perfect 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 when other retailers learn its information by inferring it from the manufacturer’s adjusted wholesale prices. He shows both direct and leakage effects discourage vertical information sharing. We identify an indirect effect that prevails in various channel structures and affects the retailers’ profits under vertical information acquisition in Chapter 2 and we further study leakage effect in Chapter 4. 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 by showing that information flow can take place even when it causes supply chain profit to decrease. Li and Zhang (2008) consider a setting of one supplier selling to multiple retailers that compete in price. They consider three scenarios regarding confidentiality in vertical information sharing and show that with confidentiality, all retailers have incentives to share information with the supplier if competition is intense. Ha and Tong (2008) show, in a setting of two chains each consisting of a supplier and a retailer having access to true demand information, that vertical information sharing will hurt supply chain profit if price-only contracts are used. Ha et al. (2011) introduce production diseconomy at the suppliers to offset the effect that arises from vertical information sharing and show that overall system profit can improve only if production diseconomy is large. Guo et al. (2014) study ex-post information sharing but assume that the firms can access the true demand with different probabilities.

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 strategic cooperation between manufacturers for channel design. His main finding is that manufacturers prefer vertical integration over a decentralized structure when they cooperate, while a decentralized structure is the only equilibrium structure when they do not cooperate. Liu and Tyagi (2011) show that downstream firms can benefit from the decentralization of the upward channel. Other papers on similar topics include Coughlan and Wernerfelt (1989), Bhardwaj (2001), etc. We will explore the impacts of channel structure on the pattern of incentive-driven information flow in Chapter 2.

# Chapter 2
# Incentive-driven Information Dissemination in Two-tier Supply Chains

## 2.1 Introduction

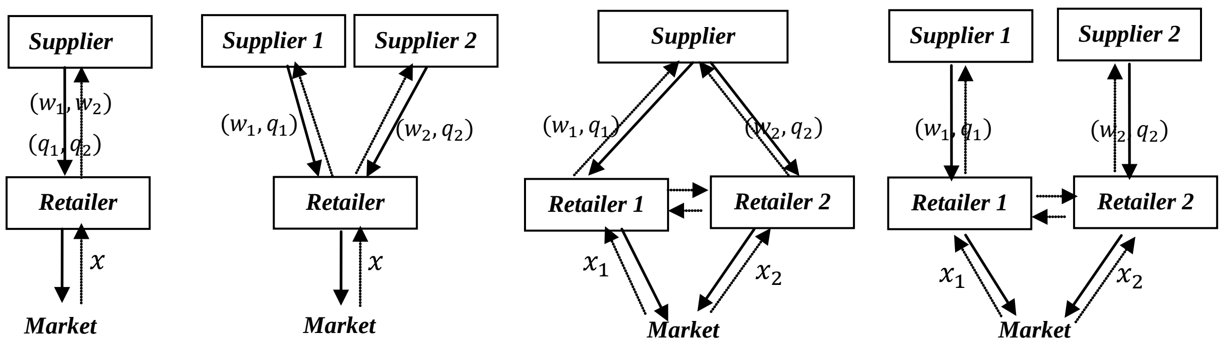
In this chapter, we consider two-tier supply chains in which the suppliers sell products through the retailers in a market with uncertain demand. The retailers each have access to a demand signal. They can exchange signals to engage in horizontal information sharing and the suppliers can access their signals through vertical information acquisition.

We characterize the information structures sustainable in four representative channel structures (to be specified later) that are differentiated by the existence of horizontal competition in either one or both tiers. The new features of demand correlation and the combination of the two forms of information flow allow us to reveal substantially new findings relating to information sharing and provide concrete insights into the issues of interest. Channel structure, market competition, and signal structure are crucial in the sustainability of incentive-driven information flow.

## 2.2 The Model

Figure 2.1 illustrates four channel structures, where a dotted arrow indicates signal flow and a solid arrow indicates product flow. System B (Figure 2.1.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 system SC (Figure 2.1.b), where SC stands for Supplier Competition, 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 various suppliers. In system RC (Figure 2.1.c), where RC stands for Retailer Competition, 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 powertrains from BorgWarner, a parts supplier headquartered in Auburn Hills, MI, USA. In system SRC (Figure 2.1.d), where SRC stands for Supplier and Retailer Competition, 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 anti-coagulant 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).

**Figure 2.1. Supply chain structures**




a) System B b) System SC c) System RC d) System SRC

*Notes.* $w_1$ 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.

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

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

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

**Assumption A about signal structure:**

[A1] *In systems B and SC, the monopolist retailer has signal $X = \mu + \varepsilon$, where $\varepsilon$ is the noise term and follows normal $N(0, \sigma_\varepsilon)$. $(\mu, \varepsilon)$ is bi-variate normal, with $cov(\mu, \varepsilon) = 0$.*

[A2] *In systems RC and SRC, retailer $i$ has signal $X_i = \mu + \varepsilon_i$, where $\varepsilon_i$ is the noise term and follows normal $N(0, \sigma_\varepsilon)$. $(\mu, \varepsilon_i)$ is bi-variate normal, with $cov(\mu, \varepsilon_i) = 0$. $(\mu, X_1, X_2)$ is multi-variate normal, with $cov(\varepsilon_1, \varepsilon_2) = \rho \in (0, \sigma_\varepsilon)$.*

Note that, we assume that the two retailers(if any) have symmetric signal status. This assumption is valid in almost all literatures. 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 sales are linked to the economic condition, as reflected by home price and consumption index. This practically correlates sales data as the signals received by the retailers. In recent 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 significant correlation. Under the assumptions about signal structure, we can derive the conditional expectations as: $E(\mu|X = x) = \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}x$, $E(\mu|X_i = x_i) = \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}x_i$, $E(\mu|X_1 = x_1, X_2 = x_2) = \frac{\sigma_\mu}{2\sigma_\mu+\sigma_\varepsilon+\rho}(x_1 + x_2)$, and $E\left(X_j\middle|X_i = x_i\right) = \frac{\sigma_\mu+\rho}{\sigma_\mu+\sigma_\varepsilon}x_i$. As $\rho \to 0$, $E\left(X_j\middle|X_i = x_i\right) \to \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}x_i$, which is consistent with the existing literature (see, for instance, Li and Zhang, 2002, and Ha et al., 2011).

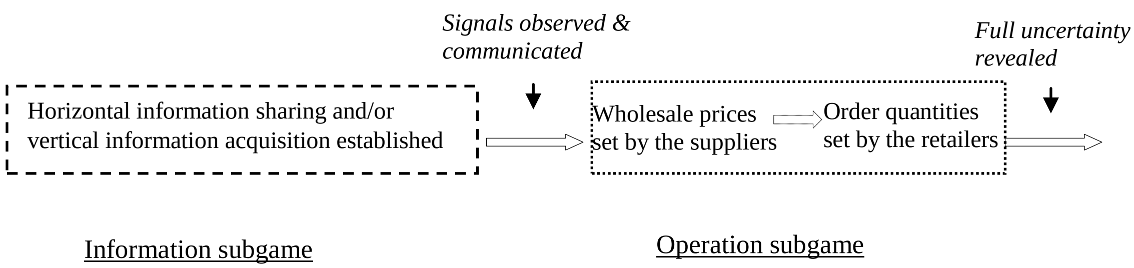
Information flow can take place in two forms. Horizontally, the retailers can exchange signals as a means of cooperation (horizontal information sharing) provided that they each will earn a profit gain, which is the rationality requirement to sustain cooperation. Vertically, the suppliers can offer the retailers payments to acquire their signals (vertical information acquisition). We assume that the signals are about the data that can be utilized to forecast the demand, such as sales data, pre-order data, and basket data. 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, while horizontal information sharing is a strategic option with retailer competition 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 in the supply chain. A comparative analysis of the information structures sustainable in the four structures can shed light on the effects of various factors on building information flow.

Price-only contracts govern vertical interactions. The suppliers and retailers will 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 if all the exogenous variables are normally distributed. The policy structures are common knowledge. The retailers' quantities affect market price, and consumer utility that is defined as:

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

As illustrated in Figure 2.2, our decision framework is composed of an information subgame and an operation subgame that are separated by signal receipt and communication. In the information subgame, which occurs before the signals are received, the retailers and suppliers sign information agreements to establish an information structure. After the signals are received, they are communicated according to the agreements. In the operation subgame, using 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 the parties accrue revenue.

**Figure 2.2. Decision framework**




We assume the retailers will truthfully disclose signals according to the information agreement, and reflect them in the order decisions; otherwise the agreement will be nullified. Li (1985), Zhang (2002), and Ha et al. (2011) explicitly make this assumption in their investigations, while Vives (1984) and Li (2008) 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 information confidentiality must be technically 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.

## 2.3 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 effects of information flow on the performance of the individual parties and the system, as well as the implications for the customers.

### 2.3.1 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, while $n = 1$ indicates that it does. Upon receiving the signal, the retailer will disclose it according to the agreement. In the operation 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:

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

Let its orders be $q(w|x) = (q_1(w|x), q_2(w|x))$. 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 $\pi_S^{(0)} = \mathrm{E}[\sum_{i=1}^{2}(w_i - c_i)q_i\,(w|x)]$. With vertical information acquisition ($n = 1$), the supplier maximizes its profit, conditional on the received signal $x$, of $\pi_S^{(1)}(x) = \mathrm{E}[\sum_{i=1}^{2}(w_i - c_i)q_i(w|x)\,|x]$. The equilibrium outcomes are shown in Table 2.1.

**Table 2.1. Operation equilibria in system B**

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

The supplier will utilize the signal, available from vertical 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 be smaller as market competition intensifies ($\beta$ increases). Vertical signal acquisition has its direct effect to improve the supplier's responsiveness in wholesale pricing but restricts the retailer's flexibility in responsive ordering. The system profit will decrease. The supplier will be unable to offer an incentive payment that is sufficient for the retailer to disclose signal. This excludes vertical information acquisition as a sustainable strategic move.

This result is against the common belief that information sharing is good to the channel. For instance, information sharing is necessary under VMI model. The reason is that we consider the operation subgame a single-period Stackelberg game in this paper. However, VMI requires long-term cooperative relations between the supplier and the the retailer.

### 2.3.2 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 operation subgame, given the wholesale prices offered by the suppliers, the retailer maximizes its profit, as given in (2-3), by choosing order quantities $q(w|x)$. When $n = (0,0)$, each supplier $i$, with no signal access, anticipates the retailer's signal-based order to maximize its profit of:

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

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

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

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

Table 2.2 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 Appendix.

**Table 2.2 Operation subgame equilibria in system SC**

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

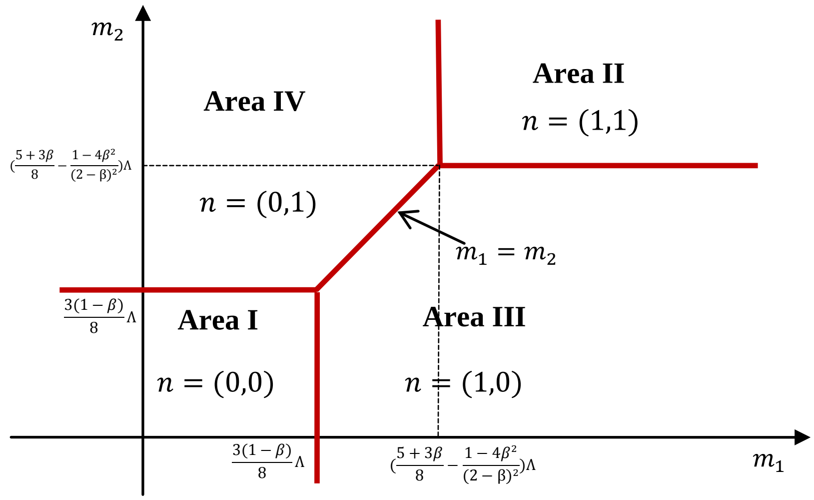
| | | |
|---|---|---|
| (0,1) | $w_1^{(0,1)} = w_1^0.$<br>$w_2^{(0,1)}(x) = w_2^0 + \frac{1-\beta}{2}Ax.$<br>$q_1^{(0,1)}(x) = q_1^0 + \frac{2+\beta}{4(1+\beta)}Ax\ .$<br>$q_2^{(0,1)}(x) = q_2^0 + \frac{1}{4(1+\beta)}Ax.$ | $\pi_R^{(0,1)} = \pi_R^0 + \frac{(5+3\beta)\sigma_u^2}{16(1+\beta)(\sigma_\varepsilon+\sigma_\mu)} + m_2.$<br>$\pi_{S1}^{(0,1)} = \pi_{S1}^{(0,0)}.$<br>$\pi_{S2}^{(0,1)} = \pi_{S2}^{(0,0)} + \frac{(1-\beta)\sigma_u^2}{8(1+\beta)(\sigma_\varepsilon+\sigma_\mu)} - m_2.$ |

*Notes.* $w_i^0 = \frac{(2-\beta^2)a_i - \beta a_{3-i} + 2c_i + \beta c_{3-i}}{4-\beta^2}$, $q_i^0 = \frac{(2-\beta^2)(a_i-c_i) - \beta(a_{3-i}-c_{3-i})}{2(1-\beta^2)(4-\beta^2)}$, $A = \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}$,

$\pi_R^0 = \sum_{i=1}^2 (a_i - q_i^0 - \beta q_{3-i}^0 - w_i^0)q_i^0$. $\frac{A}{2(1+\beta)}$ captures the retailer's signal reliance when ordering from supplier $i$ without information flow.

By granting access to its signal to a supplier $i$ only, the retailer will rely less (more, resp.) on its signal in ordering from supplier $i$ (supplier $3-i$, resp.). This reveals the direct effect of signal acquisition on the retailer in ordering from the supplier that has access to its signal and its indirect effect on the retailer in ordering from the other supplier with no access to signal. While the direct effect limits the retailer's flexibility, the indirect effect plays the opposite role. As competition intensifies ($\beta$ 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. By granting signal access to both suppliers, the retailer will lower signal reliance when ordering from them both and the reductions will increase with competition intensity. A supplier's reliance on the acquired signal to set its wholesale price will be greater when the signal is available to the other supplier as well. This can be attributed to product substitution. As $\beta \to 1$, signal access will have a negligible effect on the suppliers' wholesale prices, but the retailer will continue to adapt orders to their signal statuses.

**Figure 2.3. Equilibrium transaction decision in system SC, given $(m_1, m_2)$,** $\Lambda = \frac{\sigma_u^2}{2(1+\beta)(\sigma_\varepsilon+\sigma_\mu)}$




The retailer decides on disclosing its signal to the two suppliers given their offered payments. As illustrated in Figure 2.3, vertical information acquisition will not take place if the suppliers' offered payments are low (Area I); both suppliers will acquire the signal from the retailer with high payments (Area II); and only the supplier that offers a larger payment will acquire the signal otherwise (Areas III and IV). Anticipating these, the suppliers will choose to offer the payments $m = (m_1, m_2)$.

**Proposition 2.1.** *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 2.1 shows that neither of the two independent suppliers will have incentive to acquire the signal at the monopolist retailer in system SC. Vertical information acquisition by a supplier from the retailer will have a direct effect to hurt the retailer's profit, but an indirect effect to make the retailer rely more on its signal and gain more flexibility in responsive ordering from the other supplier. Regardless of the status of information acquisition by the other supplier, the direct effect will dominate the indirect effect to cause the retailer to suffer a profit loss from disclosing its signal to a supplier that is more than what the supplier can compensate with its profit gain from enhanced signal availability. As a result, it is the dominant strategy for either supplier not to acquire signal from the retailer.

### 2.3.3 Downstream retailer competition (System RC)

In system RC, a monopolist upstream supplier sells to two competing downstream retailers. Since 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 to acquire 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 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 operation 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:

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

when they forfeit horizontal information sharing, or:

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

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:

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

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 2.3.

**Table 2.3. Operation subgame equilibria in system RC, without horizontal information sharing**

| $(n_1, n_2)$ | Decision policy | Ex-ante profit |
|---|---|---|
| (0,0) | $w_i^{(0,0)} = w_i^0$<br>$q_i^{(0,0)} = q_i^0 + Bx_i$ | $\pi_{Ri}^{(0,0)} = \pi_{Ri}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2}$.<br>$\pi_S^{(0,0)} = \sum_{i=1}^{2}(w_i^0 - c_i)q_i^0$. |
| (1,1) | $w_i^{(1,1)} = w_i^0 + Bx_i + \frac{\beta}{2}Bx_{3-i}$.<br>$q_i^{(1,1)} = q_i^0 + \frac{B}{2}x_i$. | $\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} + m_i$.<br>$\pi_S^{(1,1)} = \pi_S^{(0,0)} + \frac{\sigma_u^2}{2[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]} - m_1 - m_2$. |

| | | |
|---|---|---|
| (1,0) | $w_1^{(1,0)} = w_1^0 + (1 + \frac{\beta k}{2})Bx_1.$<br>$w_2^{(1,0)} = w_2^0 + (k + \frac{\beta}{2})Bx_1.$<br>$q_1^{(1,0)} = q_1^0 + \frac{B}{2}x_1.$<br>$q_2^{(1,0)} = q_2^0 + Bx_2 - \frac{k}{2}Bx_1.$ | $\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} + m_1.$<br>$\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \frac{\sigma_u^2[(1-2\beta)\rho^2+4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2-2\rho((2-\beta)\sigma_\varepsilon+(1+\beta)\sigma_\mu)]}{4(\sigma_\varepsilon+\sigma_\mu)[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2}.$<br>$\pi_S^{(1,0)} = \pi_S^{(0,0)} + \frac{\sigma_u^2[\rho^2+\sigma_\varepsilon^2+(2+\beta)\sigma_\varepsilon\sigma_\mu+(2+\beta)\sigma_u^2+\rho(\beta\sigma_\varepsilon+(2+\beta)\sigma_\mu)]}{2(\sigma_\varepsilon+\sigma_\mu)[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} - m_1.$ |
| (0,1) | $w_1^{(0,1)} = w_1^0 + (k + \frac{\beta}{2})Bx_2.$<br>$w_2^{(0,1)} = w_2^0 + (1 + \frac{\beta k}{2})Bx_2.$<br>$q_1^{(0,1)}(x) = q_1^0 + Bx_1 - \frac{k}{2}Bx_2.$<br>$q_2^{(0,1)}(x) = q_2^0 + \frac{B}{2}x_2.$ | $\pi_{R1}^{(0,1)} = \pi_{R1}^0 + \frac{\sigma_u^2[(1-2\beta)\rho^2+4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2-2\rho((2-\beta)\sigma_\varepsilon+(1+\beta)\sigma_\mu)]}{4(\sigma_\varepsilon+\sigma_\mu)[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2}.$<br>$\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} + m_2.$<br>$\pi_S^{(0,1)} = \pi_S^{(0,0)} + \frac{\sigma_u^2[\rho^2+\sigma_\varepsilon^2+(2+\beta)\sigma_\varepsilon\sigma_\mu+(2+\beta)\sigma_u^2+\rho(\beta\sigma_\varepsilon+(2+\beta)\sigma_\mu)]}{2(\sigma_\varepsilon+\sigma_\mu)[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2} - m_2.$ |

*Notes.* $w_i^0 = \frac{a_i+c_i}{2}$ $q_i^0 = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}$, $B = \frac{\sigma_\mu}{(2+\beta)\sigma_\mu+2\sigma_\varepsilon+\beta\rho}$, $k = \frac{\sigma_\mu+\rho}{\sigma_\mu+\sigma_\varepsilon}$, $\pi_{Ri}^0 = (\frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)})^2$. $B$ captures a retailer's reliance on its own signal when ordering from the supplier, without any information flow.

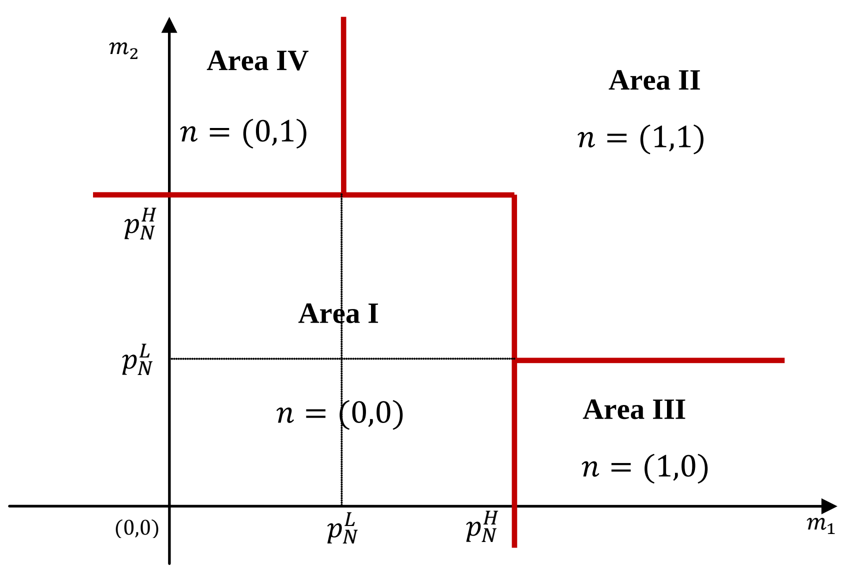
When only retailer $i$ discloses its signal $x_i$, the supplier will adjust wholesale price $w_i$ by $B(1 + \frac{\beta k}{2})x_i$, which is independent of market competition and signal correlation, and $w_{3-i}$ by $B(k + \frac{\beta}{2})x_i$, which increases as market competition intensifies or signal correlation strengthens. As $1 + \frac{\beta k}{2} > k + \frac{\beta}{2}$, $w_i$ is more responsive to $x_i$ than $w_{3-i}$. Retailer $i$ will halve its reliance on $x_i$ when ordering from the supplier, while retailer $3 - i$ will lower its order quantity by $\frac{k\beta}{2}x_i$, which decreases in $\beta$ but increases in $\rho$. Note that the direct and indirect effects of signal acquisition by the supplier from a retailer limit the flexibility in responsive ordering by this particular retailer and the other retailer, respectively, though by 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 both retailers will halve their reliance on respective signals in ordering. In this case, each retailer is mainly under the influence of the direct effect of signal acquisition. The supplier's responsive wholesale prices will decrease as signal correlation strengthens ($\rho$ increases). As competition intensifies ($\beta$ increases), the supplier will rely less on $x_i$ but more on $x_{3-i}$ when setting $w_i$.

**Lemma 2.1**. *In system RC where a supplier sells to two retailers, if the retailers do not share signals, let* $p_N^L = \frac{(\sigma_\varepsilon-\rho)\sigma_u^2(3\sigma_\varepsilon+2\sigma_\mu+2\beta\sigma_\mu-(1-2\beta)\rho)}{4(\sigma_\varepsilon+\sigma_\mu)(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu))^2}$ *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* $\beta$ *and* $\rho$:

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

Lemma 2.1 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 (indirect 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 negligible adjustments and the incremental direct effect will have a less influence on the profit of the retailer who discloses its signal. Both $p_N^H$ and $p_N^L$ decrease with $\beta$ and $\rho$. 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 due to signal disclosure will reduce, making vertical information links more affordable for the supplier.

**Figure 2.4. Information acquisition in system RC, without horizontal information sharing**




The retailers' signal-disclosure decisions given $m = (m_1, m_2)$ are illustrated in Figure 2.4. In each area of Figure 2.4, the equilibrium status of signal disclosure by the retailers is unique. Neither retailer will disclose 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 for signal acquisition, then either both retailers disclose their signals (at a high payment) or neither of them does (at a low payment). This is consistent with the finding in Ha et al. (2011). Offering differential payments provides the supplier with an effective instrument to adjust the retailers' incentives to disclose signals and profit from their competitive relationship.

**Lemma 2.2.** *In system RC where a supplier sells to two retailers, if the retailers do not exchange signals, let* $\beta_{RC}^{N1} = \frac{-2\rho^2+\sigma_\varepsilon^2-4\rho\sigma_\mu+2\sigma_\varepsilon\sigma_\mu-\sigma_u^2}{2(\sigma_\varepsilon+\sigma_\mu)(\rho+\sigma_\mu)}$, $\beta_{RC}^{N2} = \frac{\rho^2-4\rho\sigma_\varepsilon+2\sigma_\varepsilon^2-2\rho\sigma_\mu-\sigma_u^2}{2(\rho+\sigma_\mu)^2}$, *and* $\beta_{RC}^{N3} = \frac{3\rho-\sigma_\varepsilon+2\sigma_\mu}{2(\rho+\sigma_\mu)}$, *then*:

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

2) *When* $0 \leq \rho < \frac{(\sigma_\varepsilon-\sigma_\mu)^+}{2}$, *no information acquisition will occur if* $0 \leq \beta \leq \beta_{RC}^{N1}$, *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 $\beta \leq \beta_{RC}^{N1}$ when $\rho$ is low or $\beta \leq \beta_{RC}^{N2}$ when $\rho$ is high. Both $\beta_{RC}^{N1}$ and $\beta_{RC}^{N2}$ decrease in $\rho$ but increase in $\sigma_\varepsilon$. This implies that weaker signal correlation or lower signal accuracy can weaken the incentive for the supplier to acquire signals. Only Case 1 in Lemma 2.2 applies when the signals are accurate ($0 \leq \sigma_\varepsilon < \sigma_\mu$). In the case of weak competition with $0 < \beta \leq \beta_{RC}^{N2}$, the direct and indirect effects of vertical acquisition will deliver joint impacts to hurt the retailers' profit, and supplier will be unable to afford the incentive required for signal solicitation. In the case of moderate competition with $\beta_{RC}^{N2} < \beta \leq \beta_{RC}^{N3}$, the supplier will acquire signals from both retailers (bilateral information acquisition), by manipulate their incentives for signal disclosure with differential payments. The profit gain to the supplier from the direct effect of information acquisition in the two competing chains is more than what it pays the retailers. When there is intense competition with $\beta > \beta_{RC}^{N3}$, the supplier will be content by having access to one signal (unilateral information acquisition) since its profit gain from acquiring an additional signal will not be enough for it to afford the incentive. $\beta_{RC}^{N3}$ increases but $\beta_{RC}^{N2}$ decreases in $\rho$. Hence, the supplier will have a stronger incentive to acquire both signals as they become more indicative of each other. Case 2 of Lemma 2.2 will apply when the signal accuracy is weak ($\sigma_\varepsilon \geq \sigma_\mu$) and signal correlation is weak ($0 \leq \rho < \frac{\sigma_\varepsilon-\sigma_\mu}{2}$); 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.

If the retailers exchange signals, the same signal status correlates their decisions. The operation subgame outcomes are as grouped in Table 2.4. Different from when the retailers forfeit signal exchange, the supplier will now utilize the signals available from acquisition to make the same adjustments to the wholesale prices offered to the retailers: $\frac{\sigma_\mu(x_1+x_2)}{2(2\sigma_\mu+\sigma_\varepsilon+\rho)}$ after it accesses both signals, and $\frac{\sigma_\mu(1+k)x_i}{2(2\sigma_\mu+\sigma_\varepsilon+\rho)}$ after it accesses signal $x_i$ only. If retailer $i$ discloses signal $x_i$ to the supplier, the direct effect of acquisition will have retailer $i$ rely less on $x_i$ and the indirect effect arising from product substitution will cause retailer $3-i$ to rely less on $x_i$ as well in making order decisions. As retailer $3-i$ discloses signal $x_{3-i}$ as well, it will halve its reliance on $x_{3-i}$ but rely more on $x_i$ in ordering. Market competition is not weighed in the supplier's signal utilization since the signals are pooled by the retailers. A stronger signal correlation will weaken the supplier's and retailers' reliance on signals in making responsive decisions.

**Table 2.4. Operation subgame equilibria in system RC, with horizontal information sharing**

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

*Notes.* $w_i^0 = \frac{a_i+c_i}{2}$. $q_i^0 = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}$, $C = \frac{\sigma_\mu}{(2+\beta)(2\sigma_\mu+\sigma_\varepsilon+\rho)}$, $k = \frac{\sigma_\mu+\rho}{\sigma_\mu+\sigma_\varepsilon}$, $\pi_{Ri}^0 = (\frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)})^2$.
$C(x_1+x_2)$ captures how a retailer utilized both signals when making order decisions, without any information flow.

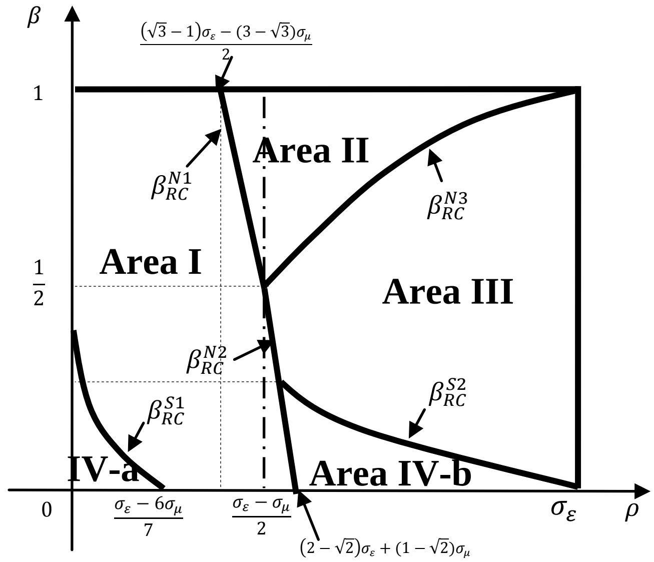
Based on these subgame outcomes, we analyze the retailers' incentive to disclose signals and the supplier's decisions on signal prices. Lemma 2.3 characterizes the subgame equilibrium outcomes when the retailers share signals.

**Lemma 2.3.** *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,* $p_S^H = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$*, 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* $\beta$ *and* $\rho$, $p_S^H$ *decreases in* $\beta$.

Lemma 2.3 states that if the retailers exchange signals, the supplier will always incentivize them both to reveal signals by differential payments. The incentive payments $p_S^H$ and $p_S^L$ are the counterparts to $p_N^H$ and $p_N^L$ that applicable when the retailers forfeit signal exchange. $p_S^H$ is insensitive to $\rho$ so that signal correlation will not be weighed in the supplier's decision to acquire signals if the retailers have exchanged signals. $p_S^L$ decreases in $\rho$. This implies that the supplier, with access to a signal, will have a stronger incentive to build 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 will cause them to suffer smaller profit losses from signal disclosure, thus giving the supplier a stronger incentive to acquire signals. $p_N^H \to p_S^H$ and $p_S^L, p_N^L \to 0$, as $\rho \to \sigma_\varepsilon$. As the signals become more indicative of each other, the status of horizontal information sharing will have a smaller impact on the supplier's incentive in signal acquisition. This is intuitive.

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 both signals, against forfeiting this option, in which case the supplier's signal acquisition depends on signal structure and market competition. Proposition 2.2, assisted by Figure 2.5, reveals the information structure sustainable in system RC.

**Figure 2.5. Information structure that is sustainable in system RC**




*Notes*. The partitioning is applicable when $\sigma_\varepsilon \geq 6\sigma_u$. The partionining for other $(\sigma_\varepsilon, \sigma_u)$ can be inferred. $\beta_{RC}^{N1}$, $\beta_{RC}^{N2}$, and $\beta_{RC}^{N3}$ are as defined in Lemma 2.2.The expressions for the threshold levels of $\beta_{RC}^{S1}$ and $\beta_{RC}^{S2}$ can be found in the Appendix. The properties of all the threshold levels can be obtained upon request.

**Proposition 2.2.** *In system RC where a supplier sells to two retailers, the information structure is as shown in Figure 2.5:*

*a.* *In Area I, neither horizontal information sharing nor vertical information acquisition will occur.*

*b.* *In Area II, no horizontal information sharing, but unilateral information acquisition will occur.*

*c.* *In Area III, no horizontal information sharing, but bilateral information acquisition will occur.*

*d.* *In Area IV, horizontal information sharing and bilateral information acquisition will both occur.*

Figure 2.5 illustrates the partitioning of $(\rho, \beta)$ on $(0, \sigma_\varepsilon) \times (0,1)$ to sustain information flow in system RC. Horizontal information sharing grants access to an additional signal to each retailer and has a pooling effect that is modulated by market competition. When competition is weak, the retailers do not face much pressure in making respective quantity decisions. With enhanced signal availability, they can make use of enhanced signal availability to gain more flexibility in ordering. When market competition is intense, however, the high pressure of quantity competition turns the retailers to be cautious in ordering. Signal exchange makes each retailer limit signal utilization and its flexibility in responsive ordering will suffer. As a result, pooling effect plays a positive role in the retailers' profits only in less competitive markets. This makes a less intense market competition a necessary condition to sustain signal exchange.

To effectively engage in horizontal information sharing, the retailers each have to earn a higher profit by signal exchange than if they forfeit this option, taking into consideration the supplier's siganl solicitation. Strategic complementarity will have the supplier acquire signals from both retailers once they exchange signals. The direct and indirect effects of signal acquisition will interact with the pooling effect to affect the retailers' profits. If the retailers forfeit signal exchange, competition and signal correlation will jointly affect the supplier's signal solicitation. As shown in Figure 2.5, the retailers are better off with signal exchange in Area IV-a and Area IV-b. The supplier forfeits signal acquisition (acquire both signals, resp.) if the retailers forfeit signal exchange in Area IV-a (Area IV-b, resp.). Signal correlation adjusts the relative extents of the pooling and direct effects. Weakened market competition ($\beta$ decreases) strengthens the positive pooling effect on the retailers and gives them a stronger incentive to exchange signals.

When signal exchange is not sustainable between the retailers, vertical signal acquisition remains a feasible strategic move. By Figure 2.5, this form of information flow will occur when $\rho$ is large or $\sigma_\varepsilon$ is small. A strong signal correlation allows the supplier, with access to a signal, to infer with confidence the other signal for use in decision making and encourages it to build vertical information links. The supplier can also be drawn by a high signal accuracy to acquiring signals to have its decisions aligned with those of the retailers. Note that when signal accuracy is high ($0 \leq \sigma_\varepsilon < \sigma_u$), the supplier will acquire signals in most circumstances. Through solicitation, the supplier gains access to one signal if $\beta$ is sufficiently large (Area II) but both signals otherwise (Area III), and is more likely to acquire both signals as $\rho$ increases (Area III expands with $\rho$). This is because as the competition pressure on the retailers is relieved or the signals are more indicative of one another, given the supplier has access to one signal, additional signal availability to it will trigger smaller adjustments and the incremental direct effect will be less influential in shaping the interactions among parties. The retailers' profit losses due to signal disclosure will reduce. This will enable the supplier to afford enhanced signal availability.

**Proposition 2.3**. *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 2.3 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 but limit the retailers' flexibility in responsive ordering, which will ultimately hurt customers. When only unilateral information acquisition is sustained (Area II in Figure 2.5), the supplier's payment ($p_N^H$) can compensate the retailer disclosing its signal just enough for its profit loss, while the resulting indirect effect of information acqusition will cause the other retailer to suffer a profit loss. With bilateral information acquisition, the direct and indirect effects will, by outweighing the possibly positive pooling effect of signal exchange, hurt the retailers' profits. However, the supplier can make use of its first-mover advantage to offer the retailers differential payments to maninulate their incentives for signal disclosure and trap them in a Prisoners' Dilemma type of situation. Specifically, the supplier can design its payments such that each retailer dominantly prefers to disclose its signal although they can earn higher profits by keeping signals to themselves. The total amount of the payments that the supplier offers the retailers is less than its profit gain due to the direct effect of information acqusition. When the retailers forfeit signal exchange, bilateral information acquisition confers an information advantage to the supplier (Area III in Figure 2.5). When the retailers share signals, bilateral information acquisition by the supplier will attain information transparency in the supply chain. In this case, when signal correlation is weak (Area IV-a in Figure 2.5), the streamlined system-wide decision making that results from information transparency will create an effect to outweigh the direct and indirect effects of information acquisition and the pooling effect of signal exchange to improve system profit, and the retailers can end up with higher profits under information flow although they could have earned higher profits by not disclosing signals. Otherwise (Area IV-b in Figure 2.5), 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 due to signal solicitation by the supplier.

### 2.3.4 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 operation 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 (2-6) and (2-7). When $n = (n_1, n_2) = (0,0)$, each supplier $i$ sets wholesale price, based on prior belief, to maximize its profit of $\pi_{Si}^{(0,0)} = \mathrm{E}[(w_i - c_i)q_i]$.

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 $\pi_{Si}^{(1,1)}(x_i) = \mathrm{E}[(w_i - c_i)q_i|X_i = x_i]$. If the retailers exchange signals, supplier $i$ will gain access to both signals and its profit function will be $\pi_{Si}^{(1,1)}(x_1, x_2) = \mathrm{E}[(w_i - c_i)q_i|(X_1 = x_1,\ X_2 = x_2)]$. 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 2.5, and those when the retailers exchange signals are grouped in Table 2.6.

**Table 2.5. Operation subgame equilibria in system SRC, without horizontal information sharing**

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

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

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

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

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. That is, supplier competition does not affect signal utilization by the retailers when the signals are not passed upstream. Under information acquisition, however, upstream channel structure affects the retailers' signal utilization. Suppose 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, while retailer 2 will strengthen its signal reliance in system SRC but weaken it in system RC. 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' decisions as signal correlation strengthens. That is, signal correlation will force the retailers to limit their utilization of shared 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 $\frac{4-\beta^2}{4-\beta}C > \frac{4-\beta^2}{4}C$. 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 instance. Retailer 1, after disclosing its signals, adjusts its order quantity by $\frac{C}{2}(x_1+x_2)$, while retailer 2, who does not disclose signals, adjusts its order quantity by $\left(1+\frac{\beta}{4}\right)C(x_1+x_2)$, with $\frac{1}{2} < 1+\frac{\beta}{4}$. This can be attributed to the spillover effect arising from product substitutability.

**Table 2.6. Operation subgame equilibria in system SRC, with horizontal information sharing**

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

| | | |
|---|---|---|
| | $q_1^{(0,1)}(x) = q_1^0 + (1 + \frac{\beta}{4})C(x_1 + x_2)$. | $\pi_{S1}^{(0,1)} = \pi_{S1}^{(0,0)}$. |
| | $q_2^{(0,1)}(x) = q_2^0 + \frac{C}{2}(x_1 + x_2)$. | $\pi_{S2}^{(0,1)} = \pi_{S2}^{(0,0)} + \frac{(2-\beta)\sigma_\mu^2}{4(2+\beta)(\rho+\sigma_\varepsilon+2\sigma_\mu)} - m_2$. |

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

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

**Lemma 2.4.** *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), which study a similar setting without the option of horizontal signal exchange between the retailers. We further show that the suppliers have no incentive to acquire signals if the retailers exchange signals. This can be attributed to the horizontal competition between the suppliers that aggravates the direct effect arising from their signal acquisition. This makes neither supplier able to afford the incentive required for its retailer to disclose signal. Compared with system SC, the suppliers in system SRC are exposed to more intense horizontal competition in selling to competing retailers. Since the retailers' signals will not flow upstream, horizontal information sharing is the only possible form of information flow in system SRC.

**Proposition 2.4.** *Under chain-to-chain competition in system SRC, horizontal information sharing will occur if* $\beta < \beta_{SRC} \triangleq \frac{2[\sqrt{2(\sigma_\mu+\sigma_\varepsilon)(2\sigma_\mu+\sigma_\varepsilon+\rho)} - (\sigma_\mu+\sigma_\varepsilon)]}{3\sigma_\mu+\sigma_\varepsilon+2\rho}$, *while information acquisition is unsustainable.*

The retailers in system SRC will forfeit signal exchange if market competition is intense ($\beta > \beta_{SRC}$). As $\beta_{SRC}$ decreases in $\rho$, 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. Intuitively, 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 hurt the value they 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 2.5). 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 and lead to direct and indirect effects in system RC, both of which will negatively affect the retailers' profits, but will not induce the suppliers into building any vertical link in system SRC. As a result, signal exchange is sustainable in a more less competitive market in system RC than in system SRC.

## 2.4 Comparative analysis and managerial insights

Based on the information structures that are sustainable in the four representative channel structures, we next investigate the issues that have motivated our study.

*Sustainability of incentive-driven information flow*

Table 2.7 groups the information structures sustainable in the channel structures we have analyzed thus far.

**Table 2.7. 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 $\beta$ is low | Sustained if $\beta$ is low |
| Vertical information acquisition | Unsustainable | Unsustainable | Sustained if $\rho$ is sufficiently high: unilateral if $\beta$ is high, and bilateral otherwise | Unsustainable |
| Information sharing and information acquisition | NA | NA | Sustained when $\beta$ is low and $\rho$ is moderate | Unsustainable |

Incentive-driven information flow is unsustainable in a bilateral monopoly (system B), in which the direct effect of signal acquisition will hurt system profit, to make the supplier's profit gain insufficient to compensate the retailer for its loss from signal disclosure. The introduction of supplier competition by having the retailer order from two independent suppliers (system SC) will aggravate the direct effect of information acquisition and the competitive relationship between the suppliers will deprive them of the incentives to acquire the retailer's signal. With retailer competition only (system RC), a necessary condition to sustain signal exchange is that market competition is not too intense when the pooling effect generates positive profit gains to the retailers with more flexibility in responsive ordering. Higher signal accuracy and a strengthened signal correlation drive the supplier to solicit signals, by sometimes exploiting the competitive relationship between the retailers to trap them in a Prisoner's dilemma type of situation with differential payments. The conditions for full-scale information flow that involves both horizontal information sharing and bilateral information acquisition are: 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 at the retailers. In system SRC, upstream supplier competition precludes vertical information acquisition, but the retailers will exchange signals in a less competitive market.

With retailer competition, elimination of upstream competition is a necessary condition for the retailers' signals to move upstream, and this form of information flow will be more sustainable as signal accuracy improves and signal correlation strengthens. Ample evidence indicates that retailers have "*boosted the frequency and scope of communication with vendors*" (Chain Store Age, 2003). While 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 as follows. After the suppliers have undergone waves of consolidation through mergers and acquisitions, with few suppliers remaining to produce for major retailers, the change in channel structure gives the retailers a stronger incentive than ever to solicit signals from the retailers and their intention of acquiring signals will strengthen as the signals become more correlated.

Horizontal information sharing can be sustainable as well if market competition is not too intense. Improved market knowledge is the main driver behind this strategic move. 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) while Target aims at medium-sized families with higher incomes (middle-class segment). The difference in consumer segments causes their product offerings to be not quite substitutable: Target focuses on more stylish and higher quality products than WalMart. With the sophistication of their IT systems and the fact that their store sales are correlated, MCX can be a platform for them to share data for the purpose of better understanding customer needs and forecasting sales trends. Horizontal information sharing builds the foundation of information transparency, as exemplified by the joint venture among CVS, Kmart, and WalMart into data sharing that has triggered data acquisition by major drug makers. We expect that as retailers initiate customer data sharing, more suppliers will have the intention of gaining access to their data so that system-wide information transparency can be increased.

*Profit implication of information flow*

The pattern of information flow determines the signals that are accessible to the supply chain parties, who will rely on the signals to make responsive decisions. This will have a substantial impact on their profit performance. We use $\Delta\pi_k^m$ to denote the profit gain to member $k$ and $\Delta CS^m$ to denote the change in consumer welfare in system $m$, which 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 2.5**. *Under incentive-driven information flow:*

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

Horizontal information sharing can benefit the retailers by improving their order responsiveness. Vertical signal acquisition favors the supplier who can exploit the retailers' profit gains by offering them differential payments. With retailer competition, elimination of upstream competition will strengthen the suppliers' power in vertical interaction. Information-wise, this channel structual change encourages the suppliers to solicit signals but discourages the retailers from exchanging signals. As shown in part 1) of Proposition 2.5, compared with those in system SRC, the retailers in system RC earn less from having access to signals but the suppliers are better off with enhanced signal availability. The system will suffer a profit loss and the customers will be worse off. It is possible that the retailers exchange signals and the suppliers do not acquire signals in system SRC, but the retailers forfeit signal exchange and the supplier acquires signals in system RC. Even in this circumstance, however, the direct effect of signal acquisition will take away the retailers' gains due to the positive pooling effect of signal exchange and cause them to suffer profit losses.

When independent suppliers provide for retailers, the suppliers will have no incentive to acquire signals. This is mainly attributed to the competitive relationship between the suppliers. Regardless of the status of vertical information acquisition by the other supplier, it is the dominant strategy for a supplier not to acquire signal since it is unable to afford the incentive required for the retailer to disclose signal. According to part 2) of Proposition 2.5, a monopolist retailer can better utilize the signals than competing retailer, which, together with its stronger channel position, can help it earn a higher profit. The system profits more from incentive-driven information flow with a monopolist retailer than with two competing retailers. However, the customers can be better off with retailer competition. This occurs when market competition is weak ($\beta < \beta_{SRC}$), in which case the competing retailers will exchange signals to make the customers better off with higher product availability and lower price, compared with when a monopolist retailer exists in the downstream. The information structures sustained in system SC and system B are identical. This is reflected in part 3) that with the supplier(s) acquiring no signals, the monopolist retailer makes the same signal utilization in ordering, and the signal-driven system profit and consumer welfare

are the same in both systems. Part 4) states that compared with a bilateral monopoly (system B), retailer competition can drive the supplier to establish vertical information links. This will however make the retailers lose profits due to the direct and indirect effects of information acquisition. System profit and consumer welfare will be worse off as well.

With horizontal competition in both tiers of a supply chain, only horizontal information sharing between the retailers can be sustained and in less competitive markets. Elimination of competition in any tier will strengthen the channel power of the parties in that particular tier. A monopolist supplier is a necessary condition to sustain vertical signal acquisition, though it weakens the retailers' incentive to exchange signals. In this case, the supplier can use its monopolist position and first-mover advantage to solicit signals from retailers. A monopolist retailer will preclude any form of information flow from being sustained. Horizontal information sharing, once established, can benefit the retailers, while vertical information acquisition, though benefiting the suppliers for enhanced signal availability, is detrimental to the retailers and even hurt the profit of the entire system.

## 2.5 Concluding remarks

In this chapter, 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. They can exchange signals to engage in horizontal information sharing and the suppliers can access their signals through vertical information acquisition. We identify the direct and indirect effects of signal acquisition and the pooling effect of signal exchange, as well as the factors that affect their interaction. The direct effect of signal acquisition benefits the supplier and hurts the retailer, but the indirect effect has mixed implications for the profit of retailer not directly involved in signal acquisition. The pooling effect is modulated by market competition and can benefit the retailers if market competition is less intense. Our results reveal that channel structure (horizontal competition at either one or both tiers), signal structure (signal correlation and accuracy), and market competition are crucial in sustaining information flow.

Retailer competition is necessary for information flow of any form to be sustained. Horizontal information sharing between competing retailers equips them with the same signal status and when they order from the same supplier, stimulates the supplier to acquire signals from them both. A necessary condition for the retailers to exchange signals is that competition is not too intense. A monopolist supplier can offer them differential payments to manipulate their incentives and trap them in a Prisoner's Dilemma type of situation for signal acquisition. 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 suppliers will profit from enhanced signal availability, the retailers can be better off as well when signal correlation is weak, but the customers will be hurt by increased prices and lowered product availability.

# Chapter 3
# On Strategic Demand Information Dissemination

## 3.1 Introduction

According to Chapter 2, the sustainable pattern of information flow is rich when two retailers that sell substitutable products order from the same supplier. In this chapter, we study further information sharing in system RC. The issues of particular academic interest of this chapter are: 1) the incentive by the supplier to solicit signals from the retailers and the procedure it should follow; 2) the strategic interplay between horizontal and vertical information flow; and 3) the attainability of system-wide information transparency so that the demand signals are made visible to each and every party through incentive-driven information flow.

To address these issues, we assume that the retailers can strategically disclose signals to each other (horizontal information sharing), and the supplier can select a procedure to acquire their signals (vertical information acquisition). The status of horizontal (vertical, resp.) information flow enhances as more retailers horizontally (vertically, resp.) disclose signals. We examine the incentives for the retailers to share signals, and for the supplier to solicit signals from the retailers, together with the procedure it should follow.

## 3.2 Model preliminaries

We consider two retailers that order from an external supplier and sell in a market with uncertain demand. This approximates the reality where few suppliers provide for major competitors in the industry. Over the past decades, the suppliers across industries have undergone waves of consolidations. In the electronics industry, Singapore-based Avago agreed to pay $37 billion in cash and stock for its US rival Broadcom, to create the most diversified communications platform (*Wall Street Journal*, May 29, 2015). In the automobile industry, Ford, GM, and Toyota now all source transmission parts from BorgWarner, a US-based parts supplier (*Automotive News*, April, 2012). In the fashion industry, as the entire industry moves toward greater sustainability, a consolidation of suppliers and long-term contracts has been the norm, according to a market report by cKinetics.

We follow Chapter 2 to assume that the inverse demand function for product $i$ is:

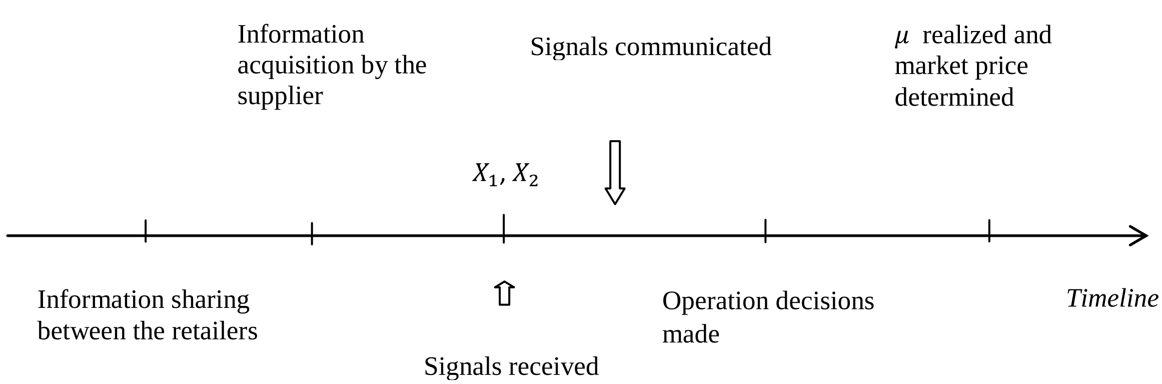
$$p_i = a_i + \mu - q_i - \beta q_{3-i}, i = 1,2, \quad (3\text{-}1)$$

where, $a_i$ is the market potential for product $i$, and $q_i$ its quantity. $\beta \in [0,1)$ is the intensity of price externality, and models the extent of the impact on a retailer's demand by the other retailer's price. We treat $\beta$ as the proxy for the intensity of market competition. The market will become more competitive as $\beta$ increases. $\mu$ models market uncertainty, whose prior distribution is normal with mean zero and variance $\sigma_\mu$. Each retailer has an exclusive access to a signal that can be utilized to update the forecast for $\mu$. We make the following assumptions on signal structure.

**Assumptions:** *Retailer $i$ has signal $X_i = \mu + \varepsilon_i$, where $\varepsilon_i$ is the noise term and follows normal $N(0, \sigma_\varepsilon)$. $(\mu, \varepsilon_i)$ is bi-variate normal, with $cov(\mu, \varepsilon_i) = 0$. $(\mu, X_1, X_2)$ is multi-variate normal, with $cov(\varepsilon_1, \varepsilon_2) = 0$.*

These assumptions are in line with those in the existing literature (see, for instance, Li and Zhang 2008, Ha et al. 2011, etc). $\sigma_\varepsilon$, as the noise variation, is an indicator of signal quality. A lower value of $\sigma_\varepsilon$ indicates a higher signal accuracy. Under these assumptions, we can derive the conditional expectations as: $E(\mu|X_i = x_i) = \frac{\sigma_\mu}{\sigma_\mu + \sigma_\varepsilon} x_i$, $E(\mu|X_1 = x_1, X_2 = x_2) = \frac{\sigma_\mu}{2\sigma_\mu + \sigma_\varepsilon}(x_1 + x_2)$, and $E(X_j|X_i = x_i) = \frac{\sigma_\mu}{\sigma_\mu + \sigma_\varepsilon} x_i$. Information flow can take place along two directions. Horizontally, the retailers can adopt two decision regimes to decide on the pattern of horizontal information sharing. One is cooperative decision making, the other is unilateral decision making. We want to know the value of cooperation in information sharing by doing so. Vertically, the supplier can solicit signals from the retailers, by strategically selecting a procedure to approach the retailers to gain signal access. Specifically, it can approach the retailers at the same time (simultaneous signal acquisition), or follow a sequence to approach them (sequential signal acquisition).

**Figure 3.1. Decision framework**



We use the decision framework as illustrated in Figure 3.1 to carry out analysis, which is in consistent with that of Chapter 2. The retailers first choose to disclose signals to each other, and the supplier then acquires signals from them. Once the retailers exchange signals, the horizontal information links are publically known. After receiving the signals, the retailers will transmit them horizontally and vertically as per the agreement. The supplier and the retailers will utilize the signals available to them in making operation decisions. Price-only contracts govern their vertical relationships. The supplier sets wholesale prices $(w_1, w_2)$ to the retailers who order $(q_1, q_2)$. We still consider linear additive policy structures. The policy structures are common knowledge. Finally, full market uncertainty is revealed, market price is cleared, and revenues accrue to all the parties.

## 3.3 Information structure

To analyze the information structure that can be sustained based on the incentives of the supply chain participants, we first analyze the supplier's signal acquisition decision for given status of horizontal information flow, and then proceed to analyze the incentive by the retailers to disclose signals and further establish the equilibrium information structure. Then the retailers make decisions on horizontal information sharing, taking the supplier's vertical signal acquisition into consideration.

### 3.3.1 Analytical procedure

Under our decision sequence, horizontal information sharing between the retailers is set up before vertical information acquisition by the supplier. The retailers engage in one of three possible statuses of horizontal information flow: no information sharing, when neither retailer discloses signal; bilateral information sharing, when both retailers exchange signals with each other; and unilateral information sharing, when only one retailer discloses signal to the other but not vice versa. Under unilateral information sharing, we call the retailer that discloses signal as the communicating retailer, and its rival the non-communicating retailer. In this situation, note that between the two retailers, the non-communicating retailer has access to more signals than the communicating retailer.

Given the status of horizontal information flow, the supplier proceeds to acquire signals from the retailers. Let the status of vertical signal disclosure be $n = (n_1, n_2)$, where $n_i = 1$ indicates retailer $i$ discloses signal to the supplier, and $n_i = 0$ indicates it does not. In the operation subgame, given the supplier's wholesale prices $w = (w_1, w_2)$ and the signal values $x = (x_1, x_2)$, the retailers choose order quantities to maximize their respective profits.

When the retailers forfeit information sharing, each retailer has access to its own signal and attains a profit of:

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

Under bilateral information sharing, each retailer has access to both signals and attains a profit of:

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

Under unilateral information sharing, the profit of the communicating retailer, with access to its signal only, takes the form of (3-2), while the profit of the non-communicating retailer, with access to the signals at both retailers, takes the form of (3-3).

With the status of horizontal information sharing, the supplier can anticipate the signal-triggered order decisions by the retailers under any status of vertical information acquisition, and chooses the wholesale prices to maximize its profit of:

$$\pi_S^n = \begin{cases} \pi_S^{(0,0)} = E[\sum_{i=1}^{2}(w_i-c_i)q_i] & n=(0,0) \\ \pi_S^{(1,1)}(x) = E[\sum_{i=1}^{2}(w_i-c_i)q_i\,|(X_1=x_1,X_2=x_2)] & n=(1,1) \\ \pi_S^{(1,0)}(x_1) = E[\sum_{i=1}^{2}(w_i-c_i)q_i\,|X_1=x_1] & n=(1,0) \\ \pi_S^{(0,1)}(x_2) = E[\sum_{i=1}^{2}(w_i-c_i)q_i\,|X_2=x_2] & n=(0,1) \end{cases}. \quad (3\text{-}4)$$

Note that the profit functions, as given in (3-2)-(3-4), are contingent on the realized signal values. The supplier and retailers value expected ex-ante profits in making information decisions.

Under simultaneous signal acquisition, for given payments $m=(m_1,m_2)$ by the supplier, each retailer unilaterally makes the decision to disclose signal. If the supplier offers different payments to the retailers, without loss of generality, we assume it will offer a larger payment to retailer 1, but a smaller payment to retailer 2. The equilibrium status of vertical information flow: $n^*(m)=(n_1^*(m),n_2^*(m))$, should satisfy:

$$\pi_{R1}^{(n_1^*(m),n_2^*(m))} + 1_{\{n_1^*(m)=1\}}\cdot m_1 \geq \pi_{R1}^{(1-n_1^*(m),n_2^*(m))} + 1_{\{n_1^*(m)=0\}}\cdot m_1; \quad (3\text{-}5)$$

$$\pi_{R2}^{(n_1^*(m),n_2^*(m))} + 1_{\{n_2^*(m)=1\}}\cdot m_2 \geq \pi_{R2}^{(n_1^*(m),1-n_2^*(m))} + 1_{\{n_2^*(m)=0\}}\cdot m_2, \quad (3\text{-}6)$$

where, $1_{\{x\}}$ is the indicator function such that $1_{\{x\}}=1$ when $x$ holds true, and $\pi_{Ri}^{(n_1\,,n_2\,)}$ is the expected ex-ante profit of retailer $i$ under vertical status $n=(n_1\,,n_2\,)$. (3-5) and (3-6) are the incentive compatibility conditions for retailer 1 and retailer 2, respectively.

The supplier will then choose payments $m^*$ to maximize its expected ex-ante profit of:

$$\pi_S(m) = \pi_S^{(n_1^*(m),n_2^*(m))} - 1_{\{n_1^*(m)=1\}}\cdot m_1 - 1_{\{n_2^*(m)=1\}}\cdot m_2, \quad (3\text{-}7)$$

where, $\pi_S^{(n_1, n_2)}$ is the expected ex-ante profit of the supplier under status $n = (n_1, n_2)$. $n^*(m^*)$ is the resulting status of vertical signal disclosure. The profits of the supplier and the retailers in the equilibrium can be determined accordingly.

Under sequential signal acquisition, suppose that the supplier first approaches retailer $i$ and then retailer $3 - i$ to gain signal access. Given the status $n_i$ of vertical signal disclosure by retailer $i$, the supplier offers $m_{3-i}$ to retailer $3 - i$, who chooses $n_{3-i}^*(m_{3-i}|n_i)$ to maximize its profit of:

$$\pi_{R,3-i}(n_{3-i}|m_{3-i}, n_i) = \pi_{R,3-i}^{(n_i, n_{3-i})} + 1_{\{n_{3-i}(m_{3-i})=1\}} \cdot m_{3-i}. \quad (3\text{-}8)$$

Responding to $n_{3-i}^*(m_{3-i}|n_i)$, the supplier chooses payment $m_{3-i}^*(n_i)$ to maximize its profit of:

$$\pi_S(m_{3-i}|n_i) = \pi_S^{(n_i, n_{3-i}^*(m_{3-i}|n_i))} - 1_{\{n_{3-i}^*(m_{3-i}|n_i)=1\}} \cdot m_{3-i}. \quad (3\text{-}9)$$

Anticipating the status of signal acquisition from retailer $(3 - i)$, the supplier offers $m_i$ to retailer $i$, who makes decision $n_i^*(m_i)$ to maximize its profit of:

$$\pi_{Ri}(m_i) = \pi_{Ri}^{(n_i(m_i), n_{3-i}^*(m_{3-i}^*|n_i))} + 1_{\{n_i(m_i)=1\}} \cdot m_i, \quad (3\text{-}10)$$

at which the supplier chooses payment $m_i^*$ to maximize its ex-ante profit of:

$$\pi_S(m_i) = \pi_S^{(n_i^*(m_i), n_{3-i}^*(m_{3-i}^*|n_i^*))} - 1_{\{n_i^*(m_i)=1\}} \cdot m_i - 1_{\{n_{3-i}^*(m_{3-i}^*|n_i^*)=1\}} \cdot m_{3-i}^*. \quad (3\text{-}11)$$

The supplier will choose the signal-acquisition procedure to maximize its profit. The retailers are able to anticipate the supplier's signal acquisition decision and the profits they can earn under any status of horizontal information flow. They will cooperatively choose to build horizontal information flow that maximizes their expected total profit. Once their decision is made, the supplier will follow the determined sequence to acquire signals from them. The information structure is thus set up.

### 3.3.2 Signal acquisition by the supplier

We first analyze the supplier's signal-acquisition decision and the procedure it should follow to approach the retailers, conditional on the status of horizontal information flow.

*No information sharing*

Suppose the retailers forfeit horizontal information sharing, so that each retailer can only utilize its own signal in demand updating and order adjustment. We group the subgame equilibrium operation outcomes, derived according to (3-2)-(3-4), and the corresponding expected ex-ante profits of the retailers and the supplier in Table 3.1. The payments for vertical signal disclosure are excluded from the ex-ante profits.

**Table 3.1. Operation subgame equilibria, without horizontal information sharing**

| $(n_1, n_2)$ | Decision policy | Ex-ante profit |
|---|---|---|
| (0,0) | $w_i^{(0,0)} = w_i^0$<br>$q_i^{(0,0)} = q_i^0 + Bx_i$ | $\pi_{Ri}^{(0,0)} = \pi_{Ri}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}$.<br>$\pi_S^{(0,0)} = \sum_{i=1}^2 (w_i^0 - c_i) q_i^0$. |
| (1,1) | $w_i^{(1,1)} = w_i^0 + Bx_i + \frac{\beta}{2}Bx_{3-i}$.<br>$q_i^{(1,1)} = q_i^0 + \frac{1}{2}Bx_i$. | $\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}$.<br>$\pi_S^{(1,1)} = \pi_S^{(0,0)} + \frac{\sigma_u^2}{2[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]}$. |
| (1,0) | $w_1^{(1,0)} = w_1^0 + (1 + \frac{\beta k}{2})Bx_1$.<br>$w_2^{(1,0)} = w_2^0 + (k + \frac{\beta}{2})Bx_1$.<br>$q_1^{(1,0)} = q_1^0 + \frac{B}{2}x_1$.<br>$q_2^{(1,0)} = q_2^0 + Bx_2 - \frac{k}{2}Bx_1$. | $\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}$.<br>$\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \frac{\sigma_u^2[4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2]}{4(\sigma_\varepsilon+\sigma_\mu)[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}$.<br>$\pi_S^{(1,0)} = \pi_S^{(0,0)} + \frac{\sigma_u^2[\sigma_\varepsilon^2+(2+\beta)\sigma_\varepsilon\sigma_\mu+(2+\beta)\sigma_u^2]}{2(\sigma_\varepsilon+\sigma_\mu)[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}$. |
| (0,1) | $w_1^{(0,1)} = w_1^0 + (k + \frac{\beta}{2})Bx_2$.<br>$w_2^{(0,1)} = w_2^0 + (1 + \frac{\beta k}{2})Bx_2$.<br>$q_1^{(0,1)}(x) = q_1^0 + Bx_1 - \frac{k}{2}Bx_2$.<br>$q_2^{(0,1)}(x) = q_2^0 + \frac{1}{2}Bx_2$. | $\pi_{R1}^{(0,1)} = \pi_{R1}^0 + \frac{\sigma_u^2[4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_\mu{}^2]}{4(\sigma_\varepsilon+\sigma_\mu)[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}$.<br>$\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{4[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}$.<br>$\pi_S^{(0,1)} = \pi_S^{(0,0)} + \frac{\sigma_u^2[\sigma_\varepsilon^2+(2+\beta)\sigma_\varepsilon\sigma_\mu+(2+\beta)\sigma_u^2]}{2(\sigma_\varepsilon+\sigma_\mu)[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}$. |

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

Notice that, once the supplier acquires both signals, i.e., $n = (1,1)$, it will rely more on retailer $i$'s signal than that from retailer $3 - i$ in adjusting $w_i$. As both retailers lower signal reliance in ordering from the supplier, the quantity competition between them is mitigated. As market competition intensifies, i.e., $\beta$ increases, the supplier will rely less on retailer $i$'s signal but more on retailer $(3 - i)$'s signal in setting wholesale price $w_i$. With access to only one signal, $n = (1,0)$ for instance, the supplier will utilize the accessed signal $x_1$ to adjust $w_1$ by $B(1 + \frac{\beta k}{2})x_1$ and $w_2$ by $B(k + \frac{\beta}{2})x_1$. Since $1 + \frac{\beta k}{2} > k + \frac{\beta}{2}$, $w_1$ is made more responsive than $w_2$ to $x_1$. Once retailer $i$ discloses signal to the supplier, the status of signal disclosure by retailer $3 - i$ will not influence its reliance on $x_i$ in making order adjustment. The signal-triggered operation adjustments will taper off as $\beta$ increases. Hence, vertical signal acquisition by the supplier will exert a weaker impact on the quantity interaction between retailers, as market competition intensifies.

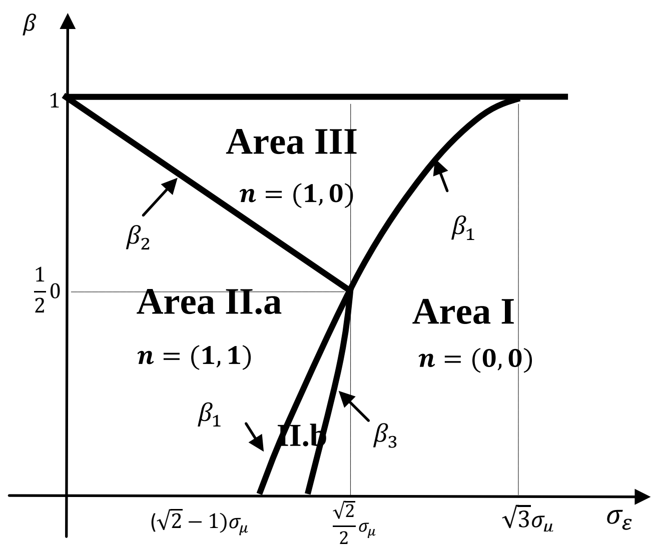
We can apply the procedure as given in (3-5)-(3-11) to analyze the signal acquisition decision by the supplier. Since the retailers forfeit information sharing, we assume without loss of generality that the supplier will approach retailer 1 first and retailer 2 later under sequential information acquisition. To ease exposition, we refer to retailer 1 as the first-approached retailer and retailer 2 the late-approached retailer. Proposition 3.1, with the assistance of Figure 3.2, shows the supplier's signal acquisition decision.

**Proposition 3.1.** *In a system of one supplier selling to two retailers each with an exclusive signal access, given that the retailers forfeit information sharing, let* $p_N^L = \frac{\sigma_\varepsilon \sigma_u^2(3\sigma_\varepsilon + 2(1+\beta)\sigma_\mu)}{4(\sigma_\varepsilon + \sigma\mu)(2\sigma_\varepsilon + (2+\beta)\sigma_\mu)^2}, p_N^H = \frac{3\sigma_u^2(\sigma_\varepsilon + \sigma_\mu)}{4(2\sigma_\varepsilon + (2+\beta)\sigma_\mu)^2}$, $\beta_1 = \frac{\sigma_\varepsilon^2 + 2\sigma_\varepsilon\sigma_\mu - \sigma_u^2}{2\sigma_\varepsilon\sigma_\mu + 2\sigma_u^2}$, $\beta_2 = \frac{2\sigma_\mu - \sigma_\varepsilon}{2\sigma_\mu}$, *and* $\beta_3 = \frac{2\sigma_\varepsilon^2 - \sigma_u^2}{2\sigma_u^2}$. *Referring to Figure 3.2:*

*1) Under simultaneous signal acquisition, the supplier will acquire no signal in area I; both signals in areas II.a and II.b by offering* $m = (p_N^H, p_N^L)$*; but only one signal in area III by offering* $m_1 = p_N^H$.

*2) Under sequential signal acquisition, the supplier will acquire no signals in area I; both signals by offering* $m = (p_N^L, p_N^L)$ *in area II.a, but* $m = (p_N^H, p_N^L)$ *in area II.b; only one signal in area III by offering* $m_1 = p_N^L$.

**Figure 3.2. Vertical signal acquisition by the supplier, without horizontal information sharing**




When the retailers completely forfeit horizontal information sharing, the establishment of vertical information flow is not influenced by the procedure whereby the supplier approaches the retailers to gain signal access. When the retailers face an intense competition ($\frac{1}{2} < \beta < 1$), the supplier acquires both signals if signal quality is high ($\sigma_\varepsilon$ is low), one signal if signal quality is moderate ($\sigma_\varepsilon$ is medium), but no signal otherwise. When the retailers face a weak competition ($0 \leq \beta < \frac{1}{2}$), the supplier acquires both signals if the signal is of high quality but no signal otherwise. The signal acquisition procedure, however, affects the payments whereby the supplier uses to incentivize the retailers to disclose signals. Under the circumstance when only one vertical link is built (Area III of figure 3.2), the supplier pays less to the retailer that discloses its signal under sequential acquisition than under simultaneous acquisition. When the supplier acquires both signals, instead of offering differential payments of $p_N^H$ and $p_N^L$ as incentives to the retailers under simultaneous acquisition, the supplier pays a uniform price of $p_N^L$ to them under sequential acquisition (Area II.a of figure 3.2). Consequently, the supplier attains the same status of signal accessibility by a smaller expense under sequential acquisition than under simultaneous acquisition.

**Corollary 3.1**. *In the system of one supplier selling to two retailers each with an exclusive signal access, given that the retailers forfeit horizontal information sharing, the supplier is better off with sequential signal acquisition, but the retailers would prefer simultaneous signal acquisition by the supplier*.

Hence, given that the supplier can strategically select the procedure to solicit signals from the retailers when they forfeit horizontal information sharing, it will prefer sequential signal acquisition. Vertical signal disclosure can occur when the signal quality is not so low as to substantially distort the value of signal in updating demand forecast. In this situation, bilateral vertical disclosure can be sustained when market competition is not too strong, but unilateral vertical disclosure can be sustained otherwise. The retailers will suffer a total profit loss when the supplier sequentially approaches them for signal access, compared with when the supplier does so simultaneously. Note however that the system profit is insensitive to the supplier's acquisition procedure, since the statuses of vertical signal disclosure are identical under sequential and simultaneous signal acquisitions by the supplier.

*Bilateral information sharing*

Suppose the two retailers mutually disclose signals to each other to attain bilateral information sharing. We group the subgame equilibrium operation outcomes, and the expected ex-ante profits (exclusive of incentive payments) of the channel members in Table 3.2.

**Table 3.2. Operation subgame equilibria, with information sharing**

| $(n_1, n_2)$ | **Decision policy** | **Ex-ante profit** |
|---|---|---|
| (0,0) | $w_i^{(0,0)} = w_i^0$. <br> $q_i^{(0,0)} = q_i^0 + C(x_1 + x_2)$. | $\pi_{Ri}^{(0,0)} = \pi_{Ri}^0 + \frac{2\sigma_\mu^2}{(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)}$. <br> $\pi_S^{(0,0)} = \sum_{i=1}^2 (w_i^0 - c_i)q_i^0$. |
| (1,1) | $w_i^{(1,1)} = w_i^0 + (1+\frac{\beta}{2})C(x_1 + x_2)$. <br> $q_i^{(1,1)} = q_i^0 + \frac{1}{2}C(x_1 + x_2)$. | $\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \frac{\sigma_\mu^2}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)}$. |

| | | |
|---|---|---|
| | | $\pi_S^{(1,1)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{(2+\beta)(\sigma_\varepsilon+2\sigma_\mu)}$. |
| (1,0) | $w_1^{(1,0)} = w_1^0 + \left(1+\frac{\beta}{2}\right)(1+k)Cx_1$.<br>$w_2^{(1,0)} = w_2^0 + \left(1+\frac{\beta}{2}\right)(1+k)Cx_1$.<br>$q_1^{(1,0)} = q_1^0 + \frac{1}{2}(1-k)Cx_1 + Cx_2$.<br>$q_2^{(1,0)} = q_2^0 + \frac{1}{2}(1-k)Cx_1 + Cx_2$. | $\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \frac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$.<br>$\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \frac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$.<br>$\pi_S^{(1,0)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}$. |
| (0,1) | $w_1^{(0,1)} = w_1^0 + \left(1+\frac{\beta}{2}\right)(1+k)Cx_2$.<br>$w_2^{(0,1)} = w_2^0 + \left(1+\frac{\beta}{2}\right)(1+k)Cx_2$.<br>$q_1^{(0,1)}(x) = q_1^0 + \frac{1}{2}(1-k)Cx_2 + Cx_1$.<br>$q_2^{(0,1)}(x) = q_2^0 + \frac{1}{2}(1-k)Cx_2 + Cx_1$. | $\pi_{R1}^{(0,1)} = \pi_{R1}^0 + \frac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$.<br>$\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \frac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$.<br>$\pi_S^{(0,1)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}$. |

*Notes.* $w_i^0 = \frac{a_i+c_i}{2}$. $q_i^0 = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}$, $C = \frac{\sigma_\mu}{(2+\beta)(2\sigma_\mu+\sigma_\varepsilon)}$, $k = \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}$, $\pi_{Ri}^0 = (\frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)})^2$.

The even signal statuses at the retailers under bilateral information sharing correlate their orders. Different from when the retailers forfeit information sharing, the supplier will utilize any signal, available through vertical acquisition, to adjust the wholesale prices to the two retailers by the same magnitudes. In particular, its wholesale price adjustment is $\frac{\sigma_\mu(x_1+x_2)}{2(2\sigma_\mu+\sigma_\varepsilon)}$ with access to both signals, but $\frac{\sigma_\mu(1+k)x_i}{2(2\sigma_\mu+\sigma_\varepsilon)}$ with access to $x_i$ only. Unilateral vertical disclosure by retailer $i$ will make both retailers rely less on signal $x_i$ when making orders. Irrespective of the status of vertical information acquisition, the supplier and the retailers will less utilize the signals accessible to them in operation adjustment as competition intensifies. This makes the access to and sharing of demand signals less consequential on the system performance, as the market becomes more competitive.

**Proposition 3.2**. *In the system of a supplier selling to two retailers each with an exclusive access to a signal,* given *that the retailers horizontally share information, let* $p_S^H = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$, $p_S^L = \frac{3\sigma_\varepsilon\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$, *with* $p_S^H > p_S^L$*:*

1) *Under simultaneous signal acquisition, the supplier will acquire both signals with* $m = (p_S^H, p_S^L)$.
2) *Under sequential signal acquisition, the supplier will acquire both signals with* $m = (p_S^L, p_S^L)$.

We can apply the procedure in (3-5)-(3-11) to analyze the signal acquisition decision by the supplier. Like in the case without horizontal information sharing, we assume without loss generality for this case that the supplier will approach retailer 1 first and retailer 2 later under sequential signal acquisition. Note that retailer $i$ in (3-8) is now retailer 1 and retailer $3 - i$ is retailer 2. Proposition 3.2 shows that, irrespective of the signal acquisition procedure, the supplier will always acquire both signals. Bilateral information sharing, with the even signal statuses at the two retailers thus results, stimulates the supplier to gain signal access. System-wide demand information transparency is thus attained. However, the supplier offers a uniform payment to the retailers under sequential signal acquisition, but offers differential payments to them under simultaneous signal acquisition. The total payment is smaller under sequential acquisition. Sequentializing the process to solicit signals from the retailers then rewards the supplier with a better profit performance.

**Corollary 3.2**. *In the system of one supplier selling to two retailers each with an exclusive signal access, given that the retailers horizontally share information, the supplier is better off with sequential signal acquisition, but the retailers would prefer simultaneous signal acquisition by the supplier.*

Given that the retailers have mutually disclosed signals, the supplier will always prefer to follow a sequence to build vertical information links by a uniform payment, though the specific procedure it follows to approach the retailers can be arbitrary. On the other hand, the retailers prefer the supplier to acquire signals simultaneously, so that they can profit more from signal access than under sequential information acquisition by the supplier. Since the supplier always acquires both signals (though with different payments), the system profit will be insensitive to the signal acquisition procedure.

*Unilateral information sharing*

Under unilateral information sharing, we analyze a representative case in which retailer 1 discloses signal to retailer 2. The analysis for the case when retailer 2 discloses signal to retailer 1 follows by symmetry. The subgame equilibrium operation outcomes and the corresponding expected ex-ante profits (exclusive of signal payments) of the channel parties are shown in Table 3.3. Given that only one retailer horizontally discloses the signal, the two retailers are equipped with asymmetric signal statuses before vertical signal acquisition by the supplier.

**Table 3.3. Operation subgame equilibria, when only retailer 1 discloses signal**

| $(n_1, n_2)$ | Decision policy | Ex-ante profit |
|---|---|---|
| (0,0) | $w_i^{(0,0)} = w_i^0$.<br>$q_1^{(0,0)} = q_1^0 + A_1 x_1$.<br>$q_1^{(0,0)} = q_1^0 + A_2 x_1 + A_3 x_2$. | $\pi_{R1}^{(0,0)} = \pi_{R1}^0 + \frac{\sigma_\mu^2}{(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$.<br>$\pi_{R2}^{(0,0)} = \pi_{R2}^0 + \frac{\sigma_\mu^2((8+4\beta+\beta^2)\sigma_\epsilon+8\sigma_\mu)}{4(2+\beta)^2(\sigma_\epsilon+\sigma_\mu)(\sigma_\epsilon+2\sigma_\mu)}$.<br>$\pi_S^{(0,0)} = \sum_{i=1}^2 (w_i^0 - c_i) q_i^0$. |

| | | |
|---|---|---|
| (1,1) | $w_1^{(1,1)} = w_1^0 + + \frac{\beta A_2 + 2A_1}{2} x_1 + \frac{\beta A_3}{2} x_2.$<br>$w_2^{(1,1)} = w_2^0 + \frac{\beta A_1 + 2A_2}{2} x_1 + A_3 x_2.$<br>$q_1^{(1,1)} = q_1^0 + \frac{A_1}{2} x_1.$<br>$q_2^{(1,1)} = q_2^0 + \frac{A_2}{2} x_1 + \frac{A_3}{2} x_2.$ | $\pi_{R1}^{(1,1)} = \pi_{R1}^0 + \frac{\sigma_\mu^2}{4(2+\beta)^2(\boldsymbol{\sigma_\epsilon} + \sigma_\mu)}.$<br>$\pi_{R2}^{(1,1)} = \pi_{R2}^0 + \frac{\sigma_\mu^2((8+4\beta+\beta^2)\boldsymbol{\sigma_\epsilon} + 8\sigma_\mu)}{16(2+\beta)^2(\boldsymbol{\sigma_\epsilon} + \sigma_\mu)(\boldsymbol{\sigma_\epsilon} + 2\sigma_\mu)}.$<br>$\pi_S^{(1,1)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2((6+\beta)\boldsymbol{\sigma_\epsilon} + 8\sigma_\mu)}{8(2+\beta)(\boldsymbol{\sigma_\epsilon} + \sigma_\mu)(\boldsymbol{\sigma_\epsilon} + 2\sigma_\mu)}.$ |
| (1,0) | $w_1^{(1,0)} = w_1^0 + \frac{(2+\beta)A_1}{2} x_1.$<br>$w_2^{(1,0)} = w_2^0 + \frac{(2+\beta)A_1}{2} x_1.$<br>$q_1^{(1,0)} = q_1^0 + \frac{A_1}{2} x_1.$<br>$q_2^{(1,0)} = q_2^0 + A_4 x_1 + A_3 x_2.$ | $\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \frac{\sigma_\mu^2}{4(2+\beta)^2(\sigma_\epsilon + \sigma_\mu)}.$<br>$\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \frac{\sigma_\mu^2((5+4\beta+\beta^2)\sigma_\epsilon + 2\sigma_\mu)}{4(2+\beta)^2(\sigma_\epsilon + \sigma_\mu)(\sigma_\epsilon + 2\sigma_\mu)}.$<br>$\pi_S^{(1,0)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{2(2+\beta)(\sigma_\epsilon + \sigma_\mu)}.$ |
| (0,1) | $w_1^{(0,1)} = w_1^0 + A_5 x_2.$<br>$w_2^{(0,1)} = w_2^0 + \frac{(2+\beta)A_1}{2} x_2.$<br>$q_1^{(0,1)}(x) = q_1^0 + A_1 x_1 + A_6 x_2.$<br>$q_2^{(0,1)}(x) = q_2^0 + A_2 x_1 + A_7 x_2.$ | $\pi_{R1}^{(0,1)} = \pi_{R1}^0 + \frac{\sigma_\mu^2(4\sigma_\epsilon^2 + (4+\beta^2)\sigma_\epsilon\sigma_\mu + \sigma_\mu^2)}{4(2+\beta)^2(\sigma_\epsilon + \sigma_\mu)^3}.$<br>$\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \frac{\sigma_\mu^2((20+4\beta+\beta^2)\sigma_\epsilon^3 + 2(24-2\beta+\beta^2)\sigma_\epsilon^2\sigma_\mu + 4(9-2\beta+\beta^2)\sigma_\epsilon\sigma_\mu^2 + 8\sigma_\mu^3)}{16(2+\beta)^2(\sigma_\epsilon + \sigma_\mu)^3(\sigma_\epsilon + 2\sigma_\mu)}.$<br>$\pi_S^{(0,1)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2((2+\beta)\sigma_\epsilon^2 + 2(2+\beta)\sigma_\epsilon\sigma_\mu + 4\sigma_\mu^2)}{8(2+\beta)(\sigma_\epsilon + \sigma_\mu)^3}.$ |

*Notes.* $w_i^0 = \frac{a_i + c_i}{2}$. $q_i^0 = \frac{2(a_i - c_i) - \beta(a_{3-i} - c_{3-i})}{2(4-\beta^2)}$, $\pi_{Ri}^0 = (\frac{2(a_i - c_i) - \beta(a_{3-i} - c_{3-i})}{2(4-\beta^2)})^2$,

$A_1 = \frac{\sigma_\mu}{(2+\beta)(\sigma_\varepsilon + \sigma_\mu)}, A_2 = \frac{\sigma_\mu(2(\sigma_\varepsilon + \sigma_\mu) - \beta\sigma_\mu)}{2(2+\beta)(\sigma_\varepsilon + \sigma_\mu)(\sigma_\varepsilon + 2\sigma_\mu)}, A_3 = \frac{\sigma_\mu}{2(2\sigma_\mu + \sigma_\varepsilon)}, A_4 = \frac{\sigma_\mu(\sigma_\epsilon - \beta\sigma_\mu)}{2(2+\beta)(\sigma_\varepsilon + \sigma_\mu)(\sigma_\varepsilon + 2\sigma_\mu)}, A_5 = \frac{\sigma_\mu(\beta\sigma_\varepsilon + 2\sigma_\mu)}{4(\sigma_\varepsilon + \sigma_\mu)^2}, A_6 = -\frac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon + \sigma_\mu)^2}, A_7 = \frac{\sigma_\mu(2\sigma_\varepsilon(\sigma_\varepsilon + \sigma_\mu) + \beta(\sigma_\varepsilon^2 + 2\sigma_\varepsilon\sigma_\mu + 2\sigma_\mu^2))}{4(2+\beta)(\sigma_\varepsilon + \sigma_\mu)^2(\sigma_\varepsilon + 2\sigma_\mu)}.$

As shown in Table 3.3, retailer 2 can utilize both signals in making order adjustment, but retailer 1 can only use its own signal. As a consequence, retailer 2, due to enhanced signal accessibilities, attains a better profit performance than retailer 1, before their signals are made accessible to the supplier. As in the previous cases, the supplier's signal acquisition will influence the retailers' reliance on signals in order adjustment. For instance, after the supplier gains access to both signals, both retailers will halve reliance on the signals that are available to them in making order decisions. After the supplier acquires the signal from the communicating retailer (retailer 1) so that the particular signal is visible to every party in the system, it will utilize the signal to raise the wholesale prices to both retailers by the same extents, while the two retailers will adjust their orders separately. The relevant impacts on the wholesale prices and order quantities of vertical signal disclosure are different when the supplier acquires the signal from the non-communicating retailer.

Under simultaneous signal acquisition, we can follow the procedure given in (3-5) – (3-7) to analyze the outcomes. Proposition 3.3 characterizes the equilibrium status of vertical signal disclosure.

**Proposition 3.3**. *In the system of one supplier selling to two retailers each with an exclusive signal access, given only retailer $i$ discloses signal to the rival, under simultaneous signal acquisition, the supplier will offer* $m_i = p_A^H = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$ *to gain access to retailer $i$'s signal only.*

With different signal accessibilities at the retailers, if the supplier approaches them at the same time to gain signal access, it will only acquire signal from the communicating retailer whose signal is thus visible throughout the system. Note that $p_A^H = p_S^H$, where $p_S^H$ is the larger payment of the two offered by the supplier to solicit signals from the retailers when they mutually disclose signals. Referring to the statuses of vertical signal disclosure under other statuses of horizontal information flow, we note that the supplier, when simultaneously soliciting signals from the retailers, will gain access to the signal(s) that are accessible to both retailers. That is, the status of horizontal information flow regulates the behavior by the supplier in signal acquisition. Given that the supplier acquires signal from the communicating retailer only, the non-communicating retailer enjoys an information advantage. To solicit its signal, the supplier will pay a price not only to compensate for its profit loss after signal disclosure, but to the communicating retailer for the additional loss it suffers from price reduction. This will be more than what the supplier can afford with the profit gain from enhanced signal availability.

Under unilateral information sharing, when the supplier sequentially solicits signals, the specific sequence whereby it follows to approach the retailers is influential in building vertical information links. Specifically, the supplier can approach the communicating retailer first or the non-communicating retailer first. The solicitation sequence will influence the payments that the supplier uses to adjust the retailers' incentives in vertical signal disclosure. Note that it is the signal accessibilities at the involved parties that determine their operation behaviors and profit performance. The first-approached retailer has access only to its own signal when it is the communicating retailer, but has access to both signals when it is the non-communicating retailer. Such difference in the signal statuses at the retailers as they are approached by the supplier is consequential in their incentives on vertical signal disclosure.

**Lemma 3.1**. *In the system of a supplier selling to two retailers each with an exclusive signal access, given only retailer $i$ discloses signal to the rival, under sequential signal acquisition, let* $\beta_4 = \frac{2\left(\sigma_\varepsilon^2-\sigma_\varepsilon\sigma_\mu-2\sigma_u^2+\sigma_\mu\sqrt{2(3\sigma_\varepsilon^2+2\sigma_u^2)}\right)}{\sigma_\varepsilon(4\sigma_\mu-\boldsymbol{\sigma_\epsilon})}$, $\beta_5 = \frac{2(\sigma_\mu\sqrt{19\sigma_\varepsilon^3+88\sigma_\varepsilon^2\sigma_\mu+127\sigma_\varepsilon\sigma_u^2+54\sigma_u^3}-(\sigma_\varepsilon^2+2\sigma_\varepsilon\sigma_\mu+\sigma_u^2)\sqrt{\sigma_\varepsilon})}{(\sigma_\varepsilon+3\sigma_\mu)^2\sqrt{\sigma_\varepsilon}}$, $p_A^L = \frac{\sigma_\varepsilon\sigma_u^2(3\sigma_\varepsilon+(2+\beta^2)\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3}$, $p_A^H = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$, $p_2 = \frac{3\sigma_\varepsilon\sigma_u^2}{16(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$:

*1) If the supplier first approaches retailer $i$ for signal access:*

*(i)* *If* $\sigma_\varepsilon \leq (\sqrt{2}-1)\sigma_\mu$, *or,* $(\sqrt{2}-1)\sigma_\mu < \sigma_\varepsilon < \frac{2\sqrt{3}}{3}\sigma_\mu$ *&* $\beta > \beta_4$, *then the supplier offers* $m_i = p_A^L$, *to gain access to retailer* $i$*'s signal only.*

*(ii)* *If* $(\sqrt{2}-1)\sigma_\mu < \sigma_\varepsilon < \frac{2\sqrt{3}}{3}\sigma_\mu$ *&* $\beta \leq \beta_4$, *or,* $\sigma_\varepsilon \geq \frac{2\sqrt{3}}{3}\sigma_\mu$, *then the supplier offers* $m_i = p_A^H$, *to gain access to retailer* $i$*'s signal only.*

*2)* *If the supplier first approaches retailer* $3-i$ *for signal access:*

*(i)* *If* $\sigma_\varepsilon \leq \frac{1+\sqrt{97}}{6}\sigma_\mu$, *or,* $\frac{1+\sqrt{97}}{6}\sigma_\mu < \sigma_\varepsilon < f(\sigma_\mu)$[1] *&* $\beta < \beta_5$, *then the supplier offers* $(m_1, m_2) = (p_A^L, p_2)$, *to gain access to both signals.*

*(ii)* *If* $\frac{1+\sqrt{97}}{6}\sigma_\mu < \sigma_\varepsilon < f(\sigma_\mu)$ *&* $\beta \geq \beta_5$, *or,* $\sigma_\varepsilon \geq f(\sigma_\mu)$, *then the supplier offers* $m_i = p_A^H$, *to gain access to retailer* $i$ *s signal only.*

Lemma 3.1 shows that when the supplier first approaches the communicating retailer, it will always acquire its signal, but not move on to approach the other retailer. The specific payment depends on signal quality and market competition. The supplier will offer a high payment of $p_A^H$ when the signal is noisy or the signal quality is moderate but market competition is weak, in which case the communicating retailer is more hesitant to disclose signal, but a low payment of $p_A^L$ in other cases. On the other hand, if the supplier approaches the non-communicating retailer first, it will acquire its signal and move on to approach the communicating retailer for signal access as well when signal quality is high or signal quality is moderate and market competition is weak. In the other cases, it will get around the non-communicating retailer, to build a vertical information link with the communicating retailer only with a high payment of $p_A^H$.

Weighing its profit performance under the two acquisition sequences, the supplier selects the best one to follow, as shown in Proposition 3.4.

**Proposition 3.4**. *In the system of a supplier selling to two retailers each with an exclusive signal access, suppose only retailer* $i$ *discloses signal with unilateral signal disclosure, under sequential signal acquisition, let* $\beta_4, \beta_5, p_A^L, p_A^H, p_2$ *be as defined in Lemma 3.1:*

*(i)* *If* $\sigma_\varepsilon \leq (\sqrt{2}-1)\sigma_\mu$, *or,* $(\sqrt{2}-1)\sigma_\mu < \sigma_\varepsilon < \frac{2\sqrt{3}}{3}\sigma_\mu$ *&* $\beta > \beta_4$, *then the supplier will approach retailer* $i$ *first, and offer* $m_i = p_A^L$ *to gain access to its signal only.*

*(ii)* *If* $(\sqrt{2}-1)\sigma_\mu < \sigma_\varepsilon < \frac{2\sqrt{3}}{3}\sigma_\mu$ *&* $\beta \leq \beta_4$, *or,* $\frac{2\sqrt{3}}{3}\sigma_\mu \leq \sigma_\varepsilon \leq \frac{1+\sqrt{97}}{6}\sigma_\mu$, *or* $\frac{1+\sqrt{97}}{6}\sigma_\mu < \sigma_\varepsilon < f(\sigma_\mu)$ *&* $\beta < \beta_5$, *then the supplier will approach* $3-i$ *first, and offer* $(m_i, m_{3-i}) = (p_A^L, p_2)$ *to gain access to both signals.*

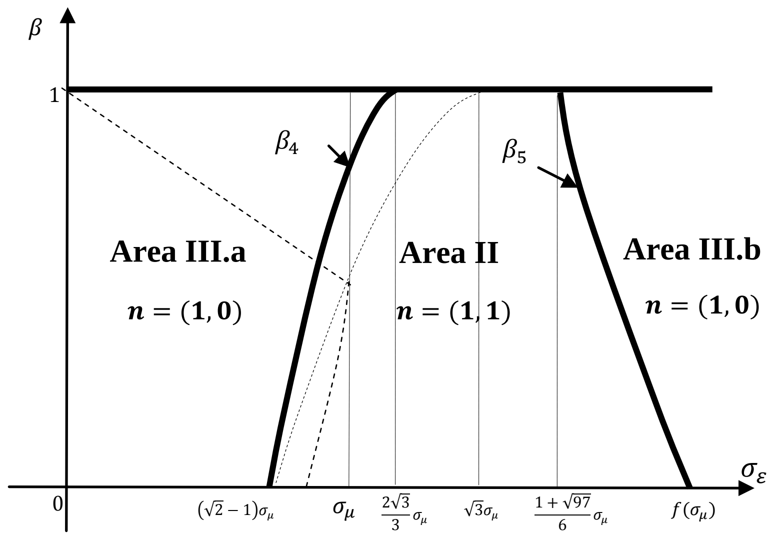
---

[1] The expression for $f(\sigma_\mu)$ is tedious and can be obtained upon request.

*(iii) If* $\frac{1+\sqrt{97}}{6}\sigma_\mu < \sigma_\varepsilon < f(\sigma_\mu)$ *&* $\beta \geq \beta_5$*, or,* $\sigma_\varepsilon \geq f(\sigma_\mu)$*, then the supplier is indifferent with respect to which retailer to approach first; and will offer* $m_i = p_A^H$ *to gain acquire retailer* $i$*'s signal only.*

Figure 3.3 illustrates the results in Proposition 3.4 with a few additional details.

**Figure 3.3. Vertical signal acquisition, given the retailers unilaterally share information**




*Notes.* The dashed curves in the background delimit the area for signal acquisition by the supplier when the retailers forfeit information sharing. The labeling for the areas is to maintain consistency of the partitioning to sustain vertical acquisition. The functional properties of the various threshold levels for market competition intensity, $\beta_1$, $\beta_2$, $\beta_3$, $\beta_4$, and $\beta_5$, can be obtained upon request.

At a high signal quality (Area III.a of Figure 3.3), the supplier first approaches the communicating retailer to acquire its signal with a payment of $p_A^L$. At a moderate signal quality (Area II of Figure 3.3), the supplier first approaches the non-communicating retailer and then the communicating retailer to gain access to both signals with payments of $(p_2, p_A^L)$ in that sequence. As such, the supplier delays contacting the communicating retailer, and affords an additional expense of $p_2$ to gain full signal access. Suppose the supplier sticks with its acquisition sequence as that when signal quality is high. After acquiring the signal from the communicating retailer, the signal statuses and signal quality will make the supplier unable to afford the payment to incentivize the non-communicating retailer to disclose signal. At a low signal quality (Area III.b in figure 3.3), the supplier can follow any sequence to approach the retailers, but acquire the communicating retailer's signal only, with a payment of $p_A^H$. Recall that, under simultaneous information acquisition, the supplier gains access to the signal at the communicating retailer only, with a payment of $p_A^H$. Under sequential information acquisition, however, it can acquire both signals, and, when acquiring only one signal, make a smaller payment. Enhanced signal accessibility with a lower payment can benefit the supplier.

**Corollary 3.3**. *In the system of one supplier selling to two retailers each with an exclusive signal access, given that the retailers unilaterally disclose signals horizontally, the supplier is better off with sequential signal acquisition, but the retailers would prefer simultaneous signal acquisition by the supplier.*

Given that only one retailer horizontally discloses signal, the supplier will prefer to sequentialize the process to gain signal access, though the specific sequence depends on both signal quality and market competition. Such preference by the supplier will make the retailers suffer profit losses, compared with under simultaneous signal acquisition. The system profit is influenced by the supplier's signal acquisition pattern. When signal quality is moderate (Area II in Figure 3.3), by sequentializing signal acquisition, the supplier will gain access to both signals, which will hurt system profit, compared with when the supplier acquires one signal. In the other situations, only one vertical link, the link between the supplier and the communicating retailer in particular, will be built, and the system profit will remain unaffected by the supplier's signal acquisition pattern.

*Strategic information sharing*

The status of horizontal information flow does not alter the preference by the supplier over the procedure of vertical signal acquisition. Sequential signal acquisition, though allowing the late-approached retailer to act on the status of vertical signal disclosure by its first-approached counterpart, in effect grants the supplier with an advantage to profit from information accessibilities, by selecting soliciting sequence and varying incentives to the retailers for signal disclosure. Under sequential signal acquisition, once gaining access to the signal at the late-approached retailer, the supplier will use it to adjust the wholesale prices for both retailers. The aggravation of double marginalization will lower the market price to hurt the profit of the early-approached retailer, who, anticipating this to occur, will have its signal-disclosure tendency boosted. In addition to a reasonable compensation to the first retailer, the vertical signal communication thus built can curb the incentive by the supplier to acquire signal from the late retailer. This will result in a lower payment whereby the supplier uses to induce the first-approached retailer to disclose signal. Under simultaneous signal acquisition, however, the retailers are unaware of the vertical signal disclosure status at one another, which exerts a negative externality on their individual profits. A retailer does not have the privilege to influence the incentive by its rival to disclose signal by pre-committing to signal disclosure, and can thus hesitate to engage in vertical information communication. The supplier then has to offer them higher premiums in return for signal access.

The status of horizontal information flow affects the supplier's incentive to acquire signals. As the supplier prefers to sequentially solicit signals, it will acquire both signals with a uniform payment of $p_S^L$ when the retailers mutually disclose signals. Under unilateral information sharing, the supplier will acquire signal from the communicating retailer at a timing influenced by signal quality, and, under certain circumstance, approach the non-communicating retailer for signal access as well. Vertical information acquisition will always happen, but bilateral signal disclosure will be less likely to occur under unilateral information sharing than bilateral information sharing. When the retailers forfeit horizontal information sharing, the supplier can use a payment of $p_N^L$ to incentive either one or both retailers to disclose signals, or offer $(p_N^H, p_N^L)$ to gain full signal access. It is however possible for the supplier not to gain signal access. Note that the status of horizontal information sharing degrades in the process.

**Lemma 3.2**. $p_S^H = p_A^H > p_A^L > p_S^L$, $p_N^H > p_N^L > p_A^L > p_S^L$, *and,* $p_N^L > p_2 > p_S^L$. *The supplier earns a higher profit under equilibrium information acquisition as the status of horizontal information flow upgrades.*

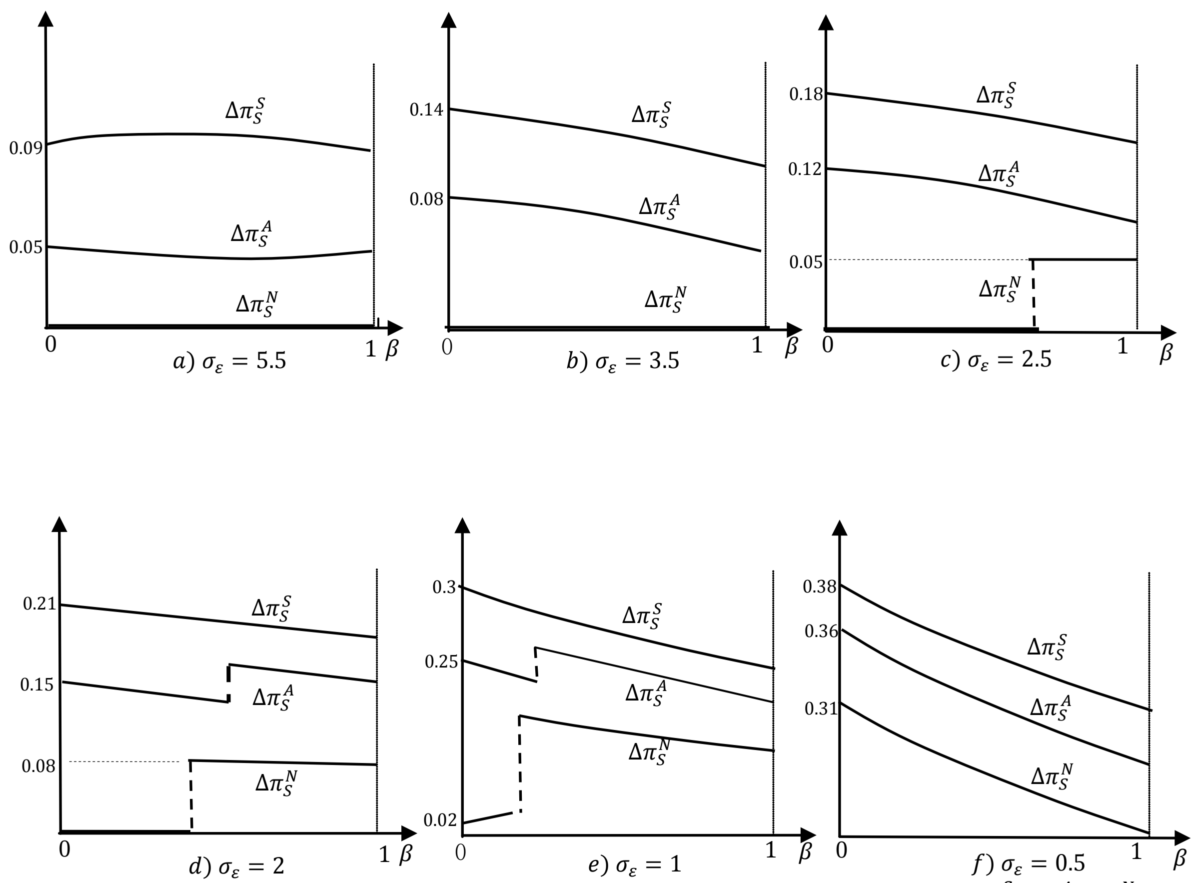
Lemma 3.2 compares the payments whereby the supplier gains signal access in various scenarios differentiated by the status of horizontal information flow. By Propositions 3.2 and 3.4, assisted by figures 3.2 and 3.3, the statuses of vertical information acquisition when the retailers engage in unilateral information sharing and forfeit information sharing are grouped in Table 3.4.

**Table 3.4. Sustainable vertical information acquisition**

| | **High signal quality** | **Moderate signal quality** | **Low signal quality** |
|---|---|---|---|
| **Unilateral information sharing** | Unilateral disclosure with a payment of $p_A^L$ to the communicating retailer | Unilateral disclosure with a payment of $p_A^H$ to the communicating retailer | Bilateral disclosure with $p_A^L$ and $p_2$ to communicating and non-communicating retailers |
| **No horizontal information sharing** | Bilateral disclosure with a total payment of $2p_N^L$,or unilateral disclosure for a payment of $p_N^L$ | No vertical signal disclosure | Bilateral disclosure with a payment of $2p_N^L$ or $p_N^L + p_H^L$,or unilateral disclosure for a payment of $p_N^L$, or no disclosure |

Note that, at a relatively high signal quality (Area III.a in Figure 3.3), the supplier acquires either one or both signals when the retailers forfeit information sharing, but always acquires one signal when they engage in unilateral information sharing. Whenever the supplier acquires only one signal in the two cases, $p_N^L > p_A^L$ by Lemma 3.2; i.e., it pays less under a higher level of horizontal information flow. It is possible for the supplier to acquire only one signal under unilateral information sharing but both signals under bilateral information sharing, but it reaps a larger profit gain from vertical acquisition in the first case, though with fewer information links. At a moderate signal quality (Area II in Figure 3.3), the supplier can build either no, one, or two vertical information links when the retailers forfeit information sharing, but always acquires both signals when one of them discloses signal. As $Min\{p_N^H + p_N^L, 2p_N^L\} > p_A^L + p_2$, the supplier pays less to attain bilateral signal disclosure under a higher level of horizontal information flow. At a weak signal quality (Area III.b in Figure 3.3), the supplier acquires no signal when the retailers do not disclose signals, but acquires signal from the communicating retailer only under unilateral information sharing. As the retailers strengthen horizontal information link from no information sharing to unilateral information sharing, the supplier has a stronger tendency to build vertical information links and profit more from information accessibility. After the level of horizontal information flow further upgrades so that the two retailers mutually disclose signals, the supplier will always acquire both signals. On one hand, more vertical links are set up. On the other hand, as $p_A^L + p_2 > 2p_S^L$ by Lemma 3.2, whenever the supplier gains full signal access, it pays less and profits more under a higher level of information flow.

**Figure 3.4. Supplier's profit gain from vertical information acquisition, $\sigma_u = 2$**




*Notes.* $\Delta\pi_S^S$, $\Delta\pi_S^A$, $\Delta\pi_S^N$ are the profit gains reaped by the supplier from vertical signal acquisition, when the retailers engage in horizontal information sharing, unilateral information sharing, and no information sharing, respectively. Whenever $\Delta\pi_S^N = 0$, the supplier does not acquire signal from any retailer.

To gain more insight into the interplay between vertical information acquisition and horizontal information sharing, we resort to a numerical study of the profits of the supplier and the retailers under various statuses of horizontal and vertical information flow. Figure 3.4 reveals the typical pattern. As we demonstrated in Lemma 3.2, the supplier profits more from vertical acquisition as the level of horizontal information flow upgrades, i.e., $\Delta\pi_S^S > \Delta\pi_S^A > \Delta\pi_S^N$. The supplier's profit gain increases as $\sigma_\varepsilon$ decreases, and displays a general decreasing trend with respect to $\beta$. Hence, a lower signal quality or an intensified market competition make the supplier profit less from signal access. There are exceptions, though. For instance, when the signal quality is weak (Figure 3.4.a) and the intensity of market competition is low, a more competitive market can make the supplier earn more from signal acquisition if the retailers enter horizontal information sharing, in which case the supplier acquires both signals. Similar situation arises when the signal quality is relatively strong (Figure 3.4.e) but the retailers forfeit information sharing, in which case bilateral vertical signal disclosure is built as well.

The profit curves are continuous, except under the circumstances when the supplier changes the strategy to acquire fewer signals at a smaller (total) payment. The resulting profit jumps occur most often when the retailers forfeit information sharing. $\Delta\pi_S^S - \Delta\pi_S^A$ and $\Delta\pi_S^A - \Delta\pi_S^N$ are the increments in profit gains to the supplier from signal acquisition, due to the upgrading in the statuses of horizontal information flow. $\Delta\pi_S^S - \Delta\pi_S^A > \Delta\pi_S^A - \Delta\pi_S^N$ indicates that the increment in the supplier's profit gain from vertical signal acquisition is larger when the retailers upgrade their information link from unilateral to bilateral sharing than when they upgrade from no to unilateral sharing. As can be examined from the figures, this happens when signal quality is low or when signal quality is moderate but competition is sufficiently intense. The reverse will hold in other situations. As such, given that the retailers have already engaged in a higher status of horizontal information flow, a further upgraded information linkage between them will give the supplier a stronger tendency to build vertical information links and profit more from information accessibility, particularly when signal quality is weak. From the perspective of building information flow, vertical information acquisition by the supplier thus functions as a strategic complement to horizontal information sharing between the retailers.

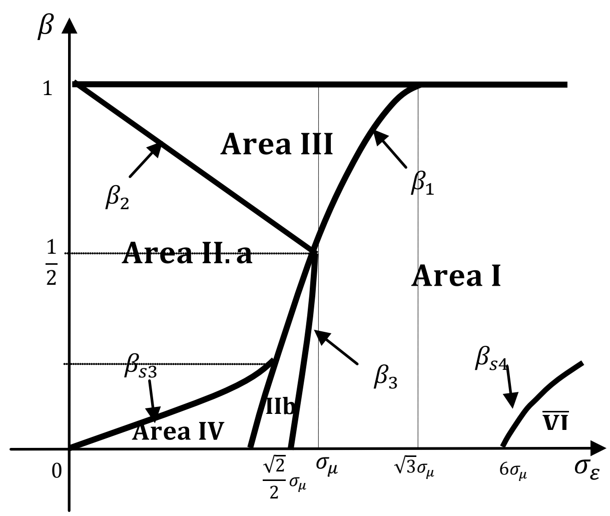
### 3.3.3 Equilibrium characterization

The retailers make decision on horizontal information sharing, taking into consideration the supplier's vertical signal acquisition and the resulting information availabilities. They choose to disclose signals to one another as a means of collaboration, and will agree on a specific status of horizontal information flow (unilateral, bilateral, or no information sharing) to maximize their total profit. Theorem 3.1 characterizes the information structure that can be sustained.

**Theorem 3.1**. *In the system of one supplier selling to two retailers each with an exclusive signal access, suppose the retailers make cooperative decision to share signals with each other. Referring to Figure 3.5:*

1) *Area I: no horizontal information sharing or vertical information acquisition is sustainable.*
2) *Area II.a: the retailers forfeit horizontal information sharing, but the supplier acquires both signals by sequentially offering* $m = (p_N^L, p_N^L)$.
3) *Area II.b: the retailers forfeit horizontal information sharing, but the supplier acquires both signals by sequentially offering* $m = (p_N^H, p_N^L)$.
4) *Area III: the retailers forfeit horizontal information sharing, but the supplier acquires the signal at a retailer by approaching it first and offering* $m_1 = p_N^L$.
5) *Areas IV and* $\overline{IV}$*: the retailers horizontally share information, and the supplier acquires both signals by sequentially offering* $m = (p_S^L, p_S^L)$.

**Figure 3.5. Equilibrium information structure**




*Notes.* The explicit expressions for $\beta_{s3} = \beta_{s3}(\sigma_\mu, \sigma_\varepsilon)$, $\beta_{s4} = \beta_{s4}(\sigma_\mu, \sigma_\varepsilon)$, and $\sigma_{\varepsilon 2} = \sigma_{\varepsilon 2}(\sigma_\mu, \sigma_\varepsilon)$ can be obtained upon request.

Hence, unilateral information sharing is not sustainable when the retailers cooperatively make decisions to disclose signals to each other. Full-scale information flow, involving bilateral information sharing and bilateral vertical acquisition, can occur when market competition is weak and signal quality is either high or rather low (Areas IV and $\overline{\text{IV}}$ of Figure 3.5). In these cases, the supplier will incentivize both retailers to disclose signals with a uniform payment. Mutual signal disclosure can even the signal statuses at the retailers to improve their market understanding, but can intensify the quantity competition between them by correlating their orders to result in market price reduction. A less competitive market condition is the necessary condition to sustain collaboration between the retailers, when the positive effect of market uncertainty reduction is substantial. Under either a high or a low signal quality, they can earn larger profit gains by exchanging signals than by forfeiting this option, though the supplier will acquire both signals in either case. In the first situation, the larger profit gain from information sharing is attributed to the high signal quality, for its value in improving market understanding and assisting in more responsive decision makings. In the latter case, signal quality is low, and the retailers resort to signal exchange to induce the supplier to build vertical information links so that the operation activities at the various parties can be streamlined to attain a system-wide profit improvement, out of which the retailers grab a share.

Whenever the retailers forfeit horizontal information sharing, the supplier can still have the incentive for vertical information acquisition, provided that signal quality is reasonable. Under an intense market competition, the supplier will offer a uniform payment to gain both signals when signal quality is high, but one signal when signal quality is moderate. Under a weak market competition, the supplier will acquire both signals at a high signal quality or no signal at all otherwise. In the first case, it is possible for the supplier to offer differentiated payments to adjust the retailers' incentives in vertical signal disclosure.

**Proposition 3.5**. *In the system of one supplier selling to two retailers each with an exclusive signal access, incentive-driven information flow makes each retailer and the system worse off, but the supplier better off, except when signal quality is low but market competition is weak (area $\overline{IV}$ in Figure 3.5), in which case each and every individual party benefits from information flow.*

Proposition 3.5 shows that the supply chain parties do not necessarily benefit from incentive-driven information flow. The supplier proactively solicits signals from the retailers, by strategically approaching them in a sequence and forcing them into an information game. The first-approached retailer, concerned about the negative externality on its profit due to vertical signal disclosure by the late-approached retailer, can have a strong tendency to disclose signal in the first place so as to curb the supplier's incentive to gain further signal access. The vertical information link thus built will restrict the information strategy adopted by the late retailer. This will in general make both retailers suffer profit losses, and negatively affect the system profit[2]. However, it is still possible for each and every individual party to benefit from information flow, and this happens when signal quality is low and market competition weak. In this situation, the weak market competition draws the retailers into bilateral

[2] Under bilateral information sharing and bilateral vertical disclosure (Area II.b), the retailer receiving the larger payment of $p_N^H$ earns a net profit equal to what it can earn before information flow, but the other retailer is strictly worse off.

information sharing and stimulates the supplier to acquire signals from them both. With a weak signal quality, vertical signal disclosure can streamline the operation activities by the supplier and the retailers, to generate a positive profit gain that outweighs the negative effect of aggravated double marginalization. As a result, system profit performance improves. This can make all the parties better off under system-wide information transparency.

*Value of cooperation in horizontal information sharing*

Traditionally, the retailers competitively manage their interaction and each act as an independent profit maximizer. If they carry that same attitude to manage horizontal information sharing, each of them will unilaterally make decision to disclose signal to the rival, taking into consideration the possible action by the rival.

**Proposition 3.6**. *In the system of one supplier selling to two retailers each with an exclusive signal access, suppose the retailers make unilateral decisions to horizontally disclose signals, neither retailer will disclose signal to the rival and the resulting information structure is as given in Proposition 3.1, and illustrated in Figure 3.2.*

Hence, when the retailers make unilateral decisions on horizontal signal disclosure, they will forfeit information sharing in its entirety. This can be attributed to the strategic complementarity of horizontal information sharing and vertical information acquisition in building information flow. Regardless of the status of horizontal signal disclosure by one retailer, the other retailer will always prefer not to disclose signal to its rival, as the upgraded status of horizontal information flow thus results can catalyze the supplier to acquire more signals. This will hurt the profit of the particular retailer. Given the dominant strategy by the retailers to forfeit horizontal information sharing, the supplier can follow any arbitrary sequence to solicit signals from them. Provided that signal quality is not too low, vertical information link can be built. By Proposition 3.6 and Theorem 3.1, information collaboration between the retailers does matter in sustaining information structure only when market competition is not too intense, in which case the positive effect of signal pooling on demand uncertainty reduction can be substantial and therefore give the retailers the incentive to seek collaboration. In particular, the retailers will engage in bilateral information sharing when market competition is not too intense and the signal quality is either rather good or very bad.

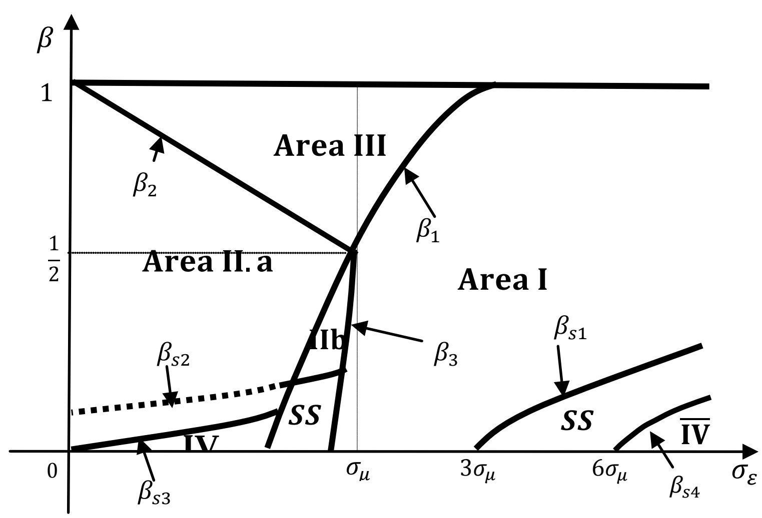
*Prior commitment on signal acquisition procedure*

So far, our exploration has been under the assumption that the supplier strategically selects the procedure for signal acquisition after the retailers make the decisions on horizontal information sharing. In reality, the suppliers can follow the industry standard or some pre-committed procedure to solicit signals. To investigate the implications of prior commitment to signal acquisition procedure on the sustainability of information flow, we analyze a model variant, in which the supplier first commits to simultaneous or sequential acquisition, and, in the latter case, fixes the sequence. Recall that the supplier's acquisition sequence depends on the status of horizontal information flow. When the two retailers mutually disclose signals or forfeit information sharing, the supplier can follow any arbitrary sequence to solicit their signals. When the retailers operate on unilateral information sharing, the supplier needs to specify the timing to approach the communicating retailer in the sequence. Then, the retailers cooperatively make decision on horizontal signal disclosure, and the supplier follows the committed procedure to acquire signals. Once the information structure is settled, the operation subgame will follow as before.

**Theorem 3.2**. *In the system of a supplier selling to two retailers each with an exclusive signal access, suppose the supplier can credibly commit to its signal acquisition procedure before the retailers choose to share signals with each other. Referring to Figure 3.6:*

1) *Area SS: the supplier commits to simultaneous signal acquisition, under which the retailers share information and the supplier gains access to both signals by offering* $(p_s^H, p_s^L)$.
2) *Areas I, IIa, IIb, III, and IV: the supplier commits to sequential signal acquisition, under which the information structures remain as those in the counterpart areas in Theorem 3.1.*

**Figure 3.6. Equilibrium information structure, with supplier's prior acquisition commitment**




*Notes*: $\beta_{s1} = -\frac{2(4\sigma_\varepsilon^2+7\sigma_\varepsilon\sigma_\mu+3\sigma_u^2)}{4\sigma_\varepsilon^2+12\sigma_\varepsilon\sigma_\mu+3\sigma_u^2} + 4\sqrt{5}\sqrt{\frac{\sigma_\varepsilon^4+3\sigma_\varepsilon^3\sigma_\mu+2\sigma_\varepsilon^2\sigma_u^2}{(4\sigma_\varepsilon^2+12\sigma_\varepsilon\sigma_\mu+3\sigma_u^2)^2}}$. The expression for $\beta_{s2} = \beta_{s2}(\sigma_\mu, \sigma_\varepsilon)$ can be obtained upon request. With respect to Figure 3.5, two areas for simultaneous signal acquisition are added.

The sustainable information structure is robust with respect to the timing at which the supplier selects signal acquisition procedure, but with two exceptions. In the circumstance where the retailers would have forfeited information sharing and the supplier would have acquired both signals under sequential information acquisition (area II.b in Figure 3.5), the supplier can have the incentive to ex-ante commit to simultaneous acquisition, inducing the retailers to mutually disclose signals, which will in turn press the supplier to acquire both signals. This will happen when market competition is weak, in which case the retailers, by signal exchange, benefits from a better market knowledge, while the supplier can profit more from signal access and offer larger payments than under sequential acquisition. In the other situation when no information flow would have been sustained under sequential acquisition (Area I in Figure 3.5), the supplier will commit to simultaneous signal acquisition when market competition is relatively weak and signal quality is low, in which case the retailers will mutually disclose signals and the supplier will acquire both signals with differential payments. As such, simultaneous information acquisition by the supplier facilitates horizontal information sharing. Prior commitment by the supplier to such acquisition procedure can then be valuable, when market competition is weak (so that the effect of improved market forecast on profit gain is substantial) and no information flow would have been built under sequential acquisition.

## 3.4 Concluding Remarks

In this chapter, we provide a complete equilibrium analysis of the information structure that can be sustained to transmit the demand signals at the retailers throughout the supply chain. Horizontally, the retailers can share signals, as a means of collaboration. Vertically, the supplier can follow a procedure to offer payments to the retailers and solicit their signals. We piece together the two forms of information flow and demonstrate that, from the perspective of building information flow, vertical information acquisition is a strategic complement to horizontal information sharing. The supplier's commitment to simultaneously approaching the retailers for signal access is conducive to establishing horizontal information links between the retailers. More importantly, we justify the sustainability of incentive-driven information flow to attain information transparency, whereby the demand signals are visible to every individual party. The key factor that drives our findings is the capability by the supplier to take advantage of the quantity competition between the retailers to trap them into an information game, by strategically soliciting signals and varying incentive payments. Market competition and signal quality jointly affect the sustainable pattern of information flow. While the supplier always benefit from incentive-driven information flow, it is also possible for the retailers and the entire system to be better off with signal communication throughout the system.

# Chapter 4
# Strategic Demand Information Dissemination under Unintentional Information Leakage

## 4.1 Introduction

One issue that we have not sufficiently explored in Chapter 2 and Chapter 3 is indirect signal divulgence. Since the supplier's signal-triggered wholesale price policy structure is publicly known, one retailer can infer the signal that the other retailer has disclosed to the supplier from the wholesale price adjustment by the latter. The indirect signal divulgence takes its root in channel structure and common knowledge of the decision policy structure, and may significantly influence the sustainable pattern of information flow. Thus, in this chapter, we consider the possibility that the retailers can further use the signal inferred through indirect signal divulgence to adjust operation decisions.

We still explicate our analysis in system RC, with two retailers order from one supplier. Same as Chapter 3, we assume that each retailer has exclusive access to a signal that distorts the actual market condition by a noise term. The retailers can disclose signals to each other, while the supplier can offer them differential payments as incentives to disclose their signals. The supplier can solicit signals from the retailers at the same time (simultaneous signal acquisition) or follow a sequence to fulfill this task (sequential signal acquisition). A vertical information link is established after a supplier gains access to a retailer's signal.

Once the supplier utilizes the signal from a retailer in responsive wholesale pricing, the other retailer can infer the disclosed signal from its adjusted wholesale prices. We call this unintentional information leakage. A horizontal information link is built once a retailer learns its rival's signal. The status of horizontal (vertical, resp) information sharing is enhanced as more horizontal (vertical, resp) information links are established. Direct information flow and unintentional information leakage jointly determine the signals accessible by channel parties and weighed in their interactions. Non-disclosure agreements are signed before the signals are observed. After the signals are observed, the retailers will communicate them as per the agreements and signal-triggered operation decisions will then follow.

## 4.2 Information structure

### 4.2.1 Analysis

The model preliminaries are in consistent with those of Chapter 3. The only difference is, we assume in this chapter that a retailer can infer the signal that the other retailer has disclosed to the supplier from its adjusted wholesale prices and utilize the inferred signal in decision making. This is referred to as indirect signal divulgence or information leakage in the literature (Li 2002, Li and Zhang 2008). In our setting, once the supplier learns a retailer's signal, it will utilize the signal in wholesale pricing, knowing the other retailer will infer the signal from its adjusted wholesale prices and further use it in responsive ordering. We bypass the involved process of signal inference and operation adjustments, and let the disclosed signal by a retailer be fully inferable by its rival. This is in line with Scenario 1 in Li and Zhang (2008). In the static state, all channel parties make decisions by use of the available signals that are obtained through direct information sharing or inference.

We first analyze the supplier's signal acquisition decision given mode of horizontal information sharing. On the basis of the outcomes thus derived, we proceed to analyze the incentive for the retailers to disclose signals to each other, unilaterally or cooperatively, to establish an information structure. We consider three modes of horizontal information sharing: no information sharing when no retailer discloses signal to the rival; bilateral information sharing when the two retailers mutually disclose signals; and unilateral information sharing when a retailer discloses its signal to the rival but not vice versa.

Knowing mode of horizontal information sharing, the supplier solicits signals from the retailers. The status of vertical information acquisition is denoted by $n = (n_1, n_2)$, where $n_i = 1$ indicates that retailer $i$ discloses its signal to the supplier and $n_i = 0$ indicates that it does not. Vertical signal disclosure by a retailer to the supplier can cause unintentional information leakage to the other retailer. Consider the situation when the retailers forfeit information sharing. When $n = (1,1)$, the supplier learns both signals and use them in responsive wholesale pricing, and unintentional information leakage makes the signals inferable by the two retailers. When $(n_i, n_{3-i}) = (1,0)$, the supplier only gains access to retailer $i$'s signal that can be inferred by retailer $3 - i$ as well. If, furthermore, only retailer $i$ discloses signal to retailer $3 - i$, the communicating retailer $i$ is able to learn the signal at the non-communicating retailer $3 - i$ by inference. Note that information leakage is not a concern under bilateral information sharing and each retailer learns both signals.

For a given information structure, in the operation subgame, when the supplier offers wholesale prices $w = (w_1, w_2)$ and the realized signals are $x = (x_1, x_2)$, the problem faced by a retailer depends on its signal availability. When a retailer only has access to its own signal, it chooses a quantity to maximize its profit of (3-2). When a retailer has access to the signals at both retailers by all means, it chooses a quantity to maximize its profit of (3-3). The supplier can anticipate the retailers' signal-triggered decisions in the information structure, taking into consideration information leakage that influences their signal availability. Given mode of horizontal information sharing, it chooses wholesale prices to maximize its profit of (3-4). The supplier and retailers make decisions to maximize their respective profits, as given in (3-2)-(3-4), which are contingent on the realized signal values. They make information sharing decisions based on the expected ex-ante profits.

### 4.2.2 Signal acquisition by the supplier

In this section, we analyze the supplier's signal acquisition decision conditional on the mode of horizontal information sharing.

*No information sharing*

Suppose the retailers forfeit horizontal information sharing. Unintentional information leakage will occur to both retailers when $(n_1, n_2) = (1,1)$, in which case each retailer can infer the signal at its rival and utilize both signals to choose a quantity to maximize its profit as given in (3-3). When $(n_i, n_{3-i}) = (1,0)$, retailer $3 - i$ can infer the signal at retailer $i$ and use both signals to maximize its profit as given in (3-3), while retailer $i$ has its own signal for use in maximizing its profit as given in (3-2). The subgame operation outcomes are derived according to (3-2)-(3-4) and the corresponding expected ex-ante profits of the retailers and supplier in Table 4.1, with the incentive payments for vertical signal disclosure excluded.

**Table 4.1. Operation subgame equilibria, without horizontal information sharing**

| $(\boldsymbol{n_1}, \boldsymbol{n_2})$ | **Decision policy** | **Ex-ante profit** |
|---|---|---|
| (0,0) | $w_i^{(0,0)} = w_i^0$<br>$q_i^{(0,0)} = q_i^0 + Bx_i$ | $\pi_{Ri}^{(0,0)} = \pi_{Ri}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}.$<br>$\pi_S^{(0,0)} = \sum_{i=1}^2 (w_i^0 - c_i) q_i^0.$ |
| (1,1) | $w_i^{(1,1)} = w_i^0 + (1+\frac{\beta}{2})C(x_1+x_2).$<br>$q_i^{(1,1)} = q_i^0 + \frac{1}{2}C(x_1+x_2)\ .$ | $\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \frac{\sigma_u^2}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)}.$<br>$\pi_S^{(1,1)} = \pi_S^{(0,0)} + \frac{{\sigma_\mu}^2}{(2+\beta)(\sigma_\varepsilon+2\sigma_\mu)}.$ |
| (1,0) | $w_i^{(1,0)} = w_i^0 + \frac{\sigma_\mu}{2(\sigma_\varepsilon+\sigma_\mu)}x_1.$<br>$q_1^{(1,0)} = q_1^0 + \frac{\sigma_\mu}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}x_1.$<br>$q_2^{(1,0)} = q_2^0 + A_1x_1 + A_2x_2.$ | $\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \frac{{\sigma_\mu}^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}.$<br>$\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \frac{{\sigma_\mu}^2((5+4\beta+\beta^2)\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}.$<br>$\pi_S^{(1,0)} = \pi_S^{(0,0)} + \frac{{\sigma_\mu}^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}.$ |

| | | |
|---|---|---|
| (0,1) | $w_i^{(0,1)} = w_i^0 + \frac{\sigma_\mu}{2(\sigma_\varepsilon+\sigma_\mu)} x_2.$<br>$q_1^{(0,1)} = q_1^0 + A_2 x_1 + A_1 x_2.$<br>$q_2^{(0,1)}(x) = q_2^0 + \frac{\sigma_\mu}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)} x_2.$ | $\pi_{R1}^{(0,1)} = \Pi_{R1}^0 + \frac{{\sigma_\mu}^2((5+4\beta+\beta^2)\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}.$<br>$\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \frac{{\sigma_\mu}^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}.$<br>$\pi_S^{(0,1)} = \pi_S^{(0,0)} + \frac{{\sigma_\mu}^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}.$ |

*Note.* $w_i^0 = \frac{a_i+c_i}{2}$ $q_i^0 = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}$, $B = \frac{\sigma_\mu}{(2+\beta)\sigma_\mu+2\sigma_\varepsilon}$, $C = \frac{\sigma_\mu}{(2+\beta)(2\sigma_\mu+\sigma_\varepsilon)}$, $A_1 = \frac{\sigma_\mu(\sigma_\varepsilon-\beta\sigma_\mu)}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$, $A_2 = \frac{\sigma_\mu}{2(2\sigma_\mu+\sigma_\varepsilon)}$, $\pi_{Ri}^0 = (\frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)})^2$.

Note that regardless of the status of vertical signal disclosure, the supplier will utilize the signals available to it in making the same adjustment to the two wholesale prices. In particular, it will adjust each wholesale price by $\frac{\sigma_\mu}{2(2\sigma_\mu+\sigma_\varepsilon)}(x_1+x_2)$ after gaining access to both signals but $\frac{\sigma_\mu}{2(\sigma_\varepsilon+\sigma_\mu)} x_i$ after gaining access to signal $x_i$ only. Once both retailers disclose their signals ($n = (1,1)$), each of them is able to infer the signal at the rival and makes decision by use of the aggregate signal values. Once one retailer discloses its signal to the supplier, say $n = (1,0)$, retailer 2 will learn both signals for use in ordering. $q_2^{(1,0)} - q_2^0 = A_1 x_1 + A_2 x_2$. As $A_1 < A_2$, retailer 2 will rely less on the inferred retailer 1's signal than on its own signal. $q_i^{(0,0)} - q_i^0 = B x_i$ and $q_1^{(1,0)} - q_1^0 = \frac{\sigma_\mu}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)} x_1$. Since $\frac{\sigma_\mu}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)} < A_2 < B$, unilateral vertical signal disclosure by a retailer will cause every retailer to lower its reliance on its own signal in ordering.

It can be verified that the retailers will rely less on the signals available to them, their own or inferred signals, as competition intensifies ($\beta$ increases). This is because stronger competition will cause the retailers' quantity decisions to be more influential in market prices and affect the profit performance of one another. This will make them more cautious in utilizing signals in ordering. The supplier is better off by having access to more signals for enhanced responsiveness in wholesale pricing. The establishment of a vertical information link has mixed implications for the retailers. Consider $n = (1,0)$, in which case the supplier directly learns retailer 1' signal that can be inferred by retailer 2. The supplier will use retailer 1's signal in wholesale pricing. This will negatively affect its ordering flexibility (direct effect), as the variance of its order quantity will decrease, i.e., $Var\left(q_1^{(1,0)}\right) < Var\left(q_1^{(0,0)}\right)$. The supplier's responsive pricing will limit retailer 2's ordering flexibility as well (indirect effect). But the leakage effect will grant retailer 2 more signal availability to improve responsiveness. We can show $Var\left(q_2^{(1,0)}\right) < Var\left(q_2^{(0,0)}\right)$ if signal quality is not too low. Hence, when the signals are valuable in indicating actual market condition, the leakage effect is weaker than the indirect effect to hurt retailer 2's ordering flexibility. When $n = (1,1)$, the two retailers attain the same signal status, with $Var\left(q_1^{(1,0)}\right) < Var\left(q_i^{(1,1)}\right) < Var\left(q_2^{(1,0)}\right)$. Once a vertical information link has been built between the supplier and retailer 1, an additional link between the supplier and retailer 2 will have a direct effect to hurt retailer 2's order responsiveness, while the leakage effect can improve retailer 1's flexibility in ordering.

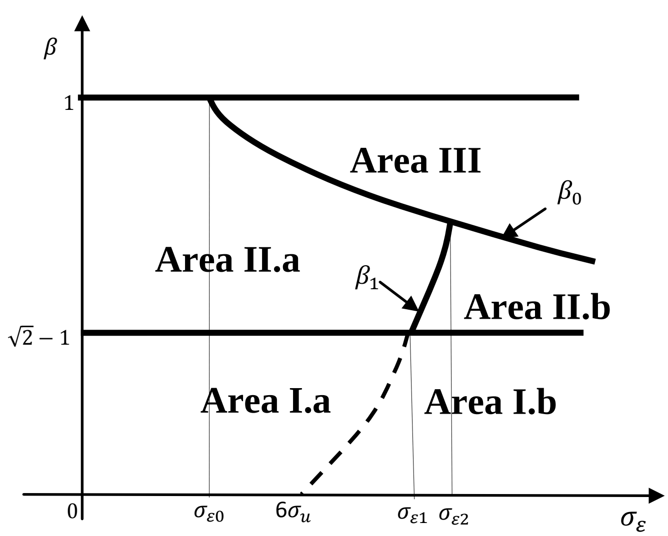
We apply the procedure as given in (3-5)-(3-11) to analyze the signal acquisition decision by the supplier. Now that the retailers forfeit information sharing, their information and decision statuses are symmetric. Suppose the supplier simultaneously approaches the retailers. To acquire only one signal, it can randomly pick a retailer and offer it the required incentive. To acquire both signals with different payments, we assume without loss of generality that the supplier will offer a larger payment to retailer 1 and a smaller one to retailer 2. In the case when the supplier sequentially acquires signals from the retailers, we assume it approaches retailer 1 first and retailer 2 later, and refer to retailer 1 as the first retailer and retailer 2 the second retailer. Proposition 4.1, with the assistance of Figure 4.1, shows the supplier's signal acquisition pattern.

**Proposition 4.1**: *In a system of one supplier selling to two retailers each with exclusive signal access, given that the retailers forfeit information sharing, let* $p_N^L = \frac{(3+4\beta+\beta^2)\sigma_\varepsilon\sigma_\mu^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$, $p_N^H = \frac{\sigma_\mu^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu))^2} - \frac{\sigma_\mu^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$, $p_1 = \frac{\sigma_\varepsilon\sigma_\mu^2}{4(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$. *Referring to Figure 4.1:*

*3) Under simultaneous signal acquisition,* $n = (1,1)$ *in area I with* $m = (p_N^H, p_N^L)$, $n = (1,0)$ *or* $n = (0,1)$ *in areas II.a and II.b with* $m_i = p_N^H$, *but* $n = (0,0)$ *in area III;*

*4) Under sequential signal acquisition,* $n = (1,1)$ *in area I with* $m = (p_N^L, p_N^L)$*;* $n = (1,0)$ *in area II.a with* $m_1 = p_1$ *and* $n = (0,1)$ *in area II.b with* $m_2 = p_N^H$, *but* $n = (0,0)$ *in area III.*

**Figure 4.1. Supplier's signal acquisition, without horizontal information sharing**



*Notes*. $\sigma_{\varepsilon 0}=\frac{3(1+\sqrt{7})\sigma_\mu}{4}$. The expressions for $\sigma_{\varepsilon 1}(\sigma_\mu)>7\sigma_\mu$, $\sigma_{\varepsilon 2}(\sigma_\mu)$, $\beta_0(\sigma_\varepsilon,\sigma_\mu)$, $\beta_1(\sigma_\varepsilon,\sigma_\mu)$ and their properties can be obtained upon request.

Without horizontal information sharing, the equilibrium status of vertical information acquisition is insensitive to the procedure whereby the supplier solicits signals. In particular, the supplier will gain access to both signals when competition is weak, one signal when competition is moderate, but no signal otherwise. Its incentive to solicit signals strengthens with signal quality. However, the procedure for signal solicitation affects the supplier's payments to incentivize the retailers to disclose signals. To solicit both signals (Area I in Figure 4.1), rather than offering differential payments of $p_N^H$ and $p_N^L$ under simultaneous acquisition, the supplier offers a uniform payment of $p_N^L$ to both retailers under sequential acquisition. To solicit one signal, the supplier offers $p_N^H$ to an arbitrary retailer under simultaneous acquisition, but offers a lower payment of $p_1$ to acquire signal from the first retailer if signal accuracy is strong (Area II.a in Figure 4.1) and reverts to $p_N^H$ to acquire the signal from the second retailer if signal accuracy is low (Area II.b in Figure 4.1) under sequential acquisition. The supplier attains the same at a lower expense by sequentially approaching the two retailers than by approaching them at the same time.

With indirect signal divulgence, we find that Corollary 3.1 is still valid here. That is, when the supplier can select a procedure to solicit signals from the retailers given that they forfeit horizontal information sharing, it will prefer sequential signal acquisition. In this case, the supplier will gain access to the signals at the retailers provided that signal accuracy is not so low as to substantially distort the actual market condition. Specifically, bilateral signal disclosure will occur if competition is not too intense, while unilateral disclosure can be sustained otherwise. On the contrary, the retailers will earn a lower profit when the supplier chooses sequential acquisition than when it chooses simultaneous acquisition, since they will be less compensated for signal disclosure. Note that the system profit is not sensitive to the supplier's signal acquisition pattern since the same status of vertical signal disclosure can be sustained.

We next examine the profit performance of the individual parties under information flow. For notational convenience, we use $\Pi_k^n$ to indicate channel parties' total profits inclusive of incentive payment, if any, where the subscript $k$ indicates retailer $i$ or supplier ($s$) and the superscript indicates the status of vertical information acquisition.

**Proposition 4.2**. *In a system of a supplier selling to two retailers each with exclusive signal access, given that the retailers forfeit information sharing and the supplier sequentially approaches them for signal acquisition, by the equilibrium status of vertical information flow as shown in Figure 4.1:*

*1)* $\Pi_S^{(1,1)}>\Pi_S^{(0,0)}$ *in area I.* $\Pi_i^{(1,1)}\le\Pi_i^{(0,0)}$ *in area I.a,* $\Pi_i^{(1,1)}>\Pi_i^{(0,0)}$ *in area I.b.*

*2)* $\Pi_i^{(1,0)} \leq \Pi_i^{(0,0)}$*, and* $\Pi_S^{(1,0)} > \Pi_S^{(0,0)}$ *in area II.a;* $\Pi_1^{(0,1)} > \Pi_1^{(0,0)}$, $\Pi_2^{(0,1)} = \Pi_2^{(0,0)}$*, and* $\Pi_S^{(0,1)} > \Pi_S^{(0,0)}$ *in area II.b.*

Vertical information acquisition always makes the supplier better off but has mixed effects on the retailers. Under bilateral information acquisition, which occurs when competition is not too intense, the two retailers are able to infer the signals and system-wide information transparency is attained. Compared with no information acquisition, their profits will improve when signal accuracy is low (Area I.b in Figure 4.1) but drop when signal accuracy is high (Area I.a in Figure 4.1). As signal accuracy worsens, the leakage effect that benefits a retailer with enhanced order responsiveness strengthens, while the direct and indirect effects weaken. When signal accuracy is low, the leakage effect is strong enough to outweigh (in)direct effect to benefit system profit. When signal accuracy is strong, however, the leakage effect is weak and system profit will be hurt by information flow. The supplier takes advantage of its first-mover advantage to trap the retailers in an information game and exploit their competitive relationship to solicit signals. By unilateral information acquisition, neither retailer is better off if the supplier solicits signal from the first retailer (area II.a), but neither is worse off if the supplier solicits signal from the second retailer (area II.b). The supplier compensates the retailer disclosing its signal just enough for its profit loss, but to leave the profit of the other retailer subject to the resulting information structure. In the first case, the indirect effect is strong to hurt the other retailer. In the latter case, however, the leakage effect is strong to make the other retailer better off and improve system profit as well.

*Bilateral information sharing*

Suppose the retailers mutually disclose signals. We group the subgame equilibrium operation outcomes and the expected ex-ante profits (exclusive of incentive payments) of channel parties in Table 4.2. Bilateral information sharing levels signal availability to the retailers and correlate their order decisions. This makes unintentional information leakage irrelevant and leakage effect inactive. After establishing vertical information links, the supplier will utilize the available signals in wholesale pricing. Its wholesale-price adjustments will be $\frac{\sigma_\mu(x_1+x_2)}{2(2\sigma_\mu+\sigma_\varepsilon)}$ when having access to both signals, but $\frac{\sigma_\mu(1+k)x_i}{2(2\sigma_\mu+\sigma_\varepsilon)}$ when having access to $x_i$ only. The two retailers will make the same order adjustment and earn the same profit. Unilateral signal acquisition from a retailer $i$ will cause both retailers to rely less on $x_i$ in ordering, while bilateral signal acquisition will have each retailer halve its utilization of aggregate signals. An intensified competition will cause the supplier and retailers to less utilize the available signals, making the access to and sharing of market signals exert a less influence on system performance.

**Table 4.2. Operation subgame equilibria, with information sharing**

| $(v_1, v_2)$ | Decision policy | Ex-ante profit |
|---|---|---|
| (0,0) | $w_i^{(0,0)} = w_i^0.$<br>$q_i^{(0,0)} = q_i^0 + C(x_1 + x_2).$ | $\pi_{Ri}^{(0,0)} = \pi_{Ri}^0 + \frac{2\sigma_\mu^2}{(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)}.$<br>$\pi_S^{(0,0)} = \sum_{i=1}^2 (w_i^0 - c_i) q_i^0.$ |
| (1,1) | $w_i^{(1,1)} = w_i^0 + (1 + \frac{\beta}{2})C(x_1 + x_2).$<br>$q_i^{(1,1)} = q_i^0 + \frac{1}{2}C(x_1 + x_2).$ | $\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \frac{\sigma_\mu^2}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)}.$<br>$\pi_S^{(1,1)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{(2+\beta)(\sigma_\varepsilon+2\sigma_\mu)}.$ |
| (1,0) | $w_i^{(1,0)} = w_i^0 + \left(1 + \frac{\beta}{2}\right)(1+k)Cx_1.$<br>$q_i^{(1,0)} = q_i^0 + \frac{1}{2}(1-k)Cx_1 + Cx_2.$ | $\pi_{Ri}^{(1,0)} = \pi_{Ri}^0 + \frac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}.$<br>$\pi_S^{(1,0)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}.$ |
| (0,1) | $w_i^{(0,1)} = w_i^0 + \left(1 + \frac{\beta}{2}\right)(1+k)Cx_2.$<br>$q_i^{(0,1)}(x) = q_i^0 + \frac{1}{2}(1-k)Cx_2 + Cx_1.$ | $\pi_{Ri}^{(0,1)} = \pi_{Ri}^0 + \frac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}.$<br>$\pi_S^{(0,1)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}.$ |

*Notes.* $w_i^0 = \frac{a_i+c_i}{2}$. $q_i^0 = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}$, $C = \frac{\sigma_\mu}{(2+\beta)(2\sigma_\mu+\sigma_\varepsilon)}$, $k = \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}$, $\pi_{Ri}^0 = (\frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)})^2$.

Now that the retailers have the same signal availability, vertical information acquisition will affect system performance mainly through its direct and indirect effects on channel parties. As the supplier acquires signals from more retailers, it can benefit from enhanced responsive wholesale pricing but both retailers will suffer from restricted flexibility in responsive ordering. This can be noted from the following comparative results on the variances of wholesale prices and order quantities: $Var\left(w_i^{(1,1)}\right) > Var\left(w_i^{(1,0)}\right)$, and $\mathrm{Var}\left(q_i^{(1,1)}\right) < \mathrm{Var}\left(q_i^{(1,0)}\right) < Var\left(q_i^{(0,0)}\right)$.

We apply the procedure in (3-5)-(3-11) to analyze the signal acquisition decision by the supplier. Like in the case when the retailers forfeit horizontal information sharing, we assume without loss of generality the supplier approaches retailer 1 first and retailer 2 later under sequential information acquisition. Note that retailer $i$ in (3-8) is now retailer 1 and retailer $3 - i$ is retailer 2.

**Proposition 4.3**. *In the system of a supplier selling to two retailers each with exclusive access to a signal, given that the two retailers mutually disclose signals, let* $p_S^H = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$ *and* $p_S^L = \frac{3\sigma_\varepsilon\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$, *with* $p_S^H > p_S^L$*:*

3) *Under simultaneous signal acquisition,* $n = (1,1)$ *with* $m = (p_S^H, p_S^L)$.

*4) Under sequential signal acquisition,* $n = (1,1)$ *with* $m = (p_S^L, p_S^L)$*.*

Proposition 4.3 shows that the supplier will always solicit signals from both retailers, irrespective of its signal acquisition procedure. Bilateral information sharing stimulates the supplier to gain full signal access and system-wide information transparency is realized. However, the supplier offers a uniform payment of $p_S^L$ to the retailers under sequential acquisition but offers differential payments of $(p_S^H, p_S^L)$ with a higher total amount under simultaneous acquisition. Sequentializing the process to approach the retailers for signal solicitation confers the supplier an advantage.

Given that the retailers have shared signals, the supplier will prefer to follow a sequence to build vertical information links with a uniform payment, though the specific procedure it follows to approach the retailers can be arbitrary. The retailers however prefer the supplier to simultaneously solicit signals. Since the supplier always acquires both signals (though with different incentive payments) under the two acquisition procedures, the system profit will be insensitive to how it gains signal availability.

**Proposition 4.4**. *In the system of a supplier selling to two retailers each with exclusive signal access, given that the retailers mutually disclose signals and the supplier sequentially solicits their signals, in the equilibrium:* $\Pi_i^{(1,1)} < \Pi_i^{(0,0)}$ *and* $\Pi_S^{(1,1)} > \Pi_S^{(0,0)}$.

The supplier profits from learning the signals at the two retailers who however suffer profit losses. With the leveled signal availability created by horizontal information sharing, the retailers earn the same profit (exclusive of the supplier's payments) regardless of the status of vertical signal disclosure. System profit decreases with information flow. The supplier's payment is not enough to fully make up for the retailers' profit loss from signal disclosure. The retailers still disclose signals because the supplier takes advantage of their competitive relationship to trap them in an information game by sequentially soliciting signals from them and offering them differential payments as incentives.

*Unilateral information sharing*

Under unilateral information sharing, we analyze a representative situation when only retailer 1 discloses signal. The analysis for the situation when only retailer 2 discloses signal follows by symmetry. As only retailer 1 discloses its signal to retailer 2, retailer 2 has access to both signals and is not much concerned about information leakage. Unintentional information leakage matters when $n = (1,1)$ or $(0,1)$. The supplier acquires both signals in the first case but only the signal at retailer 2 in the second case. In both cases, as the supplier utilizes the available signal(s) in responsive wholesale pricing, retailer 1 can infer the signal at retailer 2 to level the signal availability at both retailers. Each retailer chooses its order quantity to maximize its profit given in (3-3). When $n = (1,0)$, no unintentional information leakage will occur, though retailer 1's signal is now available to all parties. Retailers 1 and 2 choose order quantities to maximize their profits given in (3-2) and (3-3) respectively. The subgame equilibrium operation outcomes and the corresponding expected ex-ante profits (exclusive of payments) of channel parties are shown in Table 4.3.

**Table 4.3. Operation subgame equilibria, when only retailer 1 discloses signal**

| $(n_1, n_2)$ | Decision policy | Ex-ante profit |
|---|---|---|
| (0,0) | $w_i^{(0,0)} = w_i^0$. <br> $q_1^{(0,0)} = q_1^0 + A_1 x_1$. <br> $q_2^{(0,0)} = q_2^0 + A_2 x_1 + A_3 x_2$. | $\pi_{R1}^{(0,0)} = \pi_{R1}^0 + \frac{\sigma_\mu^2}{(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$. <br> $\pi_{R2}^{(0,0)} = \pi_{R2}^0 + \frac{\sigma_\mu^2((8+4\beta+\beta^2)\sigma_\varepsilon+8\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$. <br> $\pi_S^{(0,0)} = \sum_{i=1}^2 (w_i^0 - c_i) q_i^0$. |
| (1,1) | $w_i^{(1,1)} = w_i^0 + (1+\frac{\beta}{2}) C(x_1 + x_2)$. <br> $q_i^{(1,1)} = q_i^0 + \frac{1}{2} C(x_1 + x_2)$. | $\pi_{Ri}^{(1,1)} = \pi_{Ri}^0 + \frac{\sigma_\mu^2}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)}$. <br> $\pi_S^{(1,1)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{(2+\beta)(\sigma_\varepsilon+2\sigma_\mu)}$. |
| (1,0) | $w_i^{(1,0)} = w_i^0 + \frac{(2+\beta)A_1}{2} x_1$. <br> $q_1^{(1,0)} = q_1^0 + \frac{A_1}{2} x_1$. <br> $q_2^{(1,0)} = q_2^0 + A_4 x_1 + A_3 x_2$. | $\pi_{R1}^{(1,0)} = \pi_{R1}^0 + \frac{\sigma_\mu^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$. <br> $\pi_{R2}^{(1,0)} = \pi_{R2}^0 + \frac{\sigma_\mu^2((5+4\beta+\beta^2)\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$. <br> $\pi_S^{(1,0)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}$. |
| (0,1) | $w_i^{(0,1)} = w_i^0 + \left(1+\frac{\beta}{2}\right)(1+k) C x_2$. <br> $q_1^{(0,1)}(x) = q_1^0 + \frac{1}{2}(1-k) C x_2 + C x_1$. <br> $q_2^{(0,1)}(x) = q_2^0 + \frac{1}{2}(1-k) C x_2 + C x_1$. | $\pi_{R1}^{(0,1)} = \pi_{R1}^0 + \frac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$. <br> $\pi_{R2}^{(0,1)} = \pi_{R2}^0 + \frac{\sigma_\mu^2(2\sigma_\mu+5\sigma_\varepsilon)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$. <br> $\pi_S^{(0,1)} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}$. |

*Notes.* $w_i^0 = \frac{a_i+c_i}{2}$. $q_i^0 = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}$, $\pi_{Ri}^0 = (\frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)})^2$, $A_1 = \frac{\sigma_\mu}{(2+\beta)(\sigma_\varepsilon+\sigma_\mu)}$, $A_2 = \frac{\sigma_\mu(2(\sigma_\varepsilon+\sigma_\mu)-\beta\sigma_\mu)}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$, $A_3 = \frac{\sigma_\mu}{2(2\sigma_\mu+\sigma_\varepsilon)}$, $A_4 = \frac{\sigma_\mu(\sigma_\varepsilon-\beta\sigma_\mu)}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$, $k = \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}$, $C = \frac{\sigma_\mu}{(2+\beta)(2\sigma_\mu+\sigma_\varepsilon)}$.

As shown in Table 4.3, before the supplier solicits signals, retailer 2 utilizes both signals in making order decision but retailer 1 only relies on its own signal. The enhanced signal availability makes retailer 2 earn a higher profit than its rival. Once the supplier learns retailer 1's signal (the communicating retailer) to make the particular signal visible to every party, it will utilize the signal to adjust the wholesale prices to both retailers. Once the supplier learns retailer 2's signal (the non-communicating retailer), the two retailers will have the same signal availability and utilize the signals to make the same order adjustments. As such, unilateral vertical information acquisition delivers the same impact on the retailers' profits.

Note that the signals available to the retailers are identical under $n = (1,1)$ and $n = (0,1)$. We can show $Var\left(w_i^{(1,1)}\right) > Var\left(w_i^{(1,0)}\right) = Var\left(w_i^{(0,1)}\right) > Var\left(w_i^{(0,0)}\right)$. This implies that the supplier can benefit from having access to more signals for enhanced responsiveness in wholesale pricing. When the supplier acquires only one signal, its responsiveness is not sensitive to which retailer discloses its signal. Moreover, $Var\left(q_1^{(1,0)}\right) < Var\left(q_i^{(1,1)}\right) < \{Var\left(q_1^{(0,0)}\right), Var\left(q_i^{(0,1)}\right)\}$, and $Var\left(q_i^{(1,1)}\right) < Var\left(q_i^{(0,1)}\right) < Var\left(q_2^{(1,0)}\right) < Var\left(q_2^{(0,0)}\right)$. The leakage effect endows retailer 1 with a higher ordering responsiveness under $n = (1,1)$ than under $n = (1,0)$, while the direct effect of vertical signal acquisition restricts its ordering responsiveness under $n = (1,1)$ compared with that under $n = (0,1)$.

Under simultaneous signal acquisition, we can follow the procedure given in (3-5) – (3-7) to analyze the outcomes. Proposition 4.5 characterizes the equilibrium status of vertical signal disclosure.

**Proposition 4.5**. *In the system of a supplier selling to two retailers each with exclusive signal access, given only retailer 1 discloses signal to retailer 2,, under simultaneous signal acquisition,* $n = (1,0)$ *with* $m_1 = p_{A1}^H = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$ *if* $\beta > \sqrt{2} - 1$; $n = (1,1)$ *with* $m_1 = p_{A1}^H = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$ *and* $m_2 = p_{A2}^L = \frac{(3+4\beta+\beta^2)\sigma_\varepsilon{\sigma_\mu}^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$ *otherwise.*

Given only one retailer discloses its signal, under simultaneous signal acquisition, the supplier will only solicit signal from the communicating retailer (its signal is thus made available to all channel parties) when competition is intense but both signals otherwise. Recall that the supplier will solicit signals from both retailers once they mutually disclose signals. Note that $p_{A1}^H = p_S^H$ and $p_{A2}^L > p_S^L$ where $p_S^H$ ($p_S^L$, resp.) is the larger (smaller, resp.) of the two incentive payments by the supplier to solicit signals when the retailers mutually disclose signals. Under simultaneous signal acquisition by the supplier, on the basis of vertical signal acquisition sustainable for various modes of horizontal information sharing, we make two observations. 1) Irrespective of the mode of horizontal information sharing, the supplier will offer the retailers differential payments to acquire their signals when competition is weak ($0 \leq \beta \leq \sqrt{2} - 1$). With the presence of unintentional information leakage, this form of information acquisition equips all channel parties with the same signal availability. 2) Unilateral signal acquisition by the supplier will be sustained when competition is intense ($\beta > \sqrt{2} - 1$), in which case the signal at the communicating retailer is available to all parties, though the non-communicating retailer enjoys an information advantage. A lower status of horizontal information sharing then leads to the establishment of less vertical information links, but the supplier has the tendency to acquire the signal(s) that are available to both retailers.

When the supplier sequentially solicits signals from the retailers, the specific sequence whereby it follows is influential in establishing vertical information links. Specifically, the supplier can approach the communicating retailer first or the non-communicating retailer first, with the key difference residing in the retailers' signal statuses by the time the supplier approaches them. When the communicating retailer is first approached, it only has access to its own signal. When the non-communicating retailer is approached first, however, it has access to both signals. This difference will influence the payments the supplier uses to manipulate the retailers' incentives in signal disclosure, since vertical signal disclosure by the second retailer will have different effects on the profit loss to the first one.

**Lemma 4.1**. *In the system of a supplier selling to two retailers each with an exclusive signal access, given unilateral information sharing with only retailer 1 discloses signal to retailer 2, under sequential signal acquisition by the supplier, let* $\beta_2 = \frac{2\sigma_\mu - \sigma_\varepsilon + \sqrt{2(\sigma_\varepsilon^2 - \sigma_\varepsilon\sigma_\mu + 2\sigma_u^2)}}{\sigma_\varepsilon}$, $\beta_3 = \sqrt{\frac{2\sigma_\varepsilon + 6\sigma_\mu}{\sigma_\varepsilon}} - 1$, $p_{A1}^L = \frac{3\sigma_\varepsilon\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$, $p_{A1}^H = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}$, $p_{A2}^L = \frac{(3+4\beta+\beta^2)\sigma_\varepsilon\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$, $p_2 = \frac{\sigma_\varepsilon\sigma_u^2}{(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$.

*3) If the supplier first approaches retailer 1 for signal solicitation:*

*(iii) If* $0 \le \beta \le \sqrt{2} - 1$, *then* $n = (1,1)$ *with* $(m_1, m_2) = (p_{A1}^L, p_{A2}^L)$.

*(iv) If* $\sigma_\varepsilon \le 3\sigma_\mu$ & $\sqrt{2} - 1 < \beta < 1$ *or* $\sigma_\varepsilon \ge 3\sigma_\mu$ & $\sqrt{2} - 1 < \beta \le \beta_2$, *then* $n = (1,0)$ *with* $m_1 = p_2$.

*(v) If* $\sigma_\varepsilon \ge 3\sigma_\mu$ & $\beta > \beta_2$, *then* $n = (1,0)$ *with* $m_1 = p_{A1}^H$.

*4) If the supplier first approaches retailer 2 for signal solicitation:*

*(iii) If* $\sigma_\varepsilon \le 3\sigma_\mu$ *or* $\sigma_\varepsilon > 3\sigma_\mu$ & $\beta \le \beta_3$, *then* $n = (1,1)$ *with* $(m_1, m_2) = (p_{A1}^L, p_{A2}^L)$.

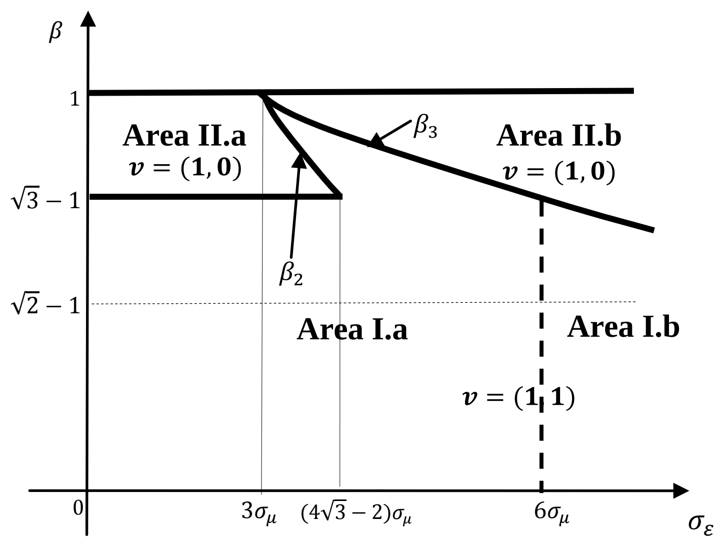
*(iv) If* $\sigma_\varepsilon > 3\sigma_\mu$ & $\beta > \beta_3$, *then* $n = (1,0)$ *with* $m_1 = p_{A1}^H$.

Lemma 4.1 states that under sequential information acquisition, if the supplier first approaches the communicating retailer, it will always acquire its signal and, when market competition is not too intense ($\beta \le \sqrt{2} - 1$), continue to solicit signal from the non-communicating retailer as well. When the supplier solicits signals from both retailers, it will offer a lower payment $p_{A1}^L$ to the communicating retailer but a higher payment $p_{A2}^L$ to the non-communicating retailer. The payment the supplier offers to solicit signal from the communicating retailer only, which is applicable when $\beta > \sqrt{2} - 1$, depends on signal quality and market competition. If the supplier first approaches the non-communicating retailer, only when signal quality is low and market competition is intense will the supplier acquire only one signal from the communicating retailer. Otherwise, it will acquire signals from both retailers by offering them $p_{A1}^L$ and $p_{A2}^L$ respectively.

Observe that irrespective of signal acquisition procedure, the supplier will solicit the signal from the communicating retailer to establish a vertical information link. Its incentive payments to the retailers to establish bilateral information links are the same under the two alternative procedures. However, the specific procedure influences the establishment of vertical signal disclosure in two aspects. Firstly, it is more likely for the supplier to acquire signals from both retailers if it approaches the non-communicating retailer first than if it approaches the communicating retailer first. Secondly, the incentive payment for unilateral signal disclosure can be lower when the supplier approaches the communicating retailer first.

By comparing its profit performance under the two acquisition procedures, the supplier selects the best one to follow. Proposition 4.6, with the assistance of Figure 4.2, shows its preference.

**Figure 4.2. Vertical information acquisition, when only retailer 1 discloses signal**




**Proposition 4.6**. *In the system of a supplier selling to two retailers each with exclusive signal access, given unilateral information sharing with only retailer 1 discloses signal to retailer 2, under sequential signal acquisition by the supplier, let $\beta_2$, $\beta_3$, $p_{A1}^L$, $p_{A1}^H$, $p_{A2}^L$, and $p_2$ be as defined in Lemma 4.1:*

1) *The supplier will acquire both signals by offering $(m_1, m_2) = (p_{A1}^L, p_{A2}^L)$ in area I;*
2) *The supplier will acquire only one signal by first approaching retailer 1 to offer $m_1 = p_2$ in area II.a, but can follow any sequence to approach retailers but only acquire signal from retailer 1 with $m_1 = p_{A1}^H$ in area II.b.*

When market competition is weak ($\beta \le \sqrt{2}-1$), the supplier can follow any arbitrary sequence to approach the retailers and solicit both signals by offering them differential payments of $(p_{A1}^L, p_{A2}^L)$. The payment to the communicating retailer (retailer 1) is smaller than that to the non-communicating retailer

(retailer 2). In area I of Figure 3 where $\beta > \sqrt{2} - 1$, the supplier will solicit signal first from the non-communicating retailer and then from the communicating retailer. In this case, the supplier intentionally postpones soliciting signal from the communicating retailer. This is because if the supplier approaches the communicating retailer first, which gives the non-communicating retailer an information advantage, it will be unable to afford the incentive required for the non-communicating retailer to disclose its signal. With a high signal quality and intense competition (Area II.a in Figure 4.2), the supplier will first approach the communicating retailer and only acquire its signal with an incentive payment of $p_2$. With a low signal quality and intense competition (Area II.b in Figure 4.2), the supplier can follow any arbitrary sequence to approach the retailers but only acquire the signal from the communicating retailer with a payment of $p_{A1}^H$.

Recall that under simultaneous information acquisition, the supplier will gain access to the signal at the communicating retailer when $\beta > \sqrt{2} - 1$ with a payment of $p_{A1}^H$, but acquire both signals with payments of $(p_{A1}^H, p_{A2}^L)$ otherwise. Under sequential information acquisition, it is able to make a smaller payment to gain access to more signals. To see this, note that in area I in Figure 4.2 where $\beta > \sqrt{2} - 1$, the supplier will acquire both signals under sequential signal acquisition with a total payment of $p_{A1}^L + p_{A2}^L$, but only acquire the signal at the communicating retailer under simultaneous signal acquisition with a payment of $p_{A1}^H$. When $\beta \leq \sqrt{2} - 1$, regardless of acquisition procedure, the supplier will always gain access to both signals but its total payment under simultaneous acquisition is $p_{A1}^H + p_{A2}^L$, which is larger than its total payment of $p_{A1}^L + p_{A2}^L$ under sequential acquisition. Enhanced signal availability with a smaller payment benefits the supplier.

Given that only one retailer horizontally discloses signal, the supplier will still prefer to sequentialize the process to gain signal access, though the specific sequence depends on market competition and signal quality. Either unilateral or bilateral vertical information links can be established. This preference by the supplier will make the retailers earn lower profits, compared with under simultaneous signal acquisition. Vertical signal acquisition influences the profit performance of the individual parties and the system.

**Proposition 4.7**. *In the system of one supplier selling to two retailers each with exclusive signal access, given unilateral information sharing with only retailer 1 discloses signal to retailer 2, and sequential signal acquisition by the supplier, referring to the equilibrium in Figure 4.2:*

1) *In Area I,* $\Pi_1^{(1,1)} < \Pi_1^{(0,0)}$ *in Area I.a,* $\Pi_1^{(1,1)} > \Pi_1^{(0,0)}$ *in Area I.b,* $\Pi_2^{(1,1)} < \Pi_2^{(0,0)}$, *and* $\Pi_S^{(1,1)} > \Pi_S^{(0,0)}$.
2) *In Area II.a,* $\Pi_i^{(1,0)} < \Pi_i^{(0,0)}$ *and* $\Pi_S^{(1,0)} > \Pi_S^{(0,0)}$*; in Area II.b,* $\Pi_1^{(1,0)} = \Pi_1^{(0,0)}$, $\Pi_2^{(1,0)} < \Pi_2^{(0,0)}$, *and* $\Pi_S^{(1,0)} > \Pi_S^{(0,0)}$.

Given that only retailer 1 discloses its signal to retailer 2, the supplier will follow a sequence to gain access to either one signal (the signal at the communicating retailer in particular) or both signals. The establishment of vertical information links always makes the supplier better off, but has mixed effects on the retailers. The non-communicating retailer always suffers a profit loss, since the direct and indirect effects of vertical signal acquisition will outweigh its profit gain from enhanced signal availability. But the communicating retailer can be better off when the supplier solicits both signals and signal accuracy is weak (Area I.b in Figure 4.2), in which case partial information transparency (with respect to its signal) is attained and this retailer benefits from the streamlined system-wide decision making thus results.

### 4.2.3 Strategic interplay

Horizontal information sharing between the retailers and vertical information acquisition by the supplier, together with unintentional information leakage, determine the signal availability to channel parties. In Table 4.4, a combination of the statuses of horizontal and vertical information sharing determines an information structure. We show the signal availability to retailer 1, retailer 2, and the supplier under each information structure, where "*h*" stands for the status of horizontal information sharing, "*v*" stands for the status of vertical information acquisition, "1" indicates retailer 1' signal, "2" indicates retailer 2's signal and "ϕ" indicates no signal availability.

**Table 4.4. Signal availability chart**

| ***h*** | ***v*** | **Retailer 1** | **Retailer 2** | **Supplier** |
|---|---|---|---|---|
| (0,0) | (0,0) | 1 | 2 | ϕ |
| | (1,0) | 1 | 1,2 | 1 |
| | (0,1) | 1,2 | 2 | 2 |
| | (1,1) | 1,2 | 1,2 | 1,2 |
| (1,0) | (0,0) | 1 | 1,2 | ϕ |
| | (1,0) | 1 | 1,2 | 1 |
| | (0,1) | 1,2 | 1,2 | 2 |
| | (1,1) | 1,2 | 1,2 | 1,2 |
| (1,1) | (0,0) | 1,2 | 1,2 | ϕ |
| | (1,0) | 1,2 | 1,2 | 1 |
| | (0,1) | 1,2 | 1,2 | 2 |

| | | | |
|---|---|---|---|
| (1,1) | 1,2 | 1,2 | 1,2 |

Irrespective of the status of horizontal information sharing, all channel parties have the same signal availability (and system-wide information transparency is attained) if the supplier acquires signals from both retailers. Unilateral signal acquisition can result in the same information structure with different modes of horizontal information sharing. For instance, given that the supplier only learns the signal at retailer 1, the signal availability to channel parties when the retailers forfeit information sharing is the same as when only retailer 1 discloses its signal to retailer 2. As the status of horizontal information sharing is enhanced, vertical information acquisition can help an individual retailer attain higher signal availability. It is the availability of signals to channel parties that influence their interactions and profit performance. The supplier and retailers weigh the information structure that results from information flow and leakage to make decisions on information sharing.

Horizontal information flow does not affect the preference by the supplier over the sequence to solicit signals from the retailers. Sequential information acquisition, though allowing the second retailer to act based on the status of signal disclosure by the first retailer, effectively places the two retailers at a disadvantageous position. Note that once the supplier acquires signal from the second retailer, it will utilize the signal to adjust the wholesale prices for both retailers. Though the first retailer can infer the disclosed signal for use in responsive ordering, the indirect effect of signal acquisition by the supplier from the second retailer will be more phenomenal to negatively affect the profit of the first retailer. Such externality will give the first retailer a strong tendency to disclose signal when approached by the supplier, despite the leakage effect thus may arise, and rely on the established vertical information link to keep more signal acquisition from taking place. As the retailers are more willing to disclose signals, the supplier needs to offer them smaller payments as incentives for signal disclosure. Under simultaneous information acquisition, however, the retailers are unaware of the status of vertical signal disclosure by one another, which exerts a negative externality on their individual profits. As such, each retailer has no privilege to enforce pressure on its rival through signal disclosure and can be hesitant to engage in vertical information communication. The supplier then has to offer them higher premiums in return for enhanced signal availability.

As the supplier prefers to sequentialize the signal solicitation procedure, it will acquire both signals with a uniform payment if the retailers mutually disclose signals. Under unilateral information sharing, vertical information acquisition will always happen, although bilateral signal disclosure is less likely to occur than under bilateral information sharing. The supplier will always acquire the signal from the communicating retailer at a timing influenced by signal quality and market competition. When the retailers forfeit horizontal information sharing, the supplier can use a payment of $p_1$ or $p_N^H$ to incentivize one retailer to disclose signals, or offer $(p_N^L, p_N^L)$ to gain full signal access. It is however possible for the supplier not to acquire any signal. We also find that the supplier earns a higher profit from information acquisition as the number of horizontal information links increases, which is consistent with the content of lemma 3.2.

### 4.2.4 Information structure

To decide on the mode of horizontal information sharing (unilateral, bilateral, no information sharing), the retailers can adopt two decision regimes. In one regime, they manage interactions competitively and each act as an independent profit maximizer to unilaterally make a signal-disclosure decision, considering the action by its rival. In the other regime, they make a cooperative decision about horizontal information sharing in a specific mode to maximize their total profit. Note that we do not exclude the possibility for the retailers to infer signals even when they cooperatively share signals. The retailers will engage in horizontal information sharing (unilateral or bilateral) to collectively earn the best total profit, which is a necessary condition to sustain cooperation. Under the circumstance in which the retailers earn a total profit gain from horizontal information sharing, they can share the profit gain, through negotiation for instance, so that neither of them has an incentive to deviate.

**Proposition 4.8**. *In the system of a supplier selling to two retailers each with exclusive signal access, irrespective of the decision regime, neither retailer will disclose signal to the rival and the resulting information structure is as given in Proposition 4.1 and illustrated in Figure 4.1.*

With the capability to utilize the inferred signals in responsive ordering, the retailers will forfeit horizontal information sharing in its entirety. This seemingly intuitive outcome is attributed to the strategic complementarity of vertical information acquisition to horizontal information sharing. The establishment of a horizontal information link between the retailers can incentivize the supplier to acquire more signals. To build vertical information links, the supplier sequentially offers the retailers payments as incentives to trap them in an information game to disclose signals. The enhanced signal availability to the supplier will, through its enhanced responsive wholesale pricing, limit both retailers' ordering flexibility. This will cause the retailers to suffer a total profit loss and this profit loss will worsen as more horizontal information links are built. As a result, the retailers, when cooperatively weighing the option of horizontal information sharing, will forfeit it entirely. When the retailers unilaterally make signal-disclosure decisions, it will be their dominant strategy to forfeit signal disclosure. This is because, irrespective of signal disclosure by the other retailer, revealing its signal to the rival by a retailer will incentivize the supplier to acquire more signals. The direct effect that arises from it will negatively influence the profit performance of the particular retailer, whose profit loss will be larger when it already has access to the other retailer's signal since the potentially positive leakage effect will then be ineffective.

While horizontal information sharing is not sustainable, vertical information acquisition can be sustained unless signal accuracy is too low and competition is too intense (Proposition 4.1). The supplier will learn signals from both retailers when competition is less intense, in which case information leakage will make the retailers' signals accessible to all channel parties. As such, information transparency is realized through a combination of direct information acquisition by the supplier and indirect information leakage to the retailers. In the case when competition is intense, partial information transparency in which one retailer's signal is visible to all channel parties is realizable. Regardless, the supplier and retailers can all benefit from information flow when their streamlined decision making leads to supply chain profit improvement. This happens when signal accuracy is weak.

## 4.3 Concluding remarks

In this chapter, we provide a complete analysis of the information structure that can be sustained to transmit the signals available to the retailers to other channel parties. Horizontally, the retailers can disclose signals to one another. Vertically, the supplier can solicit signals by offering the retailers differential payments as incentives. These two forms of information sharing intricately interplay to move signals in the supply chain. Unintentional information leakage further complicates the arena for information flow and has strategic implications on the incentives for channel parties to engage in information sharing. By piecing together horizontal and vertical information sharing, with the presence of information leakage, we show from the perspective of establishing information flow, vertical information acquisition by the supplier is a strategic complement to horizontal information sharing by the retailers. This strategic complementarity precludes horizontal information sharing in its entirety, though vertical signal acquisition is sustainable. Incentive-driven information transparency, in which the retailers' signals are accessible by all channel parties, is realizable through a combination of vertical information acquisition and unintentional information leakage.

# Chapter 5
# Summary and Future Research

We have explored the incentives for horizontal information sharing and vertical information transaction among firms facing uncertain demand in this research. In Chapter 2, we first investigate 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. They can exchange signals to engage in horizontal information sharing and the suppliers can access their signals through vertical information acquisition. We identify the direct and indirect effects of signal acquisition and the pooling effect of signal exchange, as well as the factors that affect their interaction. The direct effect of signal acquisition benefits the supplier and hurts the retailer, but the indirect effect has mixed implications for the profit of retailer not directly involved in signal acquisition. The pooling effect is modulated by market competition and can benefit the retailers if market competition is less intense. Our results reveal that channel structure (horizontal competition at either one or both tiers), signal structure (signal correlation and accuracy), and market competition are crucial in sustaining information flow.

We find that retailer competition is necessary for information flow of any form to be sustained. Horizontal information sharing between competing retailers equips them with the same signal status and when they order from the same supplier, stimulates the supplier to acquire signals from them both. A necessary condition for the retailers to exchange signals is that competition is not too intense. A monopolist supplier can offer them differential payments to manipulate their incentives and trap them in a Prisoner's Dilemma type of situation for signal acquisition. 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 suppliers will profit from enhanced signal availability, the retailers can be better off as well when signal correlation is weak, but the customers will be hurt by increased prices and lowered product availability.

Studying further the system in which two retailers order from an external supplier in Chapter 3, we find the supplier always prefers to sequentialize the process to approach the retailers to gain signal access. A higher status of horizontal information flow, with more retailers horizontally disclosing signals, can stimulate the supplier to set up more vertical information links and profit more from vertical signal access, particularly when signal quality is low. From the perspective of building information flow, vertical information acquisition by the supplier functions as a strategic complement to horizontal information sharing between the retailers.

The issue that we explore in Chapter 4 is indirect signal divulgence. Since the supplier's signal-triggered wholesale price policy structure is publicly known, one retailer can infer the signal that the other retailer has disclosed to the supplier from the wholesale price adjustment by the latter. We show that, with indirect signal divulgence, information transparency whereby the retailers' signals are accessible to all channel parties is attainable through a combination of information acquisition by the supplier and unintentional information leakage to the retailers. Under this circumstance, each and every channel party can benefit from information flow.

Our findings infuse rationality into information sharing in practice. First, we show that vertical information links are sustainable provided that demand signals are reasonably accurate. This is a practical condition, as the supplier will have the interest in acquiring signals if they are indicative of actual market condition and useful in forecasting sales trend. In the Big Data era, firms have made heavy investments to collect and analyze data with advanced computing facilities. The improved data quality thus results can then sustain upstream movement of information. Second, we perceive that the Wal-Mart-Target initiative on mobile payment system CurrentC paves the way for data sharing. Though it will remain concealed to outsiders on whether Target really lets Wal-Mart use joint data until the system is fully launched, they do have the incentive to take that strategic move. We show a less intense market competition is the necessary condition for horizontal information sharing. In reality, Wal-Mart caters to larger families with lower income (blue-collar segment), while Target aims for middle-sized families with higher income (middle-class clientele). Target focuses on more stylish and higher quality products than Wal-Mart. The difference in consumer segments makes their products, most of which come from the same suppliers, not quite substitutable. This makes information collaboration a possibility between them. We conjecture that their collaboration can further encourage the suppliers to acquire signals. More prevalent information flow is thus expected to occur.

This 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 signal exchange between retailers and signal acquisition by suppliers, it is worth the effort to examine the robustness of our findings with respect to contract format by 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 can be an important extension to extend the scope of the investigation to study both demand and cost information sharing in supply chains.

# Appendix A. Proofs for Chapter 2

**Derivation of conditional expectations under assumption A**

It follows that $(\mu, X_1, X_2)$ is multivariate normal with covariance matrix:

$$\Sigma_{(\mu,X_1,X_2)} = \left[\begin{array}{c|cc} \sigma_\mu & \sigma_\mu + \sigma_\varepsilon & \sigma_\mu + \sigma_\varepsilon \\ \hline \sigma_\mu + \sigma_\varepsilon & \sigma_\mu + \sigma_\varepsilon & \sigma_\mu + \rho \\ \sigma_\mu + \sigma_\varepsilon & \sigma_\mu + \rho & \sigma_\mu + \sigma_\varepsilon \end{array}\right] = \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix}.$$

By Degroot (1970, p. 55), it follows that $f(\mu|X_1, X_2)$ is normally distributed with the following mean:

$$E(\mu|\, X_1 = x_1, X_2 = x_2) = \Sigma_{12}\Sigma_{22}^{-1}(X_1, X_2)^T = \frac{\sigma_\mu}{2\sigma_\mu+\sigma_\varepsilon+\rho}(x_1 + x_2).$$

Similarly, $(\mu, X)$, $(\mu, X_i)$ and $\left(X_j, X_i\right)$ are bivariate normal with covariance matrixes:

$$\Sigma_{(\mu,X)} = \Sigma_{(\mu,X_i)} = \begin{bmatrix} \sigma_\mu & \sigma_\mu \\ \sigma_\mu & \sigma_\mu + \sigma_\varepsilon \end{bmatrix},$$

$$\Sigma_{(X_j,X_i)} = \begin{bmatrix} \sigma_\mu + \sigma_\varepsilon & \sigma_\mu + \rho \\ \sigma_\mu + \rho & \sigma_\mu + \sigma_\varepsilon \end{bmatrix}.$$

Thus, the posterior distribution of $\mu$ and $X_j$ given $X_i$ has the following mean and variance:

$E(\mu|X = x) = \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}x$, $E(\mu|X_i = x_i) = \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}x_i$, $E\left(X_j\middle|X_i = x_i\right) = \frac{\sigma_\mu+\rho}{\sigma_\mu+\sigma_\varepsilon}x_i$. □

**Derivation of the operation subgame equilibrium in system B, for given $n$**

By the first-order conditions of (2-3), $q_i(w|x) = \frac{a_i-\beta a_{3-i}-w_i+\beta w_{3-i}}{2(1-\beta^2)} + \frac{E(\mu|X=x)}{2(1+\beta)}, i = 1,2$. Without vertical information transaction, with $q_i(w|x)$ and the first-order conditions of $\pi_S^{(0)}$, we have $w_i^{(0)} = \frac{a_i+c_i}{2}$. Then $q_i^{(0)}(x) = \frac{a_i-c_i-\beta(a_{3-i}-c_{3-i})}{4(1-\beta^2)} + \frac{\sigma_\mu}{2(1+\beta)(\sigma_\mu+\sigma_\varepsilon)}x$.

The ex-ante system profit is: $E\left[\sum_{i=1}^2\left(a_i + \mu - q_i^{(0)} - \beta q_{3-i}^{(0)} - w_i^{(0)}\right)q_i^{(0)}\right] + E\left[\sum_{i=1}^2\left(w_i^{(0)} - c_i\right)q_i^{(0)}(x)\right] = \frac{3[(a_1-c_1)^2+(a_2-c_2)^2-2\beta(a_1-c_1)(a_2-c_2)]}{16(1-\beta^2)} + \frac{\sigma_\mu}{(1+\beta)(\sigma_\mu+\sigma_\varepsilon)}E(\mu X) - \frac{{\sigma_\mu}^2}{2(1+\beta)(\sigma_\mu+\sigma_\varepsilon)^2}E(X^2) = \frac{3[(a_1-c_1)^2+(a_2-c_2)^2-2\beta(a_1-c_1)(a_2-c_2)]}{16(1-\beta^2)} + \frac{{\sigma_\mu}^2}{2(1+\beta)(\sigma_\mu+\sigma_\varepsilon)}$, since $E(\mu X) = \sigma_\mu$ and $E(X^2) = \sigma_\mu + \sigma_\varepsilon$.

With $q_i(w|x)$ and the first-order conditions of $\pi_S^{(1)}$, we can follow similar procedures to establish the equilibrium outcomes for the case with information transaction. □

**Derivation of the operation subgame equilibrium in system SC, for given $\boldsymbol{n} = (\boldsymbol{n_1}, \boldsymbol{n_2})$**

By the first-order conditions of (2-3),we have $q_i(w_1, w_2|x) = \frac{a_i - \beta a_{3-i} - w_i + \beta w_{3-i}}{2(1-\beta^2)} + \frac{E(\mu|X=x)}{2(1+\beta)}, i = 1,2.$

If $n = (0,0)$, with $q_i(w_1, w_2|x)$ and the first-order conditions of (2-4), we have $w_i^{(0,0)} = \frac{(2-\beta^2)a_i - \beta a_{3-i} + 2c_i + \beta c_{3-i}}{4-\beta^2} = w_i^0, i = 1,2.$ $q_i^{(0,0)} = \frac{(2-\beta^2)(a_i - c_i) - \beta(a_{3-i} - c_{3-i})}{2(1-\beta^2)(4-\beta^2)} + \frac{\sigma_\mu}{2(1+\beta)(\sigma_\mu + \sigma_\varepsilon)} x = q_i^0 + \frac{1}{2(1+\beta)} Ax$. The ex-ante profit of the retailer is $E\left[\sum_{i=1}^{2}\left(a_i + \mu - q_i^{(0,0)} - \beta q_{3-i}^{(0,0)} - w_i^{(0,0)}\right) q_i^{(0,0)}\right] = \sum_{i=1}^{2}\left(a_i - q_i^0 - \beta q_{3-i}^0 - w_i^0\right) q_i^0 + \frac{\sigma_\mu}{(1+\beta)(\sigma_\mu + \sigma_\varepsilon)} E(\mu X) - 2(1+\beta)\left(\frac{\sigma_\mu}{2(1+\beta)(\sigma_\mu + \sigma_\varepsilon)}\right)^2 E(X^2) = \pi_R^0 + \frac{{\sigma_\mu}^2}{2(1+\beta)(\sigma_\varepsilon + \sigma_\mu)}$. Similarly, the ex-ante expected profit of supplier $i$ is: $E\left[(w_i^{(0,0)} - c_i) q_i^{(0,0)}\right] = (w_i^0 - c_i) q_i^0$. We can follow similar procedures to establish the equilibrium outcomes for the other three cases, $n = \{(1,1), (1,0), (0,1)\}$. Signal price $m_i$ should be deducted (added) from (to) the expected profit of the supplier $i$ (retailer) if $n_i = 1$ to obtain the total ex-ante profits. □

**Proof of Proposition 2.1.**

By Figure 2.3, we can derive the suppliers' signal prices $m_1$ and $m_2$. The expected ex-ante profits of the suppliers are as shown in Table 2.2. The equilibria are illustrated in Table A-1.

| | $m_2 < \frac{3(1-\beta)}{8}\Lambda$ | $\frac{3(1-\beta)}{8}\Lambda \le m_2 < (\frac{5+3\beta}{8} - \frac{1-4\beta^2}{(2-\beta)^2})\Lambda$ | $m_2 \ge (\frac{5+3\beta}{8} - \frac{1-4\beta^2}{(2-\beta)^2})\Lambda$ |
|---|---|---|---|
| $m_1 < \frac{3(1-\beta)}{8}\Lambda$ | ~~$\pi_{S1}^{(0,0)}$~~, ~~$\pi_{S2}^{(0,0)}$~~ | ~~$\pi_{S1}^{(0,1)}$~~, $\pi_{S2}^{(0,1)}$ | ~~$\pi_{S1}^{(0,1)}$~~, $\pi_{S2}^{(0,1)}$ |
| $\frac{3(1-\beta)}{8}\Lambda \le m_1 < (\frac{5+3\beta}{8} - \frac{1-4\beta^2}{(2-\beta)^2})\Lambda$ | $\pi_{S1}^{(1,0)}$, ~~$\pi_{S2}^{(1,0)}$~~ | $\pi_{S1}^{(1,0)}, \pi_{S2}^{(1,0)}$ $(m_1 > m_2)$<br>$\pi_{S1}^{(0,1)}, \pi_{S2}^{(0,1)}$ $(m_1 < m_2)$ | $\pi_{S1}^{(0,1)}, \pi_{S2}^{(0,1)}$ |
| $m_1 \ge (\frac{5+3\beta}{8} - \frac{1-4\beta^2}{(2-\beta)^2})\Lambda$ | $\pi_{S1}^{(1,0)}$, ~~$\pi_{S2}^{(1,0)}$~~ | $\pi_{S1}^{(1,0)}, \pi_{S2}^{(1,0)}$ | $\pi_{S1}^{(1,1)}, \pi_{S2}^{(1,1)}$ |

*Note.* $\Lambda = \frac{{\sigma_\mu}^2}{2(1+\beta)(\sigma_\varepsilon + \sigma_\mu)}$.

**Table A-1. Derivation of NE for System SC**

By Table A-1, only one pure strategy NE can be sustained in system SC, where, $m_i < \frac{3(1-\beta)}{8}\Lambda$, $n_i = 0$. □

**Derivation of the operation subgame equilibrium in system RC without information sharing**

We will focus on $q_i(x_i)$ in the form of $q_i(x_i) = q_{i0} + q_{i1}x_i, i = 1,2$. The objective functions of the retailers are given in (2-6). First-order conditions give $q_i(x_i) = \frac{a_i - \beta E[q_{3-i}(x_{3-i})|X_i = x_i] + E[\mu|X_i = x_i] - w_i}{2}$, $i = 1,2$. Under ordering policy $q_i(x_i) = q_{i0} + q_{i1}x_i$ and the first-order conditions, we have:

$$q_{i0} + q_{i1}x_1 = \frac{a_i - \beta(q_{3-i,0} + q_{3-i,1}E(X_{3-i}|X_i = x_i) + E(\mu|X_i = x_i) - w_i}{2}, i = 1,2.$$

Applying these two equations for every possible $x_1$ and $x_2$, we will have four equations in four unknowns: $2q_{10} = a_1 - \beta q_{20} - w_1$, $2q_{20} = a_2 - \beta q_{10} - w_2$, $2q_{11} = -\beta q_{21}\frac{\sigma_\mu + \rho}{\sigma_\mu + \sigma_\varepsilon} + \frac{\sigma_\mu}{\sigma_\mu + \sigma_\varepsilon}$, $2q_{21} = -\beta q_{11}\frac{\sigma_\mu + \rho}{\sigma_\mu + \sigma_\varepsilon} + \frac{\sigma_\mu}{\sigma_\mu + \sigma_\varepsilon}$. The unique coefficients are obtained by solving these equations.

The equilibrium order quantity $q_i(w_1, w_2|x_i) = \frac{2(a_i - w_i) - \beta(a_{3-i} - w_{3-i})}{4 - \beta^2} + Bx_i$, where $B = \frac{\sigma_\mu}{(2+\beta)\sigma_\mu + 2\sigma_\varepsilon + \beta\rho}$.

If $n = (0,0)$, with $q_i(w_1, w_2|x_i)$ and the first-order conditions of (2-8), $w_i^{(0,0)} = \frac{a_i + c_i}{2}, i = 1,2$. Thus, $q_i^{(0,0)} = q_i^0 + Bx_i = \frac{2(a_i - c_i) - \beta(a_{3-i} - c_{3-i})}{2(4-\beta^2)} + \frac{\sigma_\mu}{(2+\beta)\sigma_\mu + 2\sigma_\varepsilon + \beta\rho}x_i$. We can follow similar procedures to establish the outcomes for the other three cases.

When the retailers share information, we can follow a similar procedure to obtain the outcomes, except that we now focus on $q_i(x_1, x_2)$ in the form of $q_i(x_i) = q_{i0} + q_{i1}x_1 + q_{i2}x_2, i = 1,2$. With all the outcomes, we can then calculate the ex-ante profits, as in System RC. □

**Proof of Lemma 2.1.**

The results can be proved by comparing the relevant ex-ante profits, as shown in Table 2.3. □

**Proof of Lemma 2.2.**

By Figure 2.4 and Table 2.3, the supplier's maximum ex-ante profits in regions I – IV of Figure 2.4 are:

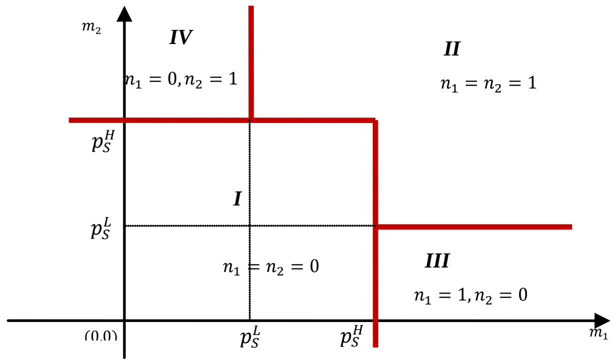
$$\pi_S^I = \pi_S^{(0,0)},\ \pi_S^{II} = \pi_S^{(0,0)} + \frac{\sigma_u^2}{2[\beta(\rho+\sigma_\mu) + 2(\sigma_\varepsilon + \sigma_\mu)]} - p_N^L - p_N^H,$$

$$\pi_S^{III} = \pi_S^{IV} = \pi_S^{(0,0)} + \frac{{\sigma_\mu}^2[\rho^2 + {\sigma_\varepsilon}^2 + (2+\beta)\sigma_\varepsilon\sigma_\mu + (2+\beta){\sigma_\mu}^2 + \rho(\beta\sigma_\varepsilon + (2+\beta)\sigma_\mu)]}{2(\sigma_\varepsilon + \sigma_\mu)[\beta(\rho+\sigma_\mu) + 2(\sigma_\varepsilon + \sigma_\mu)]^2} - p_N^H.$$

Comparing these profits, $\pi_S^{III} = \pi_S^{IV}$; and if $\beta \le \min\{\beta_{RC}^{N1}, \beta_{RC}^{N2}\}$, $\pi_S^{II} < \pi_S^I$ and $\pi_S^{III} < \pi_S^I$; if $\beta_{RC}^{N2} < \beta \le \beta_{RC}^{N3}$, $\pi_S^I < \pi_S^{II}$ and $\pi_S^{III} < \pi_S^{II}$; if $\beta > \max\{\beta_{RC}^{N1}, \beta_{RC}^{N3}\}$, $\pi_S^I < \pi_S^{III}$ and $\pi_S^{II} < \pi_S^{III}$. $\beta_{RC}^{N3} \le \beta_{RC}^{N1} \le \beta_{RC}^{N2}$ if $\sigma_\varepsilon > \sigma_\mu$ & $\rho \le \frac{\sigma_\varepsilon - \sigma_\mu}{2}$, $\beta_{RC}^{N3} \ge \beta_{RC}^{N1} \ge \beta_{RC}^{N2}$ otherwise. Hence the claim. □

**Proof of Lemma 2.3.**

Similar to Figure 2.4, we characterize the transaction decisions by the retailers in system RC when they share signals according to Table 2.4, as illustrated in Figure A-1.




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

**Figure A-1. Information transaction in system RC with information sharing**

By Figure A-1 and Table 2.4, the supplier's maximum ex-ante profits in regions I – IV are:

$$\pi_S^I = \pi_S^{(0,0)},\ \pi_S^{II} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{(2+\beta)(\rho+\sigma_\varepsilon+2\sigma_\mu)} - p_S^L - p_S^H,\ \pi_S^{III} = \pi_S^{IV} = \pi_S^{(0,0)} + \frac{\sigma_\mu^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)} - p_S^H.$$

$\pi_S^I < \pi_S^{II}$ and $\pi_S^{III} = \pi_S^{IV} < \pi_S^{II}$. Hence the claim.

□

**Proof of Proposition 2.2.**

We assume $(m_1^*, m_2^*) = (p_\cdot^H, p_\cdot^L)$ under bilateral information transaction, and $m_1^* = p_\cdot^H$ under unilateral information transaction. By Lemma 2.3, bilateral information transaction will always occur if the retailers share information. By Lemma 2.2, if the retailers forfeit information sharing, when $\sigma_\varepsilon > \sigma_\mu$ & $\rho \leq \frac{\sigma_\varepsilon-\sigma_\mu}{2}$, no information transaction will occur if $\beta \leq \beta_{RC}^{N1}$, while unilateral information transaction will occur if $\beta > \beta_{RC}^{N1}$. We analyze the retailers' decision on information sharing by comparing their ex-ante expected profits without and with information sharing, taking into consideration the supplier's signal acquisition.

The retailers will share information iff both of them are better off. We use the subscript $N$ or $S$ on the relevant profits, with $N$ for "no information sharing" and $S$ for "with information sharing".

When $0 \leq \rho < \frac{(\sigma_\varepsilon-\sigma_\mu)^+}{2}$ and $\beta \leq \beta_{RC}^{N1}$, we compare $(\pi_{Ri}^{(0,0)})_N = \pi_{Ri}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{[\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)]^2}$ in Table 2.3 with $(\pi_{Ri}^{(1,1)})_S = \pi_{Ri}^0 + \frac{\sigma_\mu^2}{2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)} + (m_i)_S$ in Table 2.4, where $(m_{1(2)})_S = p_S^H(p_S^L)$. When $\sigma_\varepsilon > 6\sigma_\mu$, $\rho < \frac{\sigma_\varepsilon-6\sigma_\mu}{7}$ and $\beta \leq \beta_{RC}^{S1}$, where $\beta_{RC}^{S1} = \frac{\alpha+\gamma}{\omega}$, with $\omega = 3\rho^3 - 5\rho^2\sigma_\varepsilon + 4\rho{\sigma_\varepsilon}^2 + 4{\sigma_\varepsilon}^3 +$

$4\rho^2\sigma_\mu - 2\rho\sigma_\varepsilon\sigma_\mu + 16\sigma_\varepsilon{}^2\sigma_\mu + 3\rho\sigma_\mu{}^2 + 15\sigma_\varepsilon\sigma_\mu{}^2 + 6\sigma_\mu{}^3$, $\alpha = -2(3\rho^2\sigma_\varepsilon - \rho\sigma_\varepsilon{}^2 + 4\sigma_\varepsilon{}^3 + 3\rho^2\sigma_\mu + 4\rho\sigma_\varepsilon\sigma_\mu + 11\sigma_\varepsilon{}^2\sigma_\mu + 5\rho\sigma_\mu{}^2 + 13\sigma_\varepsilon\sigma_\mu{}^2 + 6\sigma_\mu{}^3)$,

$$\gamma = 4\sqrt{\begin{matrix}-3\rho^4\sigma_\varepsilon{}^2 + 8\rho^3\sigma_\varepsilon{}^3 - 2\rho^2\sigma_\varepsilon{}^4 - 8\rho\sigma_\varepsilon{}^5 + 5\sigma_\varepsilon{}^6 - 6\rho^4\sigma_\varepsilon\sigma_\mu + 12\rho^3\sigma_\varepsilon{}^2\sigma_\mu + 16\rho^2\sigma_\varepsilon{}^3\sigma_\mu \\ -44\rho\sigma_\varepsilon{}^4\sigma_\mu + 22\sigma_\varepsilon{}^5\sigma_\mu - 3\rho^4\sigma_\mu{}^2 + 42\rho^2\sigma_\varepsilon{}^2\sigma_\mu{}^2 - 72\rho\sigma_\varepsilon{}^3\sigma_\mu{}^2 + 33\sigma_\varepsilon{}^4\sigma_\mu{}^2 - 4\rho^3\sigma_\mu{}^3 \\ +28\rho^2\sigma_\varepsilon\sigma_\mu{}^3 - 44\rho\sigma_\varepsilon{}^2\sigma_\mu{}^3 + 20\sigma_\varepsilon{}^3\sigma_\mu{}^3 + 4\rho^2\sigma_\mu{}^4 - 8\rho\sigma_\varepsilon\sigma_\mu{}^4 + 4\sigma_\varepsilon{}^2\sigma_\mu{}^4\end{matrix}}, \beta \leq$$

$\beta_{RC}^{N1}$ and $\min\{(\pi_{Ri}^{(1,1)})_S - (\pi_{Ri}^{(0,0)})_N, i \in \{1,2\}\} \geq 0$. Then, under such conditions, the retailers will share signals and the supplier will acquire signals from them both. Otherwise, neither information sharing nor transaction will occur.

When $0 \leq \rho < \frac{(\sigma_\varepsilon - \sigma_\mu)^+}{2}$ and $\beta > \beta_{RC}^{N1}$, we compare $(\pi_{Ri}^{(1,0)})_N$ with $(\pi_{Ri}^{(1,1)})_S$. The requirements of $\beta > \beta_{RC}^{N1}$ and $\min\{(\pi_{Ri}^{(1,0)})_S - (\pi_{Ri}^{(1,0)})_N, i \in \{1,2\}\} > 0$ cannot hold simultaneously. Thus, the retailers will not share signals, and the supplier will acquire the signal from one retailer at price $p_N^H$.

Similarly, when $\rho \geq \frac{(\sigma_\varepsilon - \sigma_\mu)^+}{2}$, we consider the ex-ante profits without information sharing in the three cases of part 1) in Lemma 2.2, and follow a similar procedure as above to establish the outcomes. Particularly, $\beta_{RC}^{S2} = Root[f(\beta),3]$, where $f(\beta) = -2\rho^2 + 4\rho\sigma_\varepsilon - 2\sigma_\varepsilon{}^2 + (2\rho^2 + 2\rho\sigma_\varepsilon + 8\sigma_\varepsilon^2 + 6\rho\sigma_\mu + 18\sigma_\varepsilon\sigma_\mu + 12\sigma_u^2)\beta + (2\rho^2 + 6\rho\sigma_\varepsilon + 2\sigma_\varepsilon^2 + 10\rho\sigma_\mu + 10\sigma_\varepsilon\sigma_\mu + 10\sigma_u^2)\beta^2 + (\rho^2 + \rho\sigma_\varepsilon + 3\rho\sigma_\mu + \sigma_\varepsilon\sigma_\mu + 2\sigma_u^2)\beta^3$, and $Root[f(\beta),1] < Root[f(\beta),2] < 0$, $Root[f,k]$ represents the $k$th root of $f$. $Root[f,k]$ represents the $k$th root of $f$. □

**Proof of Proposition 2.3**

We use $(\pi_{\cdot}^{(0,0)})_N$ in Table 2.3 as the basis. The subscript $T$ is for the system profit, i.e., the total profit of the two retailers and the supplier. The results can be proved by comparing the equilibrium profits with the basis in Area II, III, and IV of Figure 2.5 respectively. For instance, if "no information sharing and bilateral information transaction" is the outcome(Area III), with the condition $\max\{\beta_{RC}^{N2}, \beta_{RC}^{S2}\} < \beta < \beta_{RC}^{N3}$, we find that $(\pi_{Ri}^{(1,1)})_N < (\pi_{Ri}^{(0,0)})_N, i = 1,2$, $(\pi_S^{(1,1)})_N > (\pi_S^{(0,0)})_N$, and $(\pi_T^{(1,1)})_N < (\pi_T^{(0,0)})_N$ with $(m_1^*, m_2^*) = (p_N^H, p_N^L)$. As for the consumer welfare, $CS = \sum_{i=1}^{2} E[U(q_i) - p_i q_i]$, where $U(q_i) = (a + \mu)q_i - \frac{q_i{}^2}{2}$, it can be verified that $(CS^{(1,1)})_N < (CS^{(0,0)})_N$.

Similar comparative analyses can be conducted for other areas. Note that in these areas, most of the size relationships between the equilibrium and the basis remain the same as those in Area III. Except in Area IV.a of Figure 2.5 ($\rho < \frac{\sigma_\varepsilon - 6\sigma_u}{7}$), we have $(\pi_{Ri}^{(1,1)})_S > (\pi_{Ri}^{(0,0)})_N, i = 1,2$, and $(\pi_T^{(1,1)})_S > (\pi_T^{(0,0)})_N$ with $(m_1^*, m_2^*) = (p_S^H, p_S^L)$, and we have $(\pi_{R1}^{(1,1)})_S > (\pi_{R1}^{(0,0)})_N$ with $m_1^* = p_S^H$ in Area IV.b. □

**Derivation of operation subgame equilibria in system SRC, for given $(n_1, n_2)$**

Without information sharing, similar to that in system RC, $q_i(w_1, w_2|x_i) = \frac{2(a_i - w_i) - \beta(a_{3-i} - w_{3-i})}{4-\beta^2} + Bx_i$.

If $n = (0,0)$, $\pi_{Si}^{(0,0)} = \mathrm{E}[(w_i - c_i)q_i]$, $i = 1,2$. With $q_i(w_1, w_2|x_i)$ and the first-order condition of $\pi_{Si}^{(0,0)}$, we have $w_i^{(0,0)} = w_i^0 = \frac{(8-\beta^2)a_i - 2\beta a_{3-i} + 8c_i + 2\beta c_{3-i}}{16-\beta^2}$.

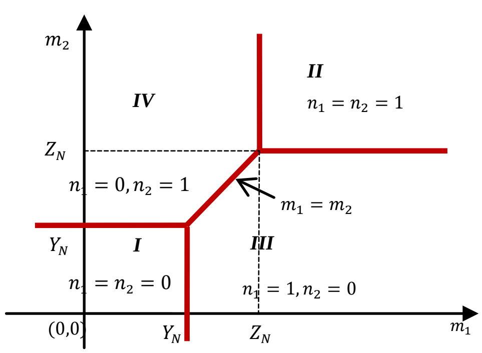
Thus, $q_i^{(0,0)} = q_i^0 + Bx_i = \frac{2((8-\beta^2)(a_i - c_i) - 2\beta(a_{3-i} - c_{3-i}))}{64 - 20\beta^2 + \beta^4} + \frac{\sigma_\mu}{(2+\beta)\sigma_\mu + 2\sigma_\varepsilon + \beta\rho} x_i$.

We can follow a similar procedure as that for $n = (0,0)$ to establish the equilibrium outcomes for the other cases. We consider $w_i(x_i)$ in the form of $w_i(x_i) = w_{i0} + w_{i1}x_i$ for $n = (1,1)$.

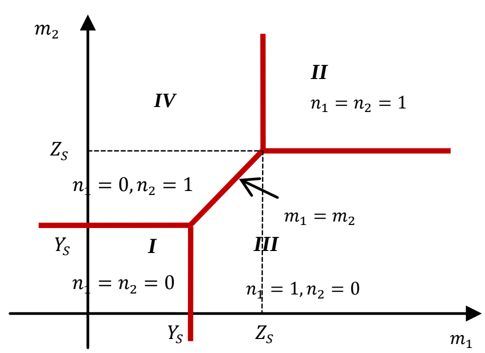
When the retailers share information, we can follow a similar procedure as above. The difference is that we now consider $q_i(x_1, x_2)$ in the form of $q_i(x_1, x_2) = q_{i0} + q_{i1}x_1 + q_{i2}x_2, i = 1,2$, and $w_i(x_1, x_2)$ in the form of $w_i(x_1, x_2) = w_{i0} + w_{i1}x_1 + w_{i2}x_2, i = 1,2$ for $n = (1,1)$. □

**Proof of Lemma 2.4.**

Similar to Figure 2.3, we characterize the transaction decisions by the retailers in system SRC without (with) information sharing according to Table 2.5(2.6), as illustrated in Figure A-2. By Figures A-2, we can derive the suppliers' equilibrium signal prices. Their expected ex-ante profits are as shown in Table 2.5 and Table 2.6, for the cases without and with information sharing respectively. The equilibria are as illustrated in Table A-2 and Table A-3.




a) With no information sharing




b) With information sharing

**Figure A-2. Information transaction in system SRC,**

Note. $Y_N = \frac{3\sigma_\mu^2(\sigma_\varepsilon+\sigma_\mu)}{4(\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}$, $Z_N = \frac{\begin{array}{c}\sigma_\mu^2(4\beta^4\rho^3+192\sigma_\varepsilon^3-\beta^3(8-9\beta)\rho^2\sigma_\mu-2\beta^2(16+4\beta-3\beta^2)\rho\sigma_\mu^2 \\ +\left(192-32\beta^2+\beta^4\right)\sigma_\mu^3-8\sigma_\varepsilon^2((4-\beta)\beta^2\rho-(72-4\beta^2+\beta^3)\sigma_\mu) \\ -\sigma_\varepsilon(\beta^3(8+3\beta)\rho^2+2\beta^2\left(32+3\beta^2\right)\rho\sigma_\mu-(576-64\beta^2+8\beta^3-3\beta^4)\sigma_\mu^2))\end{array}}{16(\beta\rho-4\sigma_\varepsilon+(-4+\beta)\sigma_\mu)^2(\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}$, $Y_S = \frac{3\sigma_\mu^2}{2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}$, $Z_S = \frac{(192-32\beta^2+\beta^4)\sigma_\mu^2}{8(4-\beta)^2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}$.

| | $m_2 < Y_N$ | $Y_N \le m_2 < Z_N$ | $m_2 \ge Z_N$ |
|---|---|---|---|
| $m_1 < Y_N$ | ~~$\pi_{S1}^{(0,0)}$~~, ~~$\pi_{S2}^{(0,0)}$~~ | ~~$\pi_{S1}^{(0,1)}$~~, $\pi_{S2}^{(0,1)}$ | ~~$\pi_{S1}^{(0,1)}$~~, $\pi_{S2}^{(0,1)}$ |
| $Y_N \le m_1 < Z_N$ | $\pi_{S1}^{(1,0)}$, ~~$\pi_{S2}^{(1,0)}$~~ | $\pi_{S1}^{(1,0)}, \pi_{S2}^{(1,0)}$ $(m_1 > m_2)$<br>$\pi_{S1}^{(0,1)}, \pi_{S2}^{(0,1)}$ $(m_1 < m_2)$ | $\pi_{S1}^{(0,1)}, \pi_{S2}^{(0,1)}$ |
| $m_1 \ge Z_N$ | $\pi_{S1}^{(1,0)}$, ~~$\pi_{S2}^{(1,0)}$~~ | $\pi_{S1}^{(1,0)}, \pi_{S2}^{(1,0)}$ | $\pi_{S1}^{(1,1)}, \pi_{S2}^{(1,1)}$ |

**Table A-2. Derivation of NE for system SRC, without information sharing**

| | $m_2 < Y_S$ | $Y_S \le m_2 < Z_S$ | $m_2 \ge Z_S$ |
|---|---|---|---|
| $m_1 < Y_S$ | ~~$\pi_{S1}^{(0,0)}$~~, ~~$\pi_{S2}^{(0,0)}$~~ | ~~$\pi_{S1}^{(0,1)}$~~, $\pi_{S2}^{(0,1)}$ | ~~$\pi_{S1}^{(0,1)}$~~, $\pi_{S2}^{(0,1)}$ |
| $Y_S \le m_1 < Z_S$ | $\pi_{S1}^{(1,0)}$, ~~$\pi_{S2}^{(1,0)}$~~ | $\pi_{S1}^{(1,0)}, \pi_{S2}^{(1,0)}$ $(m_1 > m_2)$<br>$\pi_{S1}^{(0,1)}, \pi_{S2}^{(0,1)}$ $(m_1 < m_2)$ | $\pi_{S1}^{(0,1)}, \pi_{S2}^{(0,1)}$ |
| $m_1 \ge Z_S$ | $\pi_{S1}^{(1,0)}$, ~~$\pi_{S2}^{(1,0)}$~~ | $\pi_{S1}^{(1,0)}, \pi_{S2}^{(1,0)}$ | $\pi_{S1}^{(1,1)}, \pi_{S2}^{(1,1)}$ |

**Table A-3. Derivation of NE for system SRC, with information sharing**

Table A-2 and Table A-3 show that there is a unique pure strategy NE in system SRC without and with information sharing, in which, $m_i < Y_N(Y_S)$ and $n_i = 0$, $i = 1,2$. Hence the claim. □

**Proof of Proposition 2.4.**

By Lemma 2.4, regardless of the status of information sharing, information transaction agreement will be $(n_1, n_2) = (0,0)$ in system SRC. The retailers' decision on information sharing is based on comparing their ex-ante profits without and with information sharing. We still use subscript $N(S)$ on the relevant ex-ante profits, with $N$ for "no information sharing" and $S$ for "with information sharing".

By $(\pi_{Ri}^{(0,0)})_N = \pi_{Ri}^0 + \frac{\sigma_\mu^2(\sigma_\epsilon+\sigma_\mu)}{(\beta\rho+2\sigma_\epsilon+(2+\beta)\sigma_\mu)^2}$ in Table 2.5 and $(\pi_{Ri}^{(0,0)})_S = \pi_{Ri}^0 + \frac{2\sigma_\mu^2}{(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}$ in Table 2.6, if $\beta < \beta_{SRC} = \frac{2[\sqrt{2(\sigma_\mu+\sigma_\varepsilon)(2\sigma_\mu+\sigma_\varepsilon+\rho)}-(\sigma_\mu+\sigma_\varepsilon)]}{3\sigma_\mu+\sigma_\varepsilon+2\rho}$, then $(\pi_{Ri}^{(0,0)})_S - (\pi_{Ri}^{(0,0)})_N = \frac{2\sigma_\mu^2}{(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)} - \frac{\sigma_\mu^2(\sigma_\epsilon+\sigma_\mu)}{(\beta\rho+2\sigma_\epsilon+(2+\beta)\sigma_\mu)^2} > 0$. Thus, under the above condition, the retailers will share signals with each other. □

**Proof of Proposition 2.5**.

It can be verified that if the retailer has two signals with Signal structure [A2] in system B and system SC, the conclusion that no information transaction occurs will hold. To maintain consistency, in comparing SC(B) and SRC(RC), we assume the retailer in SC(B) has two signals under Signal structure [A2], both of which are used in updating; and in comparing B and SC, we assume the retailer has only one signal with Signal structure [A1].

$\Delta\pi_S^B = \sum_i \Delta\pi_{Si}^{SC} = \sum_i \Delta\pi_{Si}^{SRC} = 0$, and,

$$\Delta\pi_R^B = \Delta\pi_R^{SC} = \Delta\pi_T^B = \Delta\pi_T^{SC} = \begin{cases} \frac{\sigma_u^2}{2(1+\beta)(\sigma_\mu+\sigma_\varepsilon)}, & \textit{the retailer has one signal in } B(SC) \\ \frac{\sigma_u^2}{(1+\beta)(2\sigma_\mu+\sigma_\varepsilon+\rho)}, & \textit{the retailer has two signals in } B(SC) \end{cases},$$

$$\sum_i \Delta\pi_{Ri}^{SRC} = \Delta\pi_T^{SRC} = \begin{cases} \frac{4\sigma_\mu^2}{(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}, & \textit{if } \beta < \beta_{SRC} \\ \frac{2\sigma_\mu^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu))^2}, & \textit{else} \end{cases}.$$

$$\Delta\pi_S^{RC} = \begin{cases} 0, & \textit{Area I in Figure } 3.5 \\ \frac{\sigma_u^2\left(2\rho^2-\sigma_\varepsilon^2-2(1-\beta)\sigma_\varepsilon\sigma_\mu+(1+2\beta)\sigma_u^2+2\rho\left(2\sigma_\mu+\beta(\sigma_\varepsilon+\sigma_\mu)\right)\right)}{4(\sigma_\varepsilon+\sigma_\mu)\left(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu)\right)^2}, & \textit{Area II in Figure } 2.5 \\ \frac{\sigma_u^2((2\beta-1)\rho^2-2\sigma_\varepsilon^2+(1+2\beta)\sigma_u^2+2\rho(2\sigma_\varepsilon+\sigma_\mu+2\beta\sigma_\mu))}{4(\sigma_\varepsilon+\sigma_\mu)(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu))^2}, & \textit{Area III in Figure } 2.5 \\ \frac{(1+2\beta)\sigma_u^2}{2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}, & \textit{Area IV in Figure } 2.5 \end{cases},$$

$$\sum_i \Delta\pi_{Ri}^{RC} = \begin{cases} \frac{2\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu))^2}, & \textit{Area I in Figure } 2.5 \\ \frac{\sigma_\mu^2\left((1-2\beta)\rho^2+8\sigma_\varepsilon^2-2(1+\beta)\rho\sigma_\mu+5\sigma_\mu^2+2\sigma_\varepsilon\left((\beta-2)\rho+(6+\beta)\sigma_\mu\right)\right)}{4(\sigma_\varepsilon+\sigma_\mu)\left(\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu\right)^2}, & \textit{Areas IIand III in Figure } 2.5 \\ \frac{5\sigma_\mu^2}{2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}, & \textit{Area IV in Figure } 2.5 \end{cases},$$

$$\Delta\pi_T^{RC} = \begin{cases} \frac{2\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu))^2}, & Area\ I\ in\ Figure\ 2.5 \\ \frac{\sigma_u^2((3-2\beta)\rho^2+7\sigma_\varepsilon{}^2+2(5+2\beta)\sigma_\varepsilon\sigma_\mu+2(3+\beta)\sigma_u^2+2\rho(2(-1+\beta)\sigma_\varepsilon+\sigma_\mu))}{4(\sigma_\varepsilon+\sigma_\mu)(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu))^2}, & Area\ II\ in\ Figure\ 2.5 \\ \frac{\sigma_u^2(3(\sigma_\varepsilon+\sigma_\mu)+\beta(\rho+\sigma_\mu))}{2(\beta(\rho+\sigma_\mu)+2(\sigma_\varepsilon+\sigma_\mu))^2}, & Area\ III\ in\ Figure\ 2.5 \\ \frac{(3+\beta)\sigma_\mu^2}{(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}, & Area\ IV\ in\ Figure\ 2.5 \end{cases},$$

$$\Delta CS^B = \Delta CS^{SC} = \begin{cases} \frac{(1+2\beta)\sigma_u^2}{4(1+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}, & the\ retailer\ has\ one\ signal\ in\ system\ B(SC) \\ \frac{(1+2\beta)\sigma_\mu^2}{2(1+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}, & the\ retailer\ has\ two\ signals\ in\ system\ B(SC) \end{cases},$$

$$\Delta CS^{SRC} = \begin{cases} \frac{2(1+2\beta)\sigma_\mu^2}{(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}, & if\ \beta < \beta_{SRC} \\ \frac{\sigma_\mu^2(2\beta\rho+\sigma_\varepsilon+(1+2\beta)\sigma_\mu)}{(\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & else \end{cases},$$

$$\Delta CS^{RC} = \begin{cases} \frac{\sigma_\mu^2(2\beta\rho+\sigma_\varepsilon+(1+2\beta)\sigma_\mu)}{(\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & Area\ I\ in\ Figure\ 2.5 \\ \frac{\sigma_\mu^2(-3\rho^2+5\sigma_\varepsilon^2-2(3-2\beta)\rho\sigma_\mu+(2+4\beta)\sigma_\mu^2+2\sigma_\varepsilon(2\beta\rho+(5+2\beta)\sigma_\mu))}{8(\sigma_\varepsilon+\sigma_\mu)(\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & Area\ II\ in\ Figure\ 2.5 \\ \frac{\sigma_\mu^2(2\beta\rho+\sigma_\varepsilon+(1+2\beta)\sigma_\mu)}{4(\beta\rho+2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & Area\ III\ in\ Figure\ 2.5 \\ \frac{(1+2\beta)\sigma_\mu^2}{2(2+\beta)^2(\rho+\sigma_\varepsilon+2\sigma_\mu)}, & Area\ IV\ in\ Figure\ 2.5 \end{cases}.$$

Proposition 2.5 can be established by comparing the relevant profit gains and consumer welfare across the various systems. □

# Appendix B. Proofs for Chapter 3

It follows from our assumptions, $(\mu, X_1, X_2)$ is multivariate normal with covariance matrix:

$$\Sigma_{(\mu,X_1,X_2)} = \begin{bmatrix} \sigma_\mu & \sigma_\mu & \sigma_\mu \\ \sigma_\mu & \sigma_\mu + \sigma_\varepsilon & \sigma_\mu \\ \sigma_\mu & \sigma_\mu & \sigma_\mu + \sigma_\varepsilon \end{bmatrix} = \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix}.$$

By Gal-Or (1985), $f(\mu|X_1, X_2)$ is normal with mean $E(\mu|X_1 = x_1, X_2 = x_2) = \Sigma_{12}\Sigma_{22}^{-1}(x_1, x_2)^T = \frac{\sigma_\mu}{2\sigma_\mu+\sigma_\varepsilon}(x_1 + x_2)$. Similarly, both $(\mu, X_i)$and $(X_i, X_j)$ are bi-variate normal with covariance matrix:

$$\Sigma_{(\mu,X_i)} = \begin{bmatrix} \sigma_\mu & \sigma_\mu \\ \sigma_\mu & \sigma_\mu + \sigma_\varepsilon \end{bmatrix}, \Sigma_{(X_i,X_j)} = \begin{bmatrix} \sigma_\mu + \sigma_\varepsilon & \sigma_\mu \\ \sigma_\mu & \sigma_\mu + \sigma_\varepsilon \end{bmatrix}.$$

Thus, the posterior distribution of $\mu$ and $X_j$ given $X_i = x_i$ has the following mean: $E(\mu|X_i = x_i) = E(X_j|X_i = x_i) = \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}x_i$. □

We next derive the operation subgame equilibrium without information sharing, for given $(n_1, n_2)$. We will focus on $q_i(x_i)$ in the form of $q_i(x_i) = q_{i0} + q_{i1}x_i, i = 1,2$. The objective functions of the retailers are given in (3-2). By the first-order conditions, $q_i(x_i) = \frac{a_i - \beta E[q_{3-i}(x_{3-i})|X_i=x_i] + E[\mu|X_i=x_i] - w_i}{2}$, $i = 1,2$. Under ordering policy $q_i(x_i) = q_{i0} + q_{i1}x_i$ and the first-order conditions, we have:

$$q_{i0} + q_{i1}x_1 = \frac{a_i - \beta(q_{3-i,0} + q_{3-i,1}E(X_{3-i}|X_i=x_i) + E(\mu|X_i=x_i) - w_i}{2}, i = 1,2.$$

Requiring these two equations to hold for every possible $x_1$and $x_2$, we will have four equations in four unknowns: $2q_{10} = a_1 - \beta q_{20} - w_1$, $2q_{20} = a_2 - \beta q_{10} - w_2$,$2q_{11} = -\beta q_{21}\frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon} + \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}$, $2q_{21} = -\beta q_{11}\frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon} + \frac{\sigma_\mu}{\sigma_\mu+\sigma_\varepsilon}$. The unique coefficients can be obtained by solving these equations.

The equilibrium order quantity $q_i(w_1, w_2|x_i) = \frac{2(a_i-w_i)-\beta(a_{3-i}-w_{3-i})}{4-\beta^2} + Bx_i$, where $B = \frac{\sigma_\mu}{(2+\beta)\sigma_\mu+2\sigma_\varepsilon}$.

If $(n_1, n_2) = (0,0)$, with $q_i(w_1, w_2|x_i)$ and the first-order conditions of (3-4), $w_i^{(0,0)} = \frac{a_i+c_i}{2}, i = 1,2$. Thus, $q_i^{(0,0)} = q_i^0 + Bx_i = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)} + \frac{\sigma_\mu}{(2+\beta)\sigma_\mu+2\sigma_\varepsilon}x_i$. The ex-ante profit of retailer $i$ is $E\left[\left(a_i + \mu - q_i^{(0,0)} - \beta q_{3-i}^{(0,0)} - w_i^{(0,0)}\right)q_i^{(0,0)}\right] = \left(a_i - q_i^0 - \beta q_{3-i}^0 - w_i^0\right)q_i^0 + BE(\mu X) - B^2E(X^2) - \beta B^2E(X_1X_2) = \pi_R^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{[(2+\beta)\sigma_\mu+2\sigma_\varepsilon]^2}$, since $E(\mu X) = E(X_1X_2) = \sigma_\mu$ and $E(X^2) = \sigma_\mu + \sigma_\varepsilon$.

Similarly, the ex-ante expected profit of the supplier is: $E\left[\sum_{i=1}^{2}(w_i^{(0,0)} - c_i)q_i^{(0,0)}\right] = \sum_{i=1}^{2}(w_i^0 - c_i)q_i^0$.

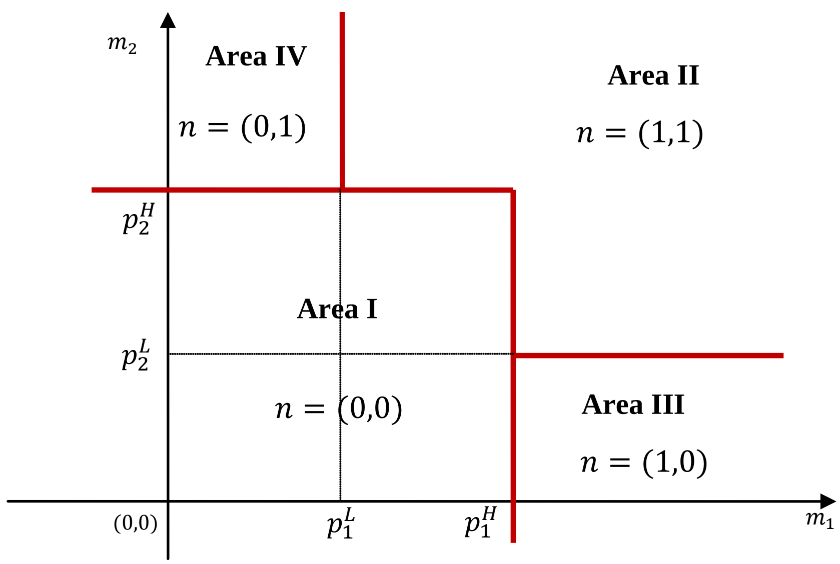
We can follow similar procedures to establish the equilibrium outcomes for the other three cases, i.e., $(n_1, n_2) = (1,1)$, $(n_1, n_2) = (1,0)$, and $(n_1, n_2) = (0,1)$.

When the retailers mutually disclose signals, the profit of retailer $i$ is given in (3-3). We can follow a similar procedure to obtain the outcomes, except that we focus on $q_i(x_1, x_2)$ in the form of $q_i(x_1, x_2) = q_{i0} + q_{i1}x_1 + q_{i2}x_2, i = 1,2$.

When only a retailer $i$ horizontally discloses signal to the other retailer but not vice versa, the profit of retailer $i$ will be as given in (3-2), while the profit of its competitor will take the form of (3-3). We then focus on $q_1(x_1) = q_{10} + q_{11}x_1, q_2(x_1, x_2) = q_{20} + q_{21}x_1 + q_{22}x_2$ . □

According to Table 3.1, Table 3.2 and Table 3.3, we characterize the status of vertical signal disclosure under simultaneous signal acquisition, as illustrated in Figure B.1.

**Figure B.1. Vertical signal disclosure under simultaneous signal acquisition**




If the retailers forfeit information sharing, then $p_i^L = p_N^L, p_i^H = p_N^H, i = 1,2$. When the retailers mutually disclosure signals, $p_i^L = p_S^L, p_i^H = p_S^H, i = 1,2$. When only retailer 1 discloses signal to retailer 2, $p_1^L = p_A^L, p_1^H = p_A^H, p_2^L = p_2, p_2^H = \frac{3\sigma_u^2((2+\beta)\sigma_\epsilon+2\sigma_\mu)^2}{16(2+\beta)^2(\sigma_\epsilon+\sigma_\mu)^3}$. □

**Proof of Proposition 3.1.** 1) By Table 3.1, the supplier's ex-ante profit under simultaneous signal acquisition in regions I – IV of Figure B.1 are:

$\pi_S^I = \pi_S^{(0,0)}$, $\pi_S^{II} = \pi_S^{(0,0)} + \frac{\sigma_u^2}{2[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]} - p_N^L - p_N^H$,

$\pi_S^{III} = \pi_S^{IV} = \pi_S^{(0,0)} + \frac{\sigma_u^2[\sigma_\varepsilon^2+(2+\beta)\sigma_\varepsilon\sigma_\mu+(2+\beta)\sigma_u^2]}{2(\sigma_\varepsilon+\sigma_\mu)[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2} - p_N^H$.

Comparing these profits, we have $\pi_S^{III} = \pi_S^{IV}$; and if $\beta \leq \min\{\beta_1, \beta_3\}$, $\pi_S^{II} < \pi_S^I$ and $\pi_S^{III} < \pi_S^I$; if $\beta_3 < \beta \leq \beta_2$, $\pi_S^I < \pi_S^{II}$ and $\pi_S^{III} < \pi_S^{II}$; if $\beta > \max\{\beta_1, \beta_2\}$, $\pi_S^I < \pi_S^{III}$ and $\pi_S^{II} < \pi_S^{III}$. Hence the claim.

2)Under sequential signal acquisition, we solve the problem backwards.

Given $n_1, m_2$, retailer 2 decides whether to disclose signal to the supplier. If $n_1 = 0$, $n_2 = 1$ if $m_2 \geq p_N^H$ by comparing $\pi_{R2}^{(0,0)}$ and $\pi_{R2}^{(0,1)} + m_2$; if $n_1 = 1$, $n_2 = 1$ if $m_2 \geq p_N^L$ by comparing $\pi_{R2}^{(1,0)}$ and $\pi_{R2}^{(1,1)} + m_2$.

The supplier deduces retailer 2's decision and chooses $m_2$. If $n_1 = 0$, by comparing $\pi_S^{(0,0)}$ and $\pi_S^{(0,1)} - m_2(m_2 \geq p_N^H)$, $m_2 = p_N^H$ if $\left(\sigma_\varepsilon \leq (\sqrt{2}-1)\sigma_\mu\right) or \left((\sqrt{2}-1)\sigma_\mu < \sigma_\varepsilon < \sqrt{3}\sigma_\mu \& \beta_1 < \beta\right)$, and $n_2 = 1$ in this case; otherwise, no information acquisition between the supplier and retailer 2. If $n_1 = 1$, by comparing $\pi_S^{(1,0)}$ and $\pi_S^{(1,1)} - m_2(m_2 \geq p_N^L)$, $m_2 = p_N^L$ if $\sigma_\varepsilon < 2\sigma_\mu$ & $\beta < \beta_2$, and $n_2 = 1$; otherwise, no information acquisition occurs between the supplier and retailer 2.

To derive retailer 1's decision on signal disclosure, we first consider the case when $\sigma_\varepsilon < (\sqrt{2}-1)\sigma_\mu$.

Given $m_1$, retailer 1 deduces $(m_2, n_2)$ and decides whether to disclose signal. When $n_1 = 0$, $(m_2, n_2) = (p_N^H, 1)$; when $n_1 = 1$, $(m_2, n_2) = \begin{cases} (p_N^L, 1), & if\ \beta < \beta_2 \\ (-\infty, 0), & else \end{cases}$. By comparing $\pi_{R1}^{(0,1)}$and $\pi_{R1}^{(1,1)}(\pi_{R1}^{(1,0)}) + m_1$ if $\beta < \beta_2 (\beta \geq \beta_2)$, we can show that $n_1 = 1$ if $m_1 \geq p_N^L$.

If $\beta < \beta_2$, by comparing $\pi_S^{(0,1)} - m_2(m_2 = p_N^H)$ and $\pi_S^{(1,1)} - m_1 - m_2(m_1 \geq p_N^L, m_2 = p_N^L)$, we find that $m_1 = p_N^L$, and thus $n_1 = 1$, $(m_2, n_2) = (p_N^L, 1)$. If $\beta \geq \beta_2$, by comparing $\pi_S^{(0,1)} - m_2(m_2 = p_N^H)$ and $\pi_{R1}^{(1,0)} - m_1(m_1 \geq p_N^L)$, we have $m_1 = p_N^L$, and $n_1 = 1$, $(m_2, n_2) = (-\infty, 0)$.

When $\sigma_\varepsilon \geq (\sqrt{2}-1)\sigma_\mu$, we can follow a similar procedure to derive the outcomes.

Combining all the outcomes, we can establish part 2) of Proposition 3.1. □

**Proof of Corollary 3.1.** By Proposition 3.1, Corollary 3.1 can be proved by comparing the expected ex-ante profits of the supplier and the retailers, with the fact that $p_N^L < p_N^H$. □

**Proof of Proposition 3.2.** By Table 3.2 and Figure B.1, we can follow a similar procedure as that in the proof for Proposition 3.1 to establish the results. □

**Proof of Corollary 3.2.** By Proposition 3.2, Corollary 3.2 can be proved by comparing the expected ex-ante profits of the supplier and the retailers, with the fact that $p_S^L < p_S^H$. □

**Proof of Proposition 3.3.** By Table 3.3 and Figure B.1, we can follow a similar procedure as that in the proof for part 1 of Proposition 3.1 to establish the results. □

**Proof of Lemma 3.1.** By Table 3.3, the process is similar to the proof of part 2) of Proposition 3.1.□

**Proof of Proposition 3.4.** Given only retailer 1 discloses signal to the rival, according to Lemma 3.1, when $\sigma_\varepsilon \le (\sqrt{2}-1)\sigma_\mu$, the supplier will offer $m_1 = p_A^L$ to gain access to retailer $i$'s signal only if it first approaches retailer 1 for signal access; for otherwise it will offer $(m_1, m_2) = (p_A^L, p_2)$ to gain access to both signals if it first approaches retailer 2 for signal access since $(\sqrt{2}-1)\sigma_\mu < \frac{1+\sqrt{97}}{6}\sigma_\mu$. In this case, by Table 3.3, $\pi_S^{(1,0)} - p_A^L > \pi_S^{(1,1)} - p_A^L - p_2$. Thus, the retailer will first approach retailer 1 for signal access. When $\sigma_\varepsilon \ge (\sqrt{2}-1)\sigma_\mu$, we can follow a similar procedure to derive the outcomes. Combining all the possible outcomes, we can establish Proposition 3.4. □

**Proof of Corollary 3.3.** By Proposition 3.3, Proposition 3.4 and Table 3.3, Corollary 3.3 can be proved by comparing the expected ex-ante profits of the supplier with the result of $p_A^L < p_A^H$ in area III.a and area III.b of Figure 3.3. In area II of Figure 3.3, we can show that $\pi_S^{(1,0)} - p_A^H < \pi_S^{(1,1)} - p_A^L - p_2$, $\pi_{R1}^{(1,0)} + p_A^H > \pi_{R1}^{(1,1)} + p_A^L$, and $\pi_{R2}^{(1,0)} = \pi_S^{(1,1)} + p_2$. Hence the claim. □

**Proof of Lemma 3.2.** Lemma 3.2 can be proved by comparing the relevant signal payments. For instance, $p_A^H - p_A^L = \frac{3\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)} - \frac{\sigma_\varepsilon\sigma_u^2(3\sigma_\varepsilon+(2+\beta^2)\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3} = \frac{\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3}\left(3\sigma_u^2 + (4-\beta^2)\sigma_\varepsilon\sigma_\mu\right) > 0$. We can then follow a similar procedure to prove the other comparison results.

As for the supplier's profits, we use superscript $N(S, A)$ on the relevant profits, with $N$ for "no information sharing", $S$ for "with bilateral information sharing", and $A$ for "with unilateral information sharing(only retailer 1 discloses signal to retailer 2)". Based on part 2) of Proposition 3.1 and Proposition 3.2, Proposition 3.4, and Table 3.1, 3.2, 3.3, we have the following ex-ante total profits of the supplier:

$$\pi_S^N = \begin{cases} \pi_S^0, & Area\ I\ of\ Figure\ 3.2 \\ \pi_S^0 + \frac{\sigma_u^2\left((2-\beta)\sigma_\varepsilon\sigma_\mu + (2+\beta)\sigma_u^2 - \sigma_\varepsilon^2\right)}{2(\sigma_\varepsilon+\sigma_\mu)\left(2\sigma_\varepsilon+(2+\beta)\sigma_\mu\right)^2}, & Area\ II.a\ of\ Figure\ 3.2 \\ \pi_S^0 + \frac{(1+2\beta)\sigma_u^4 - 2\sigma_\varepsilon^2\sigma_u^2}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & Area\ II.b\ of\ Figure\ 3.2 \\ \pi_S^0 + \frac{\sigma_u^2(2\sigma_\varepsilon\sigma_\mu + 2(2+\beta)\sigma_u^2 - \sigma_\varepsilon^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & Area\ III\ of\ Figure\ 3.2 \end{cases},$$

$\pi_S^S = \pi_S^0 + \frac{\sigma_u^2(\sigma_\varepsilon+2\beta\sigma_\varepsilon+2(2+\beta)\sigma_\mu)}{2(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$,

$$\pi_S^A = \begin{cases} \pi_S^0 + \frac{\sigma_u^2(4\beta(\sigma_\varepsilon+\sigma_\mu)^2(\sigma_\varepsilon+4\sigma_\mu)+4\sigma_\mu(6\sigma_\varepsilon^2+15\sigma_\varepsilon\sigma_\mu+8\sigma_\mu{}^2)-\beta^2\sigma_\varepsilon(\sigma_\varepsilon+3\sigma_\mu)^2)}{16(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3(\sigma_\varepsilon+2\sigma_\mu)}, & Area\ II\ of\ Figure\ 3.3 \\ \pi_S^0 + \frac{\sigma_u^2((1+2\beta)\sigma_\varepsilon^2+(6+4\beta-\beta^2)\sigma_\varepsilon\sigma_\mu+2(2+\beta)\sigma_u^2)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3}, & Area\ III.a\ of\ Figure\ 3.3 \\ \pi_S^0 + \frac{(1+2\beta)\sigma_u^2}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}, & Area\ III.b\ of\ Figure\ 3.3 \end{cases},$$

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

$\pi_S^S > \pi_S^A > \pi_S^N$ always holds in any area. Hence the claim. □

**Proof of Theorem 3.1.** We analyze the retailers' decision on information sharing by comparing their ex-ante expected profits without information sharing, with bilateral information sharing, and with unilateral information sharing, taking into consideration the supplier's signal acquisition. We use the subscript $Rs$ and superscript $N(S,A)$ on the relevant profits, with $Rs$ for "the two retailers", $N$ for "no information sharing", $S$ for "with bilateral information sharing", and $A$ for "with unilateral information sharing (only retailer 1 discloses signal to retailer 2)". Based on part 2) of Proposition 3.1 and Proposition 3.2, Proposition 3.4, and Table 3.1, 3.2, 3.3, we have the following ex-ante total profits of the two retailers:

$$\pi_{Rs}^N = \begin{cases} \pi_{Rs}^0 + \frac{2\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu))^2}, & Area\ I\ of\ Figure\ 3.2 \\ \pi_{Rs}^0 + \frac{\sigma_u^2(4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{2(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & Areas\ II.a\ and\ III\ of\ Figure\ 3.2, \\ \pi_{Rs}^0 + \frac{\sigma_u^2(8\sigma_\varepsilon^2+2(6+\beta)\sigma_\varepsilon\sigma_\mu+5\sigma_u^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & Area\ II.b\ of\ Figure\ 3.2 \end{cases}$$

$\pi_{Rs}^S = \pi_{Rs}^0 + \frac{\sigma_u^2(5\sigma_\varepsilon+2\sigma_\mu)}{2(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$,

$$\pi_{Rs}^A = \begin{cases} \pi_{Rs}^0 + \frac{\sigma_u^2((9+4\beta+\beta^2)\sigma_\varepsilon^3+(24+8\beta+3\beta^2)\sigma_\varepsilon^2\sigma_\mu+(18+4\beta+3\beta^2)\sigma_\varepsilon\sigma_u^2+4\sigma_u^3)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3(\sigma_\varepsilon+2\sigma_\mu)}, & Areas\ II\ and\ III.a\ of\ Figure\ 3.3 \\ \pi_{Rs}^0 + \frac{\sigma_u^2((9+4\beta+\beta^2)\sigma_\varepsilon+10\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}, & Area\ III.b\ of\ Figure\ 3.3 \end{cases},$$

where $\pi_{Rs}^0 = \pi_{R1}^0 + \pi_{R2}^0, \pi_{Ri}^0 = (\frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)})^2$.

Theorem 3.1 can be established by comparing the relevant profits under different pattern of horizontal signal disclosure. Particularly, $\beta_{s3} = Root[f(\beta),3]$, where $f(\beta) = -2\sigma_\varepsilon^2 + \big(8\sigma_\varepsilon^2 + 18\sigma_\epsilon\sigma_\mu +$

$12\sigma_u^2)\beta + (2\sigma_\varepsilon^2 + 10\sigma_\epsilon\sigma_\mu + 10\sigma_u^2)\beta^2 + (\sigma_\epsilon\sigma_\mu + 2\sigma_u^2)\beta^3$, and $Root[f, k]$ represents the $k$th root of $f$.

$$\beta_{s4} = \frac{4\sigma_\varepsilon\sqrt{5\sigma_\varepsilon^4+22\sigma_\varepsilon^3\sigma_\mu+33\sigma_\varepsilon^2\sigma_u^2+20\sigma_\varepsilon\sigma_u^3+4\sigma_u^4}-2(4\sigma_\varepsilon^3+11\sigma_\varepsilon^2\sigma_\mu+13\sigma_\varepsilon\sigma_u^2+6\sigma_u^3)}{4\sigma_\varepsilon^3+16\sigma_\varepsilon^2\sigma_\mu+15\sigma_\varepsilon\sigma_u^2+6\sigma_u^3}.$$ □

**Proof of Proposition 3.5.**

By Theorem 3.1, we have the following ex-ante profits (subscript $T$ is used for "the system"):

$$\pi_{R1} = \begin{cases} \pi_{R1}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu))^2}, Areas\ I\ and\ II.b\ of\ Figure\ 3.5 \\ \pi_{R1}^0 + \frac{\sigma_u^2(4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2},\ Areas\ II.a\ and\ III\ of\ Figure\ 3.5 \\ \pi_{R1}^0 + \frac{\sigma_u^2(5\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}, Area\ IV\ and\ \overline{IV}\ of\ Figure\ 3.5 \end{cases},$$

$$\pi_{R2} = \begin{cases} \pi_{R2}^0 + \frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu))^2},\ Area\ I\ of\ Figure\ 3.5 \\ \pi_{R2}^0 + \frac{{\sigma_\mu}^2(4{\sigma_\varepsilon}^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2},\ Areas\ II.a, II.b\ and\ III\ of\ Figure\ 3.5 \\ \pi_{R2}^0 + \frac{\sigma_u^2(5\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}, Area\ IV\ and\ \overline{IV}\ of\ Figure\ 3.5 \end{cases},$$

$$\pi_S = \begin{cases} \pi_S^0,\ Area\ I\ of\ Figure\ 3.5 \\ \pi_S^0 + \frac{\sigma_u^2((2-\beta)\sigma_\varepsilon\sigma_\mu+(2+\beta)\sigma_u^2-\sigma_\varepsilon^2)}{2(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2},\ Area\ II.a\ of\ Figure\ 3.5 \\ \pi_S^0 + \frac{(1+2\beta)\sigma_u^4-2{\sigma_\varepsilon}^2\sigma_u^2}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2},\ Area\ II.b\ of\ Figure\ 3.5 \\ \pi_S^0 + \frac{\sigma_u^2(2\sigma_\varepsilon\sigma_\mu+2(2+\beta)\sigma_u^2-\sigma_\varepsilon^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2},\ Area\ III\ of\ Figure\ 3.5 \\ \pi_S^0 + \frac{\sigma_u^2(\sigma_\varepsilon+2\beta\sigma_\varepsilon+2(2+\beta)\sigma_\mu)}{2(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma\epsilon+2\sigma_\mu)},\ Area\ IV\ and\ \overline{IV}\ of\ Figure\ 3.5 \end{cases},$$

$$\pi_T = \begin{cases} \pi_T^0 + \frac{2\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu))^2},\ Area\ I\ of\ Figure\ 3.5 \\ \pi_T^0 + \frac{\sigma_u^2(3\sigma_\varepsilon+(3+\beta)\sigma_\mu)}{2(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2},\ Areas\ II.a\ and\ II.b\ of\ Figure\ 3.5 \\ \pi_T^0 + \frac{\sigma_u^2(7{\sigma_\varepsilon}^2+2(5+2\beta)\sigma_\varepsilon\sigma_\mu+2(3+\beta)\sigma_u^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma\mu)^2},\ Area\ III\ of\ Figure\ 3.5 \\ \pi_T^0 + \frac{(3+\beta)\sigma_u^2}{(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)},\ Area\ IV\ and\ \overline{IV}\ of\ Figure\ 3.5 \end{cases},$$

where $\pi_T^0 = \pi_{R1}^0 + \pi_{R2}^0 + \pi_S^0$, $\pi_S^0 = \sum_{i=1}^2 (w_i^0 - c_i)q_i^0$, $w_i^0 = \frac{a_i+c_i}{2} q_i^0 = \frac{2(a_i-c_i)-\beta(a_{3-i}-c_{3-i})}{2(4-\beta^2)}$.

In area I of Figure 3.5, information flow does not occur. Proposition 3.5 can be established by comparing the relevant profits in area I with those in other areas. □

**Proof of Proposition 3.6.**

We use the superscript $A2$ on the relevant profits, with $A2$ for "with unilateral information sharing (only retailer 2 discloses signal to retailer 1)". Based on part 2) of Proposition 3.1 and Proposition 3.2, Proposition 3.4, and Table 3.1, 3.2, 3.3, we have the following ex-ante profits of retailer 1:

$$\pi_{R1}^{N}=\begin{cases}\pi_{R1}^{0}+\frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu))^2}, & Areas\ I\ and\ II.b\ of\ Figure\ 3.2\\ \pi_{R1}^{0}+\frac{\sigma_u^2(4\sigma_\varepsilon{}^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & Areas\ II.a\ and\ III\ of\ Figure\ 3.2\end{cases},$$

$$\pi_{R2}^{N}=\begin{cases}\pi_{R2}^{0}+\frac{\sigma_u^2(\sigma_\varepsilon+\sigma_\mu)}{(\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu))^2}, & Area\ I\ of\ Figure\ 3.2\\ \pi_{R2}^{0}+\frac{\sigma_u^2(4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, & Areas\ II.a, II.b\ and\ III\ of\ Figure\ 3.2\end{cases},$$

$$\pi_{Ri}^{S}=\pi_{Ri}^{0}+\frac{\sigma_u^2(5\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)},$$

$$\pi_{R1}^{A}=\begin{cases}\pi_{R1}^{0}+\frac{\sigma_u^2(4\sigma_\varepsilon{}^2+(4+\beta^2)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3}, & Areas\ II\ and\ III.a\ of\ Figure\ 3.3\\ \pi_{R1}^{0}+\frac{\sigma_u^2}{(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}, & Area\ III.b\ of\ Figure\ 3.3\end{cases},$$

$$\pi_{R2}^{A}=\pi_{R2}^{0}+\frac{\sigma_u^2((5+4\beta+\beta^2)\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)},$$

$$\pi_{R1}^{A2}=\pi_{R1}^{0}+\frac{\sigma_u^2((5+4\beta+\beta^2)\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)},$$

$$\pi_{R2}^{A2}=\begin{cases}\pi_{R2}^{0}+\frac{\sigma_u^2(4\sigma_\varepsilon^2+(4+\beta^2)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3}, & Areas\ II\ and\ III.a\ of\ Figure\ 3.3\\ \pi_{R2}^{0}+\frac{\sigma_u^2}{(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)}, & Area\ III.b\ of\ Figure\ 3.3\end{cases},$$

When $\sigma_\varepsilon<(\sqrt{2}-1)\sigma_\mu$ & $\beta<\beta_2$, Area II.a of Figure 3.2 and Area III. A of Figure 4.2, $\pi_{R1}^{N}=\pi_{R1}^{0}+\frac{\sigma_u^2(4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}$, $\pi_{R2}^{N}=\pi_{R2}^{0}+\frac{\sigma_u^2(4\sigma_\varepsilon^2+2(2+\beta)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}$, $\pi_{R1}^{A}=\pi_{R1}^{0}+\frac{\sigma_u^2(4\sigma_\varepsilon^2+(4+\beta^2)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3}$, $\pi_{R2}^{A2}=\pi_{R2}^{0}+\frac{\sigma_\mu{}^2(4\sigma_\varepsilon{}^2+(4+\beta^2)\sigma_\varepsilon\sigma_\mu+\sigma_u^2)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)^3}$. In this case, $\pi_{R1}^{N}>\pi_{R1}^{A}$,$\pi_{R1}^{A2}>\pi_{R1}^{S}$, $\pi_{R2}^{N}>\pi_{R2}^{A2}$, $\pi_{R2}^{A}>\pi_{R2}^{S}$.

The equilibrium derivation is as illustrated in Table B.

**Table B. Derivation of NE** ($\sigma_\varepsilon<(\sqrt{2}-1)\sigma_\mu$ & $\beta<\beta_2$)

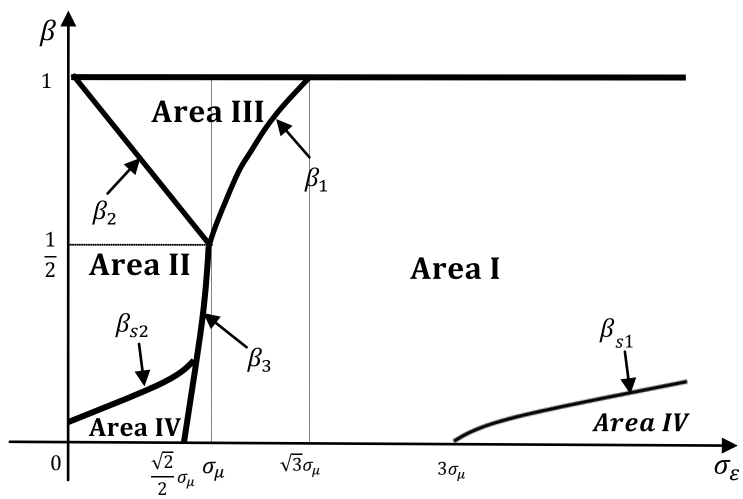
| | R2 discloses signal | R2 doesn't disclose signal |
|---|---|---|

| | | |
|---|---|---|
| R1 discloses signal | $(\pi_{R1}^{S},\pi_{R2}^{S})$ | $(\pi_{R1}^{A},\pi_{R2}^{A})$ |
| R1 doesn't disclose signal | $(\pi_{R1}^{A2},\pi_{R2}^{A2})$ | $(\pi_{R1}^{N},\pi_{R2}^{N})$ |

By Table B, only one pure strategy NE can be sustained when $\sigma_\varepsilon < (\sqrt{2}-1)\sigma_\mu$ & $\beta < \beta_2$. For other cases of $(\sigma_\varepsilon, \beta)$, we can follow a similar procedure to show that "neither retailer discloses signal to the rival" is always the only pure strategy NE when the retailers make unilateral decision on horizontal information sharing. □

**Proof of Theorem 3.2.** Similar to the proof of Theorem 3.1, we can partition the space to sustain information structure under simultaneous signal acquisition, which is showed in Figure B.2.

**Figure B.2. Information structure under simultaneous signal acquisition by the supplier**




$\beta_{s1} = \frac{4\sqrt{5}\sqrt{\sigma_\varepsilon^4+3\sigma_\varepsilon^3\sigma_\mu+2\sigma_\varepsilon^2\sigma_u^2}-2(4\sigma_\varepsilon^2+7\sigma_\varepsilon\sigma_\mu+3\sigma_u^2)}{4\sigma_\varepsilon^2+12\sigma_\varepsilon\sigma_\mu+3\sigma_u^2}$, $\beta_{s2} = Root[f(\beta),3]$, where $f(\beta) = [-8\sigma_\varepsilon^2 - 8\sigma_\varepsilon\sigma_u - 4\sigma\mu^2 + (32\sigma_\varepsilon^2 + 80\sigma_\varepsilon\sigma_u + 52\sigma_u^2)\beta + (8\sigma_\varepsilon^2 + 36\sigma_\varepsilon\sigma_u + 35\sigma_u^2)\beta^2 + (2\sigma_\varepsilon\sigma_u + 4\sigma_u^2)\beta^3$.

Under simultaneous signal acquisition by the supplier, referring to Figure B.2:

1) *Area I: no horizontal information sharing or vertical information acquisition is sustainable.*
2) *Area II: the retailers forfeit horizontal information sharing, but the supplier acquires both signals by simultaneously offering* $m = (p_N^H, p_N^L)$.
3) *Area III: the retailers forfeit horizontal information sharing, but the supplier acquires the signal at a retailer by offering* $m_1 = p_N^H$.
4) *Area IV: the retailers horizontally share information, and the supplier acquires both signals by simultaneously offering* $m = (p_S^H, p_S^L)$.

According to Figure B.2, Table 3.1 and Table 3.2, we have the following ex-ante profits.

$$\pi_S = \begin{cases} \pi_S^0, \ \ Area\ I\ of\ Figure\ B.2 \\ \pi_S^0 + \frac{(1+2\beta)\sigma_u^4 - 2\sigma_\varepsilon^2\sigma_u^2}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, \ \ Area\ II\ of\ Figure\ B.2 \\ \pi_S^0 + \frac{\sigma_u^2((1+2\beta)\sigma_u^2 - \sigma_\varepsilon^2 - 2(1-\beta)\sigma_\varepsilon\sigma_\mu)}{4(\sigma_\varepsilon+\sigma_\mu)(2\sigma_\varepsilon+(2+\beta)\sigma_\mu)^2}, \ Area\ III\ of\ Figure\ B.2 \\ \pi_S^0 + \frac{(1+2\beta)\sigma_u^2}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)}, \ Area\ IV\ of\ Figure\ B.2 \end{cases}.$$

Comparing the supplier's ex-ante profits in Figure 3.5 (sequential information acquisition) with their counterparts in Figure B.2 (simultaneous information acquisition), we can show that the supplier would prefer to commit to simultaneous signal acquisition in the two area SS of Figure 3.6, but still prefer sequential information acquisition in the other situations. Hence the claim. □

# Appendix C. Proofs for Chapter 4

We first derive the operation subgame equilibrium without horizontal information sharing, for given $(n_1, n_2)$. If $(n_1, n_2) = (0,0)$, we focus on $q_i(x_i)$ in the form of $q_i(x_i) = q_{i0} + q_{i1}x_i, i = 1,2$. The objective functions of the retailers are given in (3-2). The results are the same as those of Chapter 3.

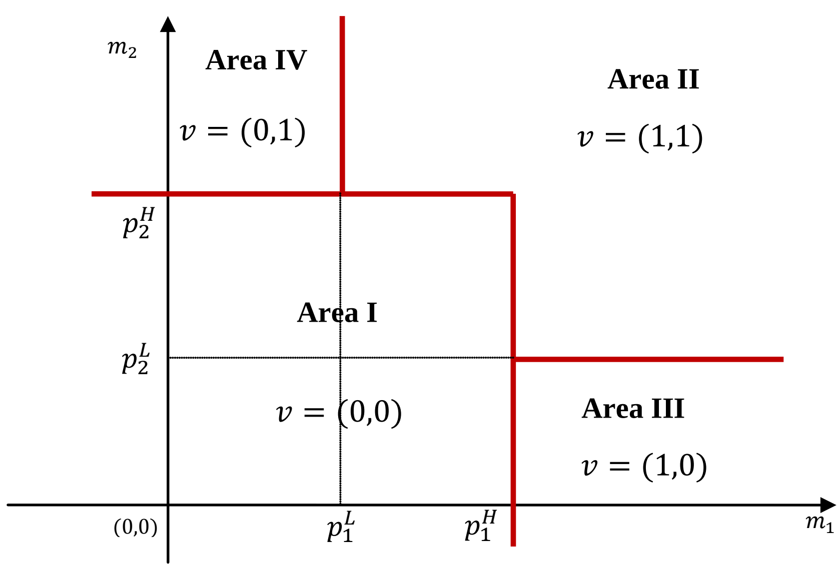
We can follow similar procedures to establish the equilibrium outcomes for the other three cases. When $(n_1, n_2) = (1,1)$, bilateral indirect signal divulgence will occur and the profit of retailer $i$ is given in (3-3). We focus on $q_i(x_1, x_2)$ in the form of $q_i(x_1, x_2) = q_{i0} + q_{i1}x_1 + q_{i2}x_2, i = 1,2$. When $(n_i, n_{3-i}) = (1,0)$, unilateral indirect signal divulgence will occur and the profit of retailer $i$ will be as given in (3-2), while the profit of its competitor will take the form of (3-3). We then focus on $q_i(x_i) = q_{i0} + q_{i1}x_{\mathrm{i}}$, $q_{3-i}(x_1, x_2) = q_{3-i,0} + q_{3-i,1}x_1 + q_{3-i,2}x_2$.

Following the similar procedure, we can get the operation subgame equilibria when the retailers mutually disclose signals, and when only retailer $i$ horizontally discloses signal to the other retailer but not vice versa, which are showed in Table 4.1, 4.2, and 4.3.

□

According to Table 4.1, Table 4.2 and Table 4.3, we characterize the status of vertical signal disclosure under simultaneous signal acquisition, as illustrated in Figure C.

**Figure C. Vertical signal disclosure under simultaneous signal acquisition**



If the retailers forfeit horizontal information sharing, then $p_i^L = p_N^L, p_i^H = p_N^H, i = 1,2$. When the retailers mutually disclosure signals, $p_i^L = p_S^L, p_i^H = p_S^H, i = 1,2$. When only retailer 1 discloses signal to retailer 2, $p_1^L = p_{A1}^L, p_1^H = p_{A1}^H, p_2^L = p_{A2}^L, p_2^H = \frac{\sigma_u^2((3+4\beta+\beta^2)\sigma_\varepsilon+6\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}$. □

**Proof of Proposition 4.1.** 1) By Table 4.1, the supplier's ex-ante profit under simultaneous signal acquisition in areas I – IV of Figure C are:

$$\Pi_S^I = \pi_S^{(0,0)},\ \Pi_S^{II} = \pi_S^{(0,0)} + \frac{\sigma_\mu{}^2}{(2+\beta)(\sigma_\varepsilon+2\sigma_\mu)} - p_N^L - p_N^H,\ \Pi_S^{III} = \Pi_S^{IV} = \pi_S^{(0,0)} + \frac{\sigma_\mu{}^2}{2(2+\beta)(\sigma_\varepsilon+\sigma_\mu)} - p_N^H.$$

Comparing these profits, we have $\Pi_S^{III} = \Pi_S^{IV}$; and if $\beta > \beta_0$, $\Pi_S^{II} < \Pi_S^I$ and $\Pi_S^{III} < \Pi_S^I$; else if $\beta < \sqrt{2} - 1$, $\Pi_S^I < \Pi_S^{II}$ and $\Pi_S^{III} < \Pi_S^{II}$; else, $\Pi_S^I < \Pi_S^{III}$ and $\Pi_S^{II} < \Pi_S^{III}$. Hence the claim.

2) Under sequential signal acquisition, we solve the problem backwards.

Given $n_1, m_2$, retailer 2 decides whether to disclose its signal to the supplier. We find that, when $n_1 = 0$, $n_2 = 1$ if $m_2 \geq p_N^H$ by comparing $\pi_{R2}^{(0,0)}$ and $\pi_{R2}^{(0,1)} + m_2$; and when $n_1 = 1$, $n_2 = 1$ if $m_2 \geq p_N^L$ by comparing $\pi_{R2}^{(1,0)}$ and $\pi_{R2}^{(1,1)} + m_2$.

The supplier deduces retailer 2's decision and chooses $m_2$. If $n_1 = 0$, by comparing $\pi_S^{(0,0)}$ and $\pi_S^{(0,1)} - m_2(m_2 \geq p_N^H)$, we get $m_2 = p_N^H$ if $(\sigma_\varepsilon \leq \sigma_{\varepsilon 0}) or (\sigma_\varepsilon > \sigma_{\varepsilon 0} \& \beta \leq \beta_0)$, and $n_2 = 1$ in this case; otherwise, no information acquisition occurs between the supplier and retailer 2. If $n_1 = 1$, by comparing $\pi_S^{(1,0)}$ and $\pi_S^{(1,1)} - m_2(m_2 \geq p_N^L)$, we get $m_2 = p_N^L$ if $\beta \leq \sqrt{2} - 1$, and $n_2 = 1$; otherwise, no information acquisition occurs between the supplier and retailer 2.

To derive retailer 1's decision on signal disclosure, we first consider the case when $\sigma_\varepsilon \leq \sigma_{\varepsilon 0}$.

Given $m_1$, retailer 1 deduces $(m_2, n_2)$ and decides whether to disclose signal. When $n_1 = 0$, $(m_2, n_2) = (p_N^H, 1)$; when $n_1 = 1$, $(m_2, n_2) = \begin{cases} (p_N^L, 1), & if\ \beta \leq \sqrt{2} - 1 \\ (-\infty, 0), & else \end{cases}$. If $\beta \leq \sqrt{2} - 1$, we can show that $n_1 = 1$ if $m_1 \geq p_N^L$ by comparing $\pi_{R1}^{(0,1)}$and $\pi_{R1}^{(1,1)} + m_1$. Else if $\beta > \sqrt{2} - 1$, we can show that $n_1 = 1$ if $m_1 \geq p_1$ by comparing $\pi_{R1}^{(0,1)}$and $\pi_{R1}^{(1,0)} + m_1$.

Then we consider the supplier's decision when $\sigma_\varepsilon \leq \sigma_{\varepsilon 0}$. If $\beta \leq \sqrt{2} - 1$, by comparing $\pi_S^{(0,1)} - m_2(m_2 = p_N^H)$ and $\pi_S^{(1,1)} - m_1 - m_2(m_1 \geq p_N^L, m_2 = p_N^L)$, we find that $m_1 = p_N^L$, thus $n_1 = 1$, and $(m_2, n_2) = (p_N^L, 1)$. If $\beta > \sqrt{2} - 1$, by comparing $\pi_S^{(0,1)} - m_2(m_2 = p_N^H)$ and $\pi_S^{(1,0)} - m_1(m_1 \geq p_1)$, we have $m_1 = p_1$, thus $n_1 = 1$, and $(m_2, n_2) = (-\infty, 0)$.

When $\sigma_\varepsilon \geq \sigma_{\varepsilon 0}$, we can follow a similar procedure to derive the outcomes.

Combining all the outcomes, we can establish part 2) of Proposition 4.1. □

**Proof of Proposition 4.2.** By part 2 of Proposition 1, Proposition 2 can be proved by comparing the expected ex-ante profits of the supplier and the retailers. Take area I for instance. In area I ($\beta \leq \sqrt{2} - 1$), $(m_1, m_2) = (p_N^L, p_N^L)$ and $(n_1, n_2) = (1,1)$. We find $\pi_S^{(1,1)} - 2p_N^L > \pi_S^{(0,0)}$, and $\pi_{Ri}^{(1,1)} + p_N^L > \pi_{Ri}^{(0,0)}$ if $\left(6\sigma_\mu < \sigma_\varepsilon \leq \sigma_{\varepsilon 1} \&\& \beta < \beta_1\right) or\ (\sigma_\varepsilon > \sigma_{\varepsilon 1} \&\& \beta \leq \sqrt{2} - 1)$. We can follow a similar procedure to establish the results for area II. □

**Proof of Proposition 4.3.** By Table 4.2 and Figure C, we can follow a similar procedure as that in the proof for Proposition 4.1 to establish the results. □

**Proof of Proposition 4.4.** By part 2 of Proposition 4.3, $\pi_S^{(1,1)} - 2p_S^L > \pi_S^{(0,0)}$, and $\pi_{Ri}^{(1,1)} + p_S^L < \pi_{Ri}^{(0,0)}$. □

**Proof of Proposition 4.5.** By Table 4.3 and Figure C, we can follow a similar procedure as that in the proof for part 1 of Proposition 4.1 to establish the results. □

**Proof of Lemma 4.1.** By Table 4.3, the process is similar to the proof of part 2) of Proposition 4.1.□

**Proof of Proposition 4.6.** Given only retailer 1 discloses signal to the rival, according to Lemma 4.1, when $\sigma_\varepsilon \leq 3\sigma_\mu$ and $\beta \leq \sqrt{2} - 1$, the supplier will always offer $(m_1, m_2) = (p_{A1}^L, p_{A2}^L)$ to gain access to both signals regardless of the sequence.

When $\sigma_\varepsilon \leq 3\sigma_\mu$ and $\beta > \sqrt{2} - 1$, the supplier will offer $m_1 = p_2$ to gain access to retailer 1's signal only if it first approaches retailer 1 for signal access; for otherwise it will offer $(m_1, m_2) = (p_{A1}^L, p_{A2}^L)$ to gain access to both signals if it first approaches retailer 2. We find that $\pi_S^{(1,0)} - p_2 > \pi_S^{(1,1)} - p_{A1}^L - p_{A2}^L$ if $\beta > \sqrt{3} - 1$, which means that the supplier will first and only approach retailer 1 for signal access when $\sigma_\varepsilon \leq 3\sigma_\mu$ and $\beta > \sqrt{3} - 1$, or first approach retailer 2 to access both signals when $\sigma_\varepsilon \leq 3\sigma_\mu$ and $\sqrt{2} - 1 < \beta \leq \sqrt{3} - 1$.

When $\sigma_\varepsilon \geq 3\sigma_\mu$, we can follow a similar procedure to derive the outcomes. Combining all possible outcomes, we can establish Proposition 4.6. □

**Proof of Proposition 4.7.** Take area I for instance. In area I, $(m_1, m_2) = (p_{A1}^L, p_{A2}^L)$ and $(n_1, n_2) = (1,1)$. We find $\pi_S^{(1,1)} - p_{A1}^L - p_{A2}^L > \pi_S^{(0,0)}$, $\pi_{R2}^{(1,1)} + p_{A2}^L > \pi_{R2}^{(0,0)}$, and $\pi_{R1}^{(1,1)} + p_{A1}^L > \pi_{R1}^{(0,0)}$if $\left(\sigma_\varepsilon > 6\sigma_\mu \&\& \beta < \beta_3\right)$. We can follow a similar procedure to establish the results for area II. □

**Proof of Proposition 4.8.** We analyze the retailers' decision on information sharing by comparing their ex-ante expected profits without information sharing, with bilateral information sharing, and with unilateral information sharing, taking into consideration the supplier's signal acquisition. We use the subscript $Rs$ and superscript $N(S, A)$ on the relevant profits, with $Rs$ for "the two retailers", $N$ for "no information sharing", $S$ for "with bilateral information sharing", and $A$ for "with unilateral information sharing (only retailer 1 discloses signal to retailer 2)". Based on part 2) of Proposition 4.1 and Proposition 4.3, Proposition 4.6, and Table 4.1, 4.2, 4.3, we have the following ex-ante profits inclusive of the incentive payments of the two retailers:

$$\Pi_{R1}^{N} = \begin{cases} \pi_{R1}^{0} + \frac{\sigma_{u}^{2}}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)} + p_{N}^{L}, & Area\ I\ in\ Figure\ 4.1 \\ \pi_{R1}^{0} + \frac{{\sigma_\mu}^{2}}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)} + p_{1}, & Areas\ II.a\ in\ Figure\ 4.1 \\ \pi_{R1}^{0} + \frac{{\sigma_\mu}^{2}((5+4\beta+\beta^2)\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}, & Areas\ II.b\ in\ Figure\ 4.1 \\ \pi_{R1}^{0} + \frac{\sigma_{u}^{2}(\sigma_\varepsilon+\sigma_\mu)}{[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}, & Areas\ III\ in\ Figure\ 4.1 \end{cases},$$

$$\Pi_{R2}^{N} = \begin{cases} \pi_{R2}^{0} + \frac{\sigma_{u}^{2}}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)} + p_{N}^{L}, & Area\ I\ in\ Figure\ 4.1 \\ \pi_{R2}^{0} + \frac{{\sigma_\mu}^{2}((5+4\beta+\beta^2)\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}, & Areas\ II.a\ in\ Figure\ 4.1 \\ \pi_{R2}^{0} + \frac{{\sigma_\mu}^{2}}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)} + p_{N}^{H}, & Areas\ II.b\ in\ Figure\ 4.1 \\ \pi_{R2}^{0} + \frac{\sigma_{u}^{2}(\sigma_\varepsilon+\sigma_\mu)}{[\beta\sigma_\mu+2(\sigma_\varepsilon+\sigma_\mu)]^2}, & Areas\ III\ in\ Figure\ 4.1 \end{cases},$$

$$\Pi_{Ri}^{S} = \pi_{Ri}^{0} + \frac{\sigma_{\mu}^{2}}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)} + p_{S}^{L},$$

$$\Pi_{R1}^{A} = \begin{cases} \pi_{R1}^{0} + \frac{\sigma_{\mu}^{2}}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)} + p_{A1}^{L}, & Areas\ I\ in\ Figure\ 4.2 \\ \pi_{R1}^{0} + \frac{\sigma_{\mu}^{2}}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)} + p_{2}, & Area\ II.a\ in\ Figure\ 4.2 \\ \pi_{R1}^{0} + \frac{\sigma_{\mu}^{2}}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)} + p_{A1}^{H}, & Area\ II.b\ in\ Figure\ 4.2 \end{cases},$$

$$\Pi_{R2}^{A} = \begin{cases} \pi_{R2}^{0} + \frac{\sigma_{\mu}^{2}}{2(2+\beta)^2(\sigma_\varepsilon+2\sigma_\mu)} + p_{A2}^{L}, & Areas\ I\ in\ Figure\ 4.2 \\ \pi_{R2}^{0} + \frac{\sigma_{\mu}^{2}((5+4\beta+\beta^2)\sigma_\varepsilon+2\sigma_\mu)}{4(2+\beta)^2(\sigma_\varepsilon+\sigma_\mu)(\sigma_\varepsilon+2\sigma_\mu)}, & Area\ II\ in\ Figure\ 4.2 \end{cases},$$

$$\Pi_{Rs}^{N} = \Pi_{R1}^{N} + \Pi_{R2}^{N},\ \Pi_{Rs}^{S} = \Pi_{R1}^{S} + \Pi_{R2}^{S},\ \Pi_{Rs}^{A} = \Pi_{R1}^{A} + \Pi_{R2}^{A}.$$

If the retailers make a cooperative decision to engage in horizontal information sharing, they should share information with each other if $\Pi_{Rs}^{S} > \Pi_{Rs}^{N}$ and $\Pi_{Rs}^{S} > \Pi_{Rs}^{A}$, or only one retailer should disclose its signal to the rival if $\Pi_{Rs}^{A} > \Pi_{Rs}^{N}$ and $\Pi_{Rs}^{A} > \Pi_{Rs}^{S}$. We find that $\Pi_{Rs}^{N} \geq \Pi_{Rs}^{S}$ and $\Pi_{Rs}^{N} \geq \Pi_{Rs}^{A}$ always hold. Thus neither retailer will disclose signal to the rival when they make a cooperative decision.

If the retailers competitively manage their interactions, we use Nash analysis to derive the result. We use superscript $B$ on the relevant profits, with $B$ for "unilateral information sharing (only retailer 2 discloses signal to retailer 1)". The result of case B is symmetric with that of case A. Thus,

$$\Pi_{R1}^{B} = \begin{cases} \pi_{R1}^{0} + \frac{\sigma_{\mu}^{2}}{2(2+\beta)^{2}(\sigma_{\varepsilon}+2\sigma_{\mu})} + p_{A2}^{L}, & Areas\ I\ in\ Figure\ 4.2 \\ \pi_{R1}^{0} + \frac{\sigma_{\mu}^{2}((5+4\beta+\beta^{2})\sigma_{\varepsilon}+2\sigma_{\mu})}{4(2+\beta)^{2}(\sigma_{\varepsilon}+\sigma_{\mu})(\sigma_{\varepsilon}+2\sigma_{\mu})}, & Area\ II\ in\ Figure\ 4.2 \end{cases},$$

$$\Pi_{R2}^{B} = \begin{cases} \pi_{R2}^{0} + \frac{\sigma_{\mu}^{2}}{2(2+\beta)^{2}(\sigma_{\varepsilon}+2\sigma_{\mu})} + p_{A1}^{L}, & Areas\ I\ in\ Figure\ 4.2 \\ \pi_{R2}^{0} + \frac{\sigma_{\mu}^{2}}{4(2+\beta)^{2}(\sigma_{\varepsilon}+\sigma_{\mu})} + p_{2}, & Area\ II.a\ in\ Figure\ 4.2 \\ \pi_{R2}^{0} + \frac{\sigma_{\mu}^{2}}{4(2+\beta)^{2}(\sigma_{\varepsilon}+\sigma_{\mu})} + p_{A1}^{H}, & Area\ II.b\ in\ Figure\ 4.2 \end{cases}.$$

When $\beta \leq \sqrt{2} - 1$, according to the results of area I in Figure 4.1 and area I in Figure 4.2, $\Pi_{Ri}^{N} = \pi_{Ri}^{0} + \frac{\sigma_{u}^{2}}{2(2+\beta)^{2}(\sigma_{\varepsilon}+2\sigma_{\mu})} + p_{N}^{L}$, $\Pi_{R1}^{A} = \pi_{R1}^{0} + \frac{\sigma_{\mu}^{2}}{2(2+\beta)^{2}(\sigma_{\varepsilon}+2\sigma_{\mu})} + p_{A1}^{L}$, $\Pi_{R1}^{B} = \pi_{R1}^{0} + \frac{\sigma_{\mu}^{2}}{2(2+\beta)^{2}(\sigma_{\varepsilon}+2\sigma_{\mu})} + p_{A2}^{L}$, $\Pi_{R2}^{B} = \pi_{R2}^{0} + \frac{\sigma_{\mu}^{2}}{2(2+\beta)^{2}(\sigma_{\varepsilon}+2\sigma_{\mu})} + p_{A1}^{L}$, $\Pi_{R2}^{A} = \pi_{R2}^{0} + \frac{\sigma_{\mu}^{2}}{2(2+\beta)^{2}(\sigma_{\varepsilon}+2\sigma_{\mu})} + p_{A2}^{L}$. In this case, $\Pi_{R1}^{N} > \Pi_{R1}^{A}$,$\Pi_{R1}^{B} > \Pi_{R1}^{S}$, $\Pi_{R2}^{N} > \Pi_{R2}^{B}$, $\Pi_{R2}^{A} > \Pi_{R2}^{S}$.

**Table C. Derivation of NE** ($\beta \leq \sqrt{2} - 1$)

| | R2 discloses signal | R2 doesn't disclose signal |
|---|---|---|
| R1 discloses signal | ($\Pi_{R1}^{S}$,$\Pi_{R2}^{S}$) | ($\Pi_{R1}^{A}$,$\underline{\Pi_{R2}^{A}}$) |
| R1 doesn't disclose signal | ($\underline{\Pi_{R1}^{B}}$,$\Pi_{R2}^{B}$) | ($\underline{\Pi_{R1}^{N}}$,$\underline{\Pi_{R2}^{N}}$) |

The equilibrium derivation is as illustrated in Table C. By Table C, only one pure strategy NE can be sustained when $\beta \leq \sqrt{2} - 1$. For other situations of $(\sigma_{\varepsilon}, \beta)$, we can follow a similar procedure to show that "neither retailer discloses signal to the rival" is always the only pure strategy NE when the retailers make unilateral decision on horizontal information sharing. Hence the claim. □

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