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Rationalizing vertical information flow in a bilateral monopoly

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ABSTRACT

We investigate vertical information sharing in a bilateral monopoly. The retailer orders from the supplier and sells in a market with uncertain demand. The retailer has access to a series of correlated demand signals and the supplier can offer payments to acquire signals from the retailer. We establish the sufficient condition to sustain vertical information flow, and examine the implications of information transaction procedure for system performance.

1. Introduction

Real-time market information visibility throughout a supply chain can effectively align the production and delivery activities among channel parties to improve their profit performance and customer service. The downstream retailers, due to their market proximity and heavy investments in IT systems, usually have access to such data as intraday in-store sales, pre-order sales data and basket data, and utilize this data in responsive decision making. The retailers' data can be made accessible to suppliers via vertical information sharing. Since the turn of this century, retailer-direct data exchange has risen as an important mode of data communication. Under this mode, a retailer provides its own data and determines the actions in response to the information from the data. Retailers may hesitate to disclose their data as they perceive insufficient efforts by suppliers in IT investment or have a trust gap about the suppliers using the data to "*put one over us*" (see [2]). As a remedy, retailers can require suppliers to pay for signals, or suppliers can offer retailers payments as incentives to disclose their signals. As noted in an article in The Guardian, vendors are willing to pay "*a lot of*" money to supermarkets for their customer information that is kept out of the third parties (see [3]).

In this paper, we investigate vertical information sharing in a setting in which a retailer orders a product from a supplier and sells the product in a market with uncertain demand. The supplier incurs a linear production cost and its relationship with the retailer is governed by a price-only contract. The retailer has access to a series of unbiased demand signals that are useful in responsive decision making, and the supplier can gain access to the retailer's signals through information transaction that can follow one of two alternative procedures. Under supplier-initiated transaction, the supplier first offers a signal price to the retailer who then chooses the number of signals to disclose. Under retailer-initiated transaction, the retailer first posts a signal price and the supplier then decides on the number of signals to acquire. We show that information transaction will occur if the retailer has a sufficiently large number of weakly correlated signals and, under certain circumstance, the retailer is willing to pay the supplier to acquire its signals. Once information transaction occurs, the supplier solicits all signals if it initiates the transaction, but solicits part of the signals if the retailer initiates the transaction. System profit is higher under supplier-initiated transaction, but consumers are better off under retailer-initiated transaction.

Incentive-driven vertical information sharing in supply chains between upstream parties without market access and downstream parties with market access has aroused the interests in the Economics and OM areas. Most of the existing literature precludes this form of information flow as a sustainable strategic move under such assumptions as linear production costs at the suppliers and price-only contracts that govern the vertical relationships. Please refer to [1] for a review. The standard setting consists of an upstream player and multiple downstream players who each have access to one demand signal. [8] considers a manufacturer selling to multiple retailers with demand information and reveals two effects that arise from vertical information sharing, namely the direct effect and the leakage effect. Under the leakage effect, one retailer is hurt when other retailers learn its information by inferring

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it from the manufacturer's adjusted operations decisions. In a bilateral monopoly, as modeled in our paper, the leakage effect is nonexistent, but the direct effect is in force to enhance the supplier's responsiveness in wholesale pricing but affect the retailer's flexibility in ordering. When the retailer has access to one signal, the direct effect of information sharing will make the supplier better off but the retailer worse off, and cause system profit to decrease. When the retailer has access to multiple signals, however, we show that this effect can improve system profit as the supplier gains access to at least some of the signals through information transaction.

[11] studies information sharing between a firm and two competing retailers that each have access to one signal. It is shown that the firm benefits from having access to more signals but the retailers are at a disadvantageous position after disclosing their signals. A statement is that information trading involving all retailers occurs if it increases supply chain profit. In a bilateral monopoly, we provide the sufficient condition for system profit to improve with vertical information flow and hence to sustain this form of information sharing. [9] considers a supplier selling to multiple retailers that compete in price under three scenarios regarding the extent to which retailers learn the signals at one another by various means, and shows that with confidentiality, all retailers can have the incentives to share information with the supplier. In a bilateral monopoly, confidentiality is not an issue and plays no role in sustaining information sharing. [6] shows that a large production diseconomy at the supplier is able to make vertical information sharing improve system profit. In our setting, the supplier incurs linear production cost, which is inconsequential in offsetting the direct effect that arises from vertical information sharing. [5] shows that, in a setting of two chains each consisting of a supplier and a retailer that has access to the true demand information, vertical information sharing will hurt supply chain profit if price-only contracts are used. Though vertical channel relationship is still governed by a price-only contract in our setting, we exclude chain competition and have the retailer disclose its signals instead of the true demand information.

Vertical information sharing is a common phenomenon but has not been well established in the existing literature. As an attempt to bridge this gap, we include practical features, such as multiple signal availability to the retailer and incentive payment by the supplier for signal acquisition, into an otherwise standard investigating framework, and produce new insights into the sustainability of vertical information sharing, with its implications for system performance.

2. The model

Consider a supply chain consisting of a supplier and a retailer. This approximates the practical situation in which the supplier and retailer hold monopolist power in their respective markets. In this bilateral monopoly, the supplier produces at a marginal cost of c and sells at a wholesale price of w to the retailer, who then sells in a market with uncertain demand. We define the inverse demand function as:

$$p = a + \mu - q, \tag{1}$$

where $a >$ represents the market potential, q is the quantity, and p the market cleaning price. μ captures the uncertainty in the general market condition. The prior distribution of μ is normal with mean zero and variance σ.

The retailer has access to a series of signals for μ. These signals can be POS data, pre-order sales data, basket data etc., and can be utilized in responsive decision making. We denote the full set of signals available to the retailer as $s = (x_1, x_2, \ldots, x_N)$, where $N \geq 1$ is the cardinality of s, and assume that s is multivariate normal. The supplier and retailer ex-ante sign an information agreement, which grants the supplier access to the signals at the retailer for a unit price of m. In reality, under retailer-direct exchange mode, the supplier can acquire multiple signals in a single transaction and, as anecdotal evidence shows, can simply pay the retailer to "*burn data on a CD and pass it back*" (see [2]). Let $\hat{s} = (x_1, x_2, \ldots, x_n)$, where $0 \leq n \leq N$ is the cardinality of $\hat{s}$, be the set of signals acquired by the supplier. $(s, \hat{s})$ indicates the information agreement.

We make the following assumptions about signal structure. Signal $x_i = \mu_i + \varepsilon_i, i = 1, \ldots, N$, where $\mu_i \sim N(0, \sigma_\mu)$, $\varepsilon_i \sim N(0, \sigma_\varepsilon)$, $Cov(\mu_i, \varepsilon_j) = 0$, $\forall i, j = 1, 2, \ldots, N$; $Cov\left(\mu_i, \mu_j\right) = h \in (0, \sigma_\mu)$, $i \neq j$; $Cov\left(\varepsilon_i, \varepsilon_j\right) = \rho \in (0, \sigma_\varepsilon)$, $i \neq j$. $\mu = \frac{\sum_{i=1}^N \mu_i}{N}$, and hence $\sigma = \frac{\sigma_\mu + (N-1)h}{N}$. The N signals are collected from different sources, and h reflects their correlation that cannot exceed σ_μ when the signals have equal variance and positive correlation. ε_i's are signal noises and positively correlated. These assumptions are in line with those in [4] except that noise variations are positively correlated.

The conditional expectations and the results in Lemma 1 are useful for our subsequent analysis. All proofs are relegated to an online Appendix A. $E(\mu|s)$ is the retailer's expectation of market uncertainty μ, conditional on all observed signals, while $E\left(E(\mu|s)\,|\hat{s}\right)$ is the supplier's expectation of μ, conditional on its acquired signals. $E(\mu M)$, $E\left(\mu \hat{M}(n)\right)$, $E\left(M^2\right)$, $E\left(\hat{M}(n)^2\right)$, and $E\left(M\hat{M}(n)\right)$ are needed in expressing the expected ex-ante profits of the supplier and retailer under given transaction agreement.

Lemma 1. *Given full signal set s and transacted signal set $\hat{s}$, we have:*

(1) $E(\mu|s) = M$, *where* $M = \frac{\sigma_\mu}{\sigma_\mu + \sigma_\varepsilon} \frac{\sum_{i=1}^N x_i}{N}$.

(2) $E\left(E(\mu|s)\,|\hat{s}\right) = \hat{M}(n)$, *where*
$$\hat{M}(n) = \frac{\sigma_\mu}{\sigma_\mu + \sigma_\varepsilon} \cdot \frac{n(\sigma_\mu + \sigma_\varepsilon) + n(N-1)(h+\rho)}{N(\sigma_\mu + \sigma_\varepsilon) + N(n-1)(h+\rho)} \cdot \frac{\sum_{i=1}^n x_i}{n}.$$

(3) $E(\mu M) = \frac{\sigma_\mu}{\sigma_\mu + \sigma_\varepsilon} \frac{\sigma_\mu + (N-1)h}{N}$,
$$E\left(\mu \hat{M}(n)\right) = \frac{n\sigma_\mu[\sigma_\mu + \sigma_\varepsilon + (N-1)(h+\rho)][\sigma_\mu + (N-1)h]}{N^2(\sigma_\mu + \sigma_\varepsilon)[\sigma_\mu + \sigma_\varepsilon + (n-1)(h+\rho)]},$$
$$E\left(M^2\right) = \frac{\sigma_u^2}{\left(\sigma_\mu + \sigma_\varepsilon\right)^2} \frac{\sigma_\mu + \sigma_\varepsilon + (N-1)(h+\rho)}{N},$$
$$E\left(M\hat{M}(n)\right) = E\left(\hat{M}(n)^2\right) = \frac{n\sigma_u^2\left[\sigma_\mu + \sigma_\varepsilon + (N-1)(h+\rho)\right]^2}{N^2\left(\sigma_\mu + \sigma_\varepsilon\right)^2\left[\sigma_\mu + \sigma_\varepsilon + (n-1)(h+\rho)\right]}.$$

Fig. 1 illustrates the applicable decision sequence that consists of an ex-ante information transaction subgame and an ex-post operations subgame. We examine two procedures for information transaction to determine the signal price and the number of transmitted signals. Under supplier-initiated transaction (SL transaction, for short), the supplier first offers a signal price and the retailer then chooses the number of signals to disclose. Under retailer-initiated transaction (RL transaction, for short), the retailer first announces a signal price and the supplier then chooses the number of signals to acquire. The information agreement is signed before the signals are observed. After receiving the signals, the retailer discloses them to the supplier as per the information agreement. Suppose the agreement stipulates that the retailer discloses n out of the N signals to the supplier. Since the signals are of identical statistical value, the retailer can randomly pick n signals and pass them to the supplier. With the signals available for use, the supplier sets a wholesale price and the retailer then chooses an order quantity. Finally, full market uncertainty is revealed, market price is cleared and revenues accrue to channel parties.

We assume the retailer will truthfully disclose its signals according to the information agreement, and reflect them in order decisions; otherwise the information agreement will be nullified. [6] and [11] explicitly make this assumption in their