Optimal Pricing with Vertical Information Exchange under Upstream Competition

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***Abstract*—This paper studies firms' pricing strategies in a supply chain in which two manufacturers sell substitutable products to a common retailer. Each firm has access to a signal about the uncertain demand. The manufacturers make the wholesale price decisions, and subsequently the retailer makes the retail price decision. If a manufacturer and the retailer exchange their demand signals with each other, their channel is communicative, and is non-communicative otherwise. As the retailer may infer a manufacturer's demand signal through his wholesale price even if their channel is non-communicative, the vertical information exchange can alter firms pricing strategies. We consider three informational scenarios, both channels communicative, exactly one channel communicative, and both channels non-communicative. We fully characterize the optimal prices in each scenario and then compare them. The more number of communicative channels, the higher the expected wholesale price. We show that vertical information exchange is always beneficial to the manufacturer but may be harmful to the retailer.**

***Index Terms*—information sharing, Supply chain, Upstream competition, Bilateral information exchange**

I. Introduction

The demand uncertainty is a salient feature of markets in many industries like fashion products. The mismatch between supply and demand is a core issue of firms to strategize their operations and marketing. Such mismatch issue is amplified across a supply chain due to information asymmetry. Furthermore, manufacturers and retailers may have different kinds of demand information. Retailers have point-of-sale (POS) data, while manufacturers often have better understanding about the national trends, consumer motivations, and demographic patterns [1]. Consequently, various tools/technologies are developed to accurately forecast demand and to exchange data in supply chains, e.g., Electronic Data Interchange (EDI) and Multi-Enterprise Demand Sensing software (MDS). Vertical information exchange becomes prevalent in practical supply chain management. More and more manufacturers, like Kraft, Procter & Gamble, and Warner-Lambert, encourage downstream retailers to get involved in their decision-making process, through information sharing [2]. However, it is unclear how vertical information exchange impacts firms pricing strategies. On the other hand, with the globalization, competition pressures are noticeably exerted onto manufacturing companies. It is also unclear how the manufacturer-level competition impacts supply chain firms' pricing strategies.

This paper considers a two-tier supply chain where two competing manufacturers sell substitutable products to a common retailer. Each firm has access to a signal about the uncertain demand. We call a channel (consisting of one manufacturer and the retailer) is communicative if a manufacturer and the retailer exchange their demand signals, and non-communicative otherwise. There are three vertical information exchange scenarios: both channels communicative, exactly one channel communicative, and both channel non-communicative. Two manufacturers simultaneously determine the wholesale prices based on their demand signals. After that, the retailer determines retail prices. The model differs from the classic models in two ways. First, the retailer can make rational inferences about a manufacturer's private information from his wholesale price, even if their channel is non-communicative. Second, the upstream competition together with the information asymmetry may alter the pricing incentives.

This paper fully characterizes the optimal prices set by the manufacturers and the retailer. We find that vertical information exchange is always beneficial to the manufacturer but may be harmful to the retailer. The more number of communicative channels, the higher the expected wholesale price. In fact, no information exchange will increase retailer's rational expectation over the market demand, and hence will drive down the wholesale prices due to upstream competition. Information barriers (non-communication) in the rival channel can lower a non-communicative channel's expected wholesale price, if the competition is not intense.

II. Literature Review

This study is related to the literature about vertical information sharing under different supply chain structures. Most extant studies consider information sharing in a one-to-many supply chain with downstream competition. Representative papers include Li [3], and Li and Zhang [4]. Several papers consider intra-channel information sharing under chain-to-chain competition [5]. He et al. [6] study information sharing when both the manufacturer and the retailer have private demand

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information without considering the rational inference. This paper studies pricing strategies in different informational scenarios.

There is a stream of research studying signaling or inference such that a less-informed firm can infer a better-informed firm's information through the latter's action. Pioneer work like Spence [7]. In the supply chain setting, Gal-Or et al. [8] and Jiang et al. [9] identify the inference effect that leads to price distortions under information asymmetry with downstream competition. Our paper, in contrast, considers the manufacturer-level upstream competition.

This paper is also related to the literature on upstream competition in a supply chain. Ha et al. [10] study incentives for information sharing from a retailer to upstream manufacturers under production diseconomy and economy. Ha et al. [11] consider manufacturer rebate competition and show that more intense competition could benefit the manufacturers and hurt the retailer. In contrast, our paper focuses on the pricing issue with consideration of upstream competition, highlighting the impact of information exchange arrangement.

III. The Model

Consider a supply chain consisting of two manufacturers (indexed by $i, j = 1, 2$ and $i \neq j$) and one retailer (indexed by r). The manufacturers sell substitutable products through a common retailer to a market characterized by demand uncertainty. Each firm observes a signal about the demand. Each manufacturer i offers a wholesale price w_i to the retailer. The retailer sets retail prices p_1 and p_2 of the two products, respectively. Assume that the marginal costs for the manufacturers and the retailer are zero and all firms are risk neutral (e.g. [8]). For convenience, we refer to the retailer as she and a manufacturer as he.

The demand function of product i takes the following form, directly derived from Singh and Vives [12],

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

where p_i and q_i are respectively the retail price or quantity of product i . $\gamma \in (0,1)$ is a parameter for competition intensity and larger means greater competition intensity. The demand intercept $a+\theta$ represents the market potential, where is a constant and θ is a random variable with mean zero and standard deviation σ . Assume $a \geq \sigma$, so that the probability of negative demand intercept is negligible (e.g. [11]).

The signal observed by the retailer is Y_r and by manufacturer i is Y_i . All signals are unbiased estimators of θ . We assume linear-expectation information structure: the expectation of θ conditional on the signal(s) is a linear function of the signal(s), and the signals are independent conditional on θ . This information structure has been commonly used in the information sharing literature (e.g. Li 2002, Li and Zhang 2008) and includes well-known prior-posterior conjugate pairs like normal-normal, beta-binomial, and gamma-Poisson. Assume that two manufacturers has the same signal accuracy and define it as $t_m = \frac{Var[\theta]}{E[Var(Y_i \mid \theta)]}$. Similarly the retailer's signal accuracy is defined as $t_r = \frac{Var[\theta]}{E[Var(Y_r \mid \theta)]}$. It can be shown (Ericson 1969) that,

$$E[\theta \mid Y_i] = E[Y_j \mid Y_i] = E[Y_r \mid Y_i] = \frac{t_m}{1+t_m} Y_i$$

$$E[\theta \mid Y_i, Y_r] = E[Y_j \mid Y_i, Y_r] = \frac{t_m Y_i + t_r Y_r}{t_m + t_r}$$

$$E[\theta \mid Y_i, Y_j, Y_r] = \frac{t_m Y_i + t_m Y_j + t_r Y_r}{t_r + 2t_m + 1}$$

We call channel i , consisting of manufacturer i and the retailer, communicative if the two firms commit to vertically exchanging their demand signals beforehand, and non-communicative otherwise. There are three informational scenarios, both channels communicative, exactly one channel communicative, and both channels non-communicative. In each scenario, we study a game with the following sequence of events.

1. Manufacturer i and the retailer observe their realized demand signals Y_i and Y_r , and share them if channel i is communicative. The two manufacturers simultaneously determine their wholesale prices w_i and w_j based on the information they have.

2. The retailer determines retail prices p_i and p_j , the market demand quantities q_i and q_j realize, each manufacturer i produces to fill the demand, and firms receive their profits.

In the above game, manufacturer i can adjust his wholesale price w_i contingent upon the demand signal Y_i . It follows that the retailer can draw inferences about Y_i via w_i even if channel i is non-communicative.

IV. Model Analysis

For each informational scenario, we solve for the equilibrium wholesale prices and retail prices, and based on these, we compute the ex-ante expected profits. We then discuss the impacts of information exchange and upstream competition on firms' pricing and profitability.

A. Both Channels Communicative

Given wholesale prices w_1 and w_2 , the retailer chooses p_1 and p_2 to maximize her expected profit,

$$\pi_r^B(p_1, p_2) = \sum_{i,j=1,2,i\neq j} (p_i - w_i)\left(a + E[\theta \mid Y_i, Y_j, Y_r] - \frac{p_i}{1-\gamma} + \frac{\gamma p_j}{1-\gamma}\right), \quad (1)$$

where the superscript B denotes the case with both channels communicative. Her best price for product i in response to w_1 and w_2 is

$$p_i^B(w_i, w_j) = \frac{1}{2}\left(a + E[\theta \mid Y_i, Y_j, Y_r] + w_i\right) \quad (2)$$

which turns out to be independent of w_i. Anticipating retailer's response (2), manufacturer i chooses w_i to maximize his expected profit based on his own signal Y_i and retailer's signal Y_r

$$\begin{aligned}&\pi_i^B\left(w_i\right)=w_i\left(a+E\left[\theta \mid Y_i,Y_r\right]\right)\\&-w_iE\left[\left(\frac{p_i^B\left(w_i,w_j\right)}{1-\gamma}+\frac{\gamma p_j^B\left(w_i,w_j\right)}{1-\gamma}\right)\mid Y_i,Y_r\right]\end{aligned} \tag{3}$$

The following proposition shows the equilibrium prices.

Proposition 1. If both channels are communicative, the equilibrium wholesale price is

$$w_i^B=\alpha^B a+\lambda^B Y_i+\frac{2}{2-\gamma}\frac{t_r}{t_m}\lambda^B Y_r$$

where $\alpha^B=\dfrac{1-\gamma}{2-\gamma}$ and $\lambda^B=\dfrac{\left(1-\gamma\right)t_m}{2+2t_r+\left(2-\gamma\right)t_m}$; manufacturer i's and the retailer's ex ante profits are, respectively,

$$\begin{aligned}&\Pi_i^B=E_{Y_i,Y_r}\left[w_i^B\left(a+E\left[\theta \mid Y_i,Y_r\right]\right)\right]\\&-E_{Y_i,Y_r}\left[w_i^B\left(E\left[\left(\frac{1}{1-\gamma}p_i^B\left(w_i,w_j\right)+\frac{\gamma}{1-\gamma}p_j^B\left(w_i,w_j\right)\right)\mid Y_i,Y_r\right]\right)\right],\end{aligned}$$

And,

$$\begin{aligned}&\Pi_r^B=\\&E_{Y_i,Y_j,Y_r}\left[2\left(p_i^B-w_i^B\right)\left(a+E\left[\theta \mid Y_i,Y_j,Y_r\right]-\frac{p_i^B}{1-\gamma}+\frac{\gamma p_j^B}{1-\gamma}\right)\right].\end{aligned}$$

The ex ante profits are obtained by substituting w_i^B into (2) and further into (1) and (3), and then by taking expectations over the signals, which are expressed as Π_i^B and Π_r^B.

B. Exactly One Channel Communicative

Channel i is communicative and channel j is non-communicative. Although the retailer cannot get Y_j directly from manufacturer j, she can draw inferences about Y_j based on wholesale price w_j. Her belief takes the functional form of $w_j\left(Y_j\right)$. We restrict the search for equilibria to the subspace where w_j is a strictly increasing in Y_j, that is, $w_j=f\left(Y_j\right)$, or $Y_j=f^{-1}\left(w_j\right)$, with $f\left(*\right)$ a strictly increasing function. Given w_i and w_j, the retailer chooses p_1 and p_2, based on Y_i, Y_r and $f^{-1}\left(w_i\right)$, to maximize her expected profit $\pi_r^P\left(p_1,p_2\right)$, where the superscript P denotes the case where exactly one channel is communicative. Anticipating retailer's best response and conjecture, to maximize their individual profits, manufacturer i chooses w_i based on Y_i and Y_r, and manufacturer j chooses w_j based on Y_j, leading to first order conditions as follows:

$$\begin{aligned}&2E\left[\theta \mid Y_i,Y_r\right]-\frac{t_m\left(Y_i+E\left[f^{-1}\left(w_j^P\right)\mid Y_i,Y_r\right]\right)+t_rY_r}{t_r+2t_m+1}\\&+a-\frac{2}{\left(1-\gamma\right)}w_i^P+\frac{\gamma}{1-\gamma}E\left[w_j^P \mid Y_i,Y_r\right]=0\end{aligned} \tag{4}$$

$$\begin{aligned}&a+2E\left[\theta \mid Y_j\right]-\frac{2w_j^P-\gamma E\left[w_i^P \mid Y_i\right]}{\left(1-\gamma\right)}-\frac{t_rE\left[Y_r \mid Y_j\right]}{t_r+2t_m+1}\\&-\frac{t_m\left(E\left[Y_i \mid Y_j\right]+f^{-1}\left(w_j^P\right)+w_j^P\dfrac{df^{-1}\left(w_j^P\right)}{dw_j}\right)}{t_r+2t_m+1}=0\end{aligned} \tag{5}$$

In equilibrium, the retailer's conjecture is fulfilled. We can derive the perfect Bayesian Nash equilibrium outcome by simultaneously solving (4) and (5).

Proposition 2. If channel i is communicative and channel j is non-communicative, the equilibrium wholesale prices are, respectively,

$$w_i^P=\alpha_i^P a+\lambda_i^P Y_i+\frac{t_r}{t_m}\lambda_i^P Y_r,$$

and

$$w_j^P=\alpha_j^P a+\lambda_j^P Y_j,$$

where $\alpha_i^P=\dfrac{1}{2}\left(1-\gamma\right)\left(1+\dfrac{1}{\delta}\right)$, $\alpha_j^P=\left(1-\gamma\right)\dfrac{1}{\gamma\delta}$, $\lambda_i^P=2t_m\left(1-\gamma\right)\xi$ and $\lambda_j^P=2t_m\left(1-\gamma\right)\zeta$ with

$$\delta=\frac{\left(\begin{aligned}&\left(-2t_m^2-3t_mt_r-t_m-t_r^2-t_r\right)\gamma^3+\left(-2t_m^2-6t_mt_r-4t_r^2-4t_r\right)\gamma^2\\&+\left(8t_m^2+12t_mt_r+4t_m+4t_r^2+4t_r\right)\gamma+\left(8t_m^2+24t_mt_r+16t_m+16t_r^2+24t_r+8\right)\end{aligned}\right)}{\gamma\left(\gamma+2\right)\left(4t_r+4t_r^2+\gamma t_m+\gamma t_r+4t_mt_r+2\gamma t_m^2+\gamma t_r^2+3\gamma t_mt_r\right)}$$

$$\xi=\frac{3t_m+t_r+2t_m^2+t_mt_r+\gamma t_mt_r+1}{\left(2t_m+t_r+1\right)\left(8t_m+4t_r+4t_m^2-\gamma^2t_m^2+4t_mt_r-\gamma^2t_mt_r+4\right)},$$

$$\zeta=\frac{4t_r+4t_r^2+\gamma t_m+\gamma t_r+4t_mt_r+2\gamma t_m^2+\gamma t_r^2+3\gamma t_mt_r}{\left(2t_m+t_r+1\right)\left(8t_m+4t_r+4t_m^2-\gamma^2t_m^2+4t_mt_r-\gamma^2t_mt_r+4\right)},$$

and manufacturer i's and the retailer's ex ante profits are, respectively,

$$\begin{aligned}&\Pi_i^P=E_{Y_i,Y_r}\left[w_i^P\left(E\left[a+E\left[\theta \mid Y_i,Y_r\right]\mid Y_i,Y_r\right]\right)\right]\\&+E_{Y_i,Y_r}\left[w_i^P\left(E\left[\left(\frac{1}{1-\gamma}p_i^P\left(w_i,w_j\right)+\frac{\gamma}{1-\gamma}p_j^P\left(w_i,w_j\right)\right)\mid Y_i,Y_r\right]\right)\right],\end{aligned}$$

$$\begin{aligned}&\Pi_j^P=E_{Y_j}\left[w_j^P\left(a+E\left[\theta \mid Y_j\right]\right)\right]\\&-E_{Y_j}\left(w_j^PE\left[\left(\frac{1}{1-\gamma}p_j^P\left(w_i,w_j\right)+\frac{\gamma}{1-\gamma}p_i^P\left(w_i,w_j\right)\right)\mid Y_j\right]\right),\end{aligned}$$

and,

$$\begin{aligned}&\Pi_r^P=\\&E_{Y_i,Y_j,Y_r}\left[2\left(p_i^P-w_i^P\right)\left(a+E\left[\theta \mid Y_i,Y_j,Y_r\right]-\frac{p_i^P}{1-\gamma}+\frac{\gamma p_j^P}{1-\gamma}\right)\right].\end{aligned}$$

The ex ante profits are obtained by substituting into (2) and further into (1) and (3), and then by taking expectations over the signals, which are expressed as Π_i^P, Π_j^P and Π_r^P.

C. Both Channels Non-communicative

Similar to Section B the retailer conjectures that $w_i = f_i(Y_i)$ for $i = 1,2$. Following similar procedures in Sections 4.1 and 4.2, we characterize the first order condition for equilibrium wholesale price i

$$\frac{a}{2}+E[\theta \mid Y_i]-\frac{t_m\left(f_i^{-1}\left(w_i^N\right)+E\left[f_j^{-1}\left(w_j^N\right)\mid Y_i\right]\right)+t_r E[Y_r \mid Y_i]}{t_r+2t_m+1} + \frac{\gamma E\left[w_j^N \mid Y_i\right]}{2(1-\gamma)}-\frac{t_m w_i^N}{2(t_r+2t_m+1)}\frac{df_i^{-1}\left(w_i^N\right)}{dw_i}-\frac{w_i^N}{1-\gamma}=0 \quad (6)$$

where the superscript N denotes neither channel communicative case.

In equilibrium, the retailer's conjecture is fulfilled. We then can derive the perfect Bayesian Nash equilibrium outcome by simultaneously solving (6) for $i = 1,2$ and $i \neq j$.

Proposition 3. If channel i is communicative and channel j is non-communicative, the equilibrium wholesale price is

$$w_i^N = \alpha^N a + \lambda^N Y_i,$$

where $\alpha^N = \dfrac{(1-\gamma)(t_m+t_r)}{4t_m+2t_r-2\gamma t_m-\gamma t_r+2}$,

$$\lambda^N = \frac{t_m(1-\gamma)(t_m+t_r)}{(2t_m+t_r+1)(-2\gamma t_m+\gamma t_m-2)},$$

$$\lambda^N = \frac{t_m(1-\gamma)(t_m+t_r)}{(2t_m+t_r+1)(-2\gamma t_m+\gamma t_m-2)},$$

and manufacturer i's and the retailer's ex ante profits are, respectively,

$$\Pi_i^N = E_{Y_i}\left[w_i^N\left(a+E[\theta \mid Y_i]\right)\right] - E_{Y_i}\left[w_i^N\left(E\left[\left(\frac{1}{1-\gamma}p_i^N\left(w_i,w_j\right)+\frac{\gamma}{1-\gamma}p_j^N\left(w_i,w_j\right)\right)\mid Y_i\right]\right)\right],$$ and,

$$\Pi_r^N = E_{Y_i,Y_j,Y_r}\left[2\left(p_i^N-w_i^N\right)\left(a+E\left[\theta \mid Y_i,Y_j,Y_r\right]-\frac{p_i^N}{1-\gamma}+\frac{\gamma p_j^N}{1-\gamma}\right)\right].$$

The ex ante profits are obtained by substituting w_i^N into (2) and further into (1) and (3), and then by taking expectations over the signals, which are expressed as Π_i^N and Π_r^N.

V. Vertical Information Exchange, Upstream Competition Price and Profitability

Compare the expected wholesale prices in the three informational scenarios, we can get the following proposition.

Proposition 4. (i) $E\left[w_i^B\right] > E\left[w_i^P\right] > E\left[w_i^N\right]$;

(ii) $E\left[w_i^P\right] > E\left[w_j^P\right]$;

(iii) When $t_m > t_r$, there exists a unique $\hat{\gamma}$ such that $E\left[w_j^P\right] < E\left[w_j^N\right]$ if and only if $\gamma < \hat{\gamma}$.

Proposition 4 shows that a wholesale price is lower in a less communicative scenario. Hence retailer's rational inference has adverse consequences for a manufacturer's ability to set a high price. Note that when $t_m > t_r$, the non-communication of rival channel i can lower a non-communicative channel j's expected wholesale price, i.e., $E\left[w_j^P\right] < E\left[w_j^N\right]$, if the competition is not intense.

Proposition 5. Information exchange leads to:

(i) Higher expected profits for a manufacturer: $\Pi_i^B > \Pi_i^P$ and $\Pi_j^P > \Pi_j^N$;

(ii) Lower expected profits for the retailer: $\Pi_r^B < \Pi_r^N$.

Proposition 5 states that information exchange benefits the manufacturer but hurts the retailer. Thus manufacturers would like to share data to avoid the downward adjustment of wholesale prices. The retailer, however, will never enter an information sharing arrangement unless she is compensated.

VI. Conclusions

This paper studies how the vertical information exchange impacts supply chain firms' pricing strategies. We show that when a channel is communicative, the manufacturer can enjoy a high wholesale price by avoiding the retailer's rational inference. Upstream competition plays an important role in pricing, in the presence of information asymmetry. In a non-communicative channel, intense upstream competition may severely drive down wholesale prices hurting the manufacturers. Non-communication will cause a downward adjustment of wholesale price, and thus the retailer does not have an incentive to engage in an information exchange program unless she is properly compensated.

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