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# Information visibility and its impact in a supply chain

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ABSTRACT

We analyze a supply chain with two retailers facing independent demands who share an upstream supply market. Retailers can choose the extent to share signals on demand. We show that (a) there are conditions under which a retailer who unilaterally shares information, while receiving no information in return, may be better off while the recipient is worse off, (b) partial information sharing may be an equilibrium strategy.



## 1. Introduction

In this paper, we focus on a supply chain consisting of independent retailers (or, manufacturers, interchangeably) who share upstream supply. Retailers face one period of demand and a fixed retail price, and commit to satisfy the demand by ordering in the first period or back-ordering some of the demand and satisfying it in the second period. The wholesale price in the second period is decreasing in the total order size, across the two retailers, in the first period. This decrease in wholesale price captures the market learning impact of aggregate orders that empirical papers in the literature have explored (Lieberman [13] and Gruber [10]). Our model focuses on "supply competition" rather than the traditional "demand competition" that has been examined in the economics literature.

To motivate our model, consider a very common alliance between firms in the form of research or production joint ventures. However, joint ventures need substantial initial investment while the return is not immediate. Suppose two firms form a production joint venture for the purpose of cost sharing. In the first period, the firms reimburse the joint venture at a unit cost according to their order quantities. This reimbursement can be regarded as a part of initial investment. Then, in the second period, the firms reimburse the joint venture at a reduced unit cost which is proportional to the aggregate order quantity in the first period, due to the learning effect. Obviously, each firm would like to be a free rider by influencing the other to order more in the first period. This setting gives rise to the consideration of information sharing under "supply competition". In this paper, we shall examine how the level of information sharing affects order decisions and thus the Nash equilibrium solution for information sharing.

In a separate paper (Wu et al. [19]), we considered the case with symmetric retailers and symmetric decision making by both retailers. We relax that condition in this paper and permit asymmetric decisions by retailers regarding their extent of information sharing with the other retailer. Our results depend crucially on conditions when one of the retailers' optimal order decisions is at the boundary, i.e., 0 or at the maximum demand level. This pinning of a retailer at the boundary provides information to the other retailer and can be considered as an alternative way to infer a retailer's action. We show that such an effect can switch retailers from a no-sharing to a full sharing equilibrium and even generate partial information sharing as an equilibrium outcome.

Many papers in operations management focus on the value of vertical information sharing in a supply chain. In general, this line of research takes the perspective of a virtual or real central planner, who makes decisions that optimize the performance of the system. It is shown that improved information visibility increases the performance of the system compared to the case when the planner has only local information. Li [12] calls this the

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"direct effect" of vertical information sharing. This "direct effect" is studied in Chen [4], Lee et al. [11], and Cachon and Fisher [3]. Related papers highlight the benefits of information sharing from improved demand forecasting (e.g., Aviv [1], Giloni et al. [9] and Gaur et al. [8]) and/or reduction of information distortions (e.g., Lee et al. [11]).

However, the impact of information sharing among horizontal competitors is not obvious. Macleod et al. [14] claim that collaborations between competitors are increasing in the economy. Research on information sharing in an oligopoly was pioneered by Novshek and Sonnenschein [15], then followed by Clarke [5], Gal-Or [7], Raith [16], and Vives [17]. These models assumed that market uncertainty is due to either unknown constant marginal cost for the firms or unknown market demand, which could be a common or firm-specific parameter. In most of these papers, equilibrium strategies are full or no information sharing solutions depending on the assumption of competition type-Cournot or Bertrand, and the product type-substitute or complement.

For our model, we focus on providing answers to the following questions:

1. Can one retailer who unilaterally obtains more information (from the other retailer) make himself worse off while making the other retailer better off?
2. Can partial information sharing between retailers be a Nash equilibrium?

The models used in the literature have not yielded any conclusive answers to these questions. While Gal-Or [7] concludes that incentives to share information are the same with different private demand intercepts as they are with different private costs, in her case, all solutions were interior. However, the results in our settings are complicated by the possibility of a boundary equilibrium. For the second question, although in some previous models partial information sharing is a viable choice (e.g., Novshek and Sonnenschein [15], and Li [12]), the Nash equilibrium is always a bang–bang solution. We find one of the limitations of previous models is that they assume that the exogenous parameters guarantee interior solutions. In our model we extend the analysis to include cases in which some solutions are on the boundary. This allows us to generate seemingly counter-intuitive results as we answer the both questions described earlier.

The organization of this paper is as follows. In Section 2, we present the structure of our model with one supplier and two buyers with uncertain downstream demand. In Sections 3 and 4, we provide Nash equilibrium solution for information sharing with interior and boundary equilibrium of order quantity. We conclude the paper in Section 5.

## 2. The model

In this section, we set up the framework of the model. We consider a two-level supply chain consisting of a manufacturer and two retailers, labeled $A$ and $B$, who serve two independent markets with the retail price of $r_k$ ($k \in \{A, B\}$) per unit. We shall study ex ante incentives for retailers to share their demand information before it is completely realized.

### 2.1. Information structure

We assume that there is one period of demand, and the random demand ($D_k$ for retailer $k$) observed by each retailer is independent, which takes a low value $d_1$ with probability $q$ and a high value $d_2$ with probability $1 - q$. Each retailer knows his private demand at the beginning of the sales season perfectly. However, he can only infer the other's demand through a signal he receives, and the quality of signal is controlled by the information provider according to the agreement on timing of sharing information. The demand state or signal can be indexed by 1 (low) or 2 (high).

A critical feature of the model is the quality of information that is shared between the two retailers. The *nature* of the information is a forecast of the level of individual retailer's demand. One reason why the quality of the information may be less than perfect is due to the timing at which information is provided. If the information is revealed earlier, less data will have been collected, and signal (information revealed) is less likely to be accurate. The signal and associated quality is a succinct way to describe possible distributions. Before the selling season, the retailers decide when they will share their information, this data is collected by a third-party agency and shared. At the agreed time, the agency shares a high or low signal about the other retailer's demand, given demand information up to this time. The agency shares the signal to each retailer $k$ about his competitor's demand. To measure the extent (or timing) of information sharing, we let $\theta_k \in [0.5, 1]$ denote the quality of signal received by retailer $k$, which is determined by the timing of information sharing. Effectively, $\theta_k$ is the probability the high/low demand signal is accurate. If $\theta_k = 0.5$, the signal is generated when there is no demand information collected, and has the lowest quality. If $\theta_k = 1$, at the beginning of selling season, each retailer $k$ is provided a perfect signal about the other retailer's demand. Any $\theta_k \in (0.5, 1)$ represents partial information sharing.

Let $S_k$ denote the signal received by retailer $k$ about the other retailer $k'$'s demand, where $S_k$ could take the value 1 or 2 (referring to a demand of $d_1$ or $d_2$). Given signal quality $\theta_k$, we know $\text{Prob}(S_k = j | D_{k'} = d_j) = \theta_k$, where $j = 1, 2$ and $k' \in \{A, B\} \setminus k$. That is, if retailer $k'$'s demand is in state $j$, i.e., takes value $d_j$, retailer $k$ will receive a signal $S_k = j$ with probability $\theta_k$. Let $P(s^{k'}_{mn} | s^k_{ij})$ denote the probability that retailer $k'$ observes demand level $m$ and receives signal $n$, given that retailer $k$ observes demand level $i$ and receives signal $j$ (about retailer $k'$), where $i, j$ $m, n$ take values 1, 2. For example, by Bayes' rule, $P(s^B_{21} | s^A_{12}) = \theta_A \theta_B (1 - q)/(\theta_A (1 - q) + (1 - \theta_A) q)$.

### 2.2. Decision structure

Given the demand realization and belief matrix, each retailer has two ordering opportunities to satisfy the one period of demand. Let $a_{ij}$ and $b_{mn}$ denote order quantities of two retailers in period 1 respectively, where $i$ and $m$ ($j$ and $n$) represent the two retailers' demand states (signals received) respectively. Thus $a_{12}$ refers retailer $A$ facing a demand at state 1 (i.e., $d_1$) and a signal that retailer $B$'s demand is state 2 (i.e., equal to $d_2$). The wholesale price (or reimbursement cost) per unit in period 1 is $p_1$, the back order cost per unit of unsatisfied demand is $p_b$, and the wholesale price in period 2 is $p_2 - \delta(a_{ij} + b_{mn})$. Thus, there is a base price in period 2 which is reduced by a factor proportional to the aggregate volume order in period 1. A similar learning effect, linear in cumulative volume, is used in Fudenberg and Tirole [6] and Balachander and Srinivasan [2]. We assume all the price parameters are exogenously given. In addition, to exclude the possibility of the negative wholesale price in period 2, we assume $\delta < p_2/2d_2$ or $p_2 > 2d_2\delta$. We shall next consider the ex ante incentives for retailers to share their private demand information. This is a two-stage game, which is solved by backward induction.

The chronology of events and decisions is as follows (see Fig. 1):

1. Each retailer chooses the timing for sharing information (or, equivalently, the signal quality $\theta_k$). We assume that once an agreement regarding $\theta_k$ is reached, it is implemented truthfully.
2. Each retailer receives a signal about the other's demand with a quality $\theta_k$.
3. Each retailer observes his own demand at the beginning of the selling season.