Signaling in Online Retail: Efficacy of Public Signals

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With the tremendous growth of online retail, a number of services have arisen that provide customers with information about price history, product availability, demand, etc., enabling them to strategically time their purchases to obtain a better price. For example, services like Kayak inform a user whether the price of an airline ticket is likely to fall in the future. While a user of such a service may choose to wait for the price to decrease, she takes the risk that the product may go out-of-stock and become unavailable for purchase when she tries to buy it. Without the availability of demand and inventory information, a customer must rely on her beliefs about the same to optimally make this trade-off between a better price and the risk of a stock-out.

Online retailers, on the other hand, would prefer that customers do not strategize the timing of their purchase decisions since this may mean lost demand. Such online retailers have better estimates of the demand and inventory of their products, and to induce customers to purchase, they may let customers know when an item has low inventory. Some retailers, such as Amazon, give the exact number of items remaining when the inventory is low. Others just print “low stock” to encourage customers to buy the item sooner. Rarely, though, do online retailers tell customers exactly how low “low stock” implies, or even whether the definition is consistent across different products. If a firm says all items have low inventory, then customers will simply ignore the warning altogether. This leads to a natural question: how can a retailer credibly communicate inventory and demand information to customers to maximize its expected revenue?

In this paper, we consider the setting where a retailer seeks to sell their inventory of an item that will drop in price. Common examples of this are fashion (where summer wears are sold in
mass clearance sales after autumn arrives) and theater tickets (where the price of any unsold tickets drop right before a show). In particular, we consider a two period model, where prices are high the first time period and low the second, and customers who arrive at time 1 decide whether to buy the item right away or wait to buy in the next time period. The firm sends each customer at time 1 a signal that is dependent on both the total inventory available and the total number of customers at time 1. Each customer is strategic and Bayesian: before they act, they update their beliefs about the inventory and the demand based on the firm’s signal.

Previous literature (Allon and Bassamboo, 2011) has observed that without credible signaling, the firm cannot increase its revenue beyond the setting of no information sharing. To overcome this difficulty, we adopt the framework of Bayesian persuasion (Kamenica and Gentzkow, 2011; Rayo and Segal, 2010), where we assume that the firm can publicly commit to sending signals in a prespecified way.

Our model differentiates between two types of signaling. In the general setting, the firm may send a different (private) signal to each customer, possibly giving each different information. Such information sharing may involve the firm sending a tailored email message to each interested customer. On the other hand, a firm may also send a common signal to all the customers, possibly through having a “low stock” indicator on its website visible to all interested customers. Although private signals are more general, public signals are easier to implement, have lower risk of “leakage” (where customers share their private signals to each other), and are arguably more equitable.

Our primary result is that with credible signaling, a firm can substantially improve its revenue. In particular, we show that the optimal signaling mechanism is a public mechanism where a common binary signal (“buy now” or “wait”) is sent to all customers. More precisely, we show that the optimal signaling mechanism either recommends all customers to buy now or all customers to wait. Like in Kamenica and Gentzkow (2011), this mechanism recommends customers to buy now whenever it is in their interest to do so, but not exclusively so.

Using this result, we show that problem of finding the optimal signaling mechanism can be posed as a fractional knapsack problem, yielding an efficient linear time algorithm to compute the
optimal signaling mechanism. Under a mild condition on the demand distribution, we show that the optimal signaling mechanism has a threshold structure.

Finally, we numerically compare the expected revenue achieved by the optimal signaling mechanism against the expected revenue achieved by providing no-information, providing full-information (where we tell each customer the total inventory and demand) and the expected revenue in the setting where all customers are forced to buy immediately. Against the first two benchmarks, we show that the optimal signaling mechanism achieves substantial increase in revenue, often getting close to the setting where all time 1 customers are forced to buy immediately. Because full-information mechanism achieves higher revenue than the no information mechanism for sufficiently large inventory, our numerical results demonstrate that a firm obtains substantial revenue gain by committing to a signaling mechanism, even if the mechanism is not optimal.

Our work extends the literature on signaling and Bayesian persuasion by analyzing an instance where a single principal (the firm) signals to a varying number of agents (the customers), with the number of agents being part of the information being signaled. This aspect of the model requires careful determination of customers’ prior belief (before they receive their signals) when setting up the firms’ decision problem. In particular, we show that the customers’ beliefs are size-biased, causing their prior beliefs to assign higher weights to high values of the demand than the firm. This result is analogous to the friendship paradox (Feld, 1991), which states one has fewer friends on average than their friends; ignoring this subtlety leads to counter-intuitive (and false) results.