Signaling in Online Retail: Efficacy of Public Signals

Extended Abstract*

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With the rapid 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 risks the product going out-of-stock and becoming unavailable. Without the availability of demand and inventory information, a customer must rely on her beliefs 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 customers not strategize the timing of their purchase decisions since this may lead to lower revenue. 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, but rarely do they tell customers exactly how low "low stock" implies. 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. A common example of this is fashion, where summer wears are sold in mass clearance sales after autumn arrives. 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 present at time 1 a signal that is dependent on both the total inventory available and the total number of customers present 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. In contrast, we adopt the framework of Bayesian persuasion where we assume that the firm can publicly commit to sending signals in a prespecified way. Our work extends the literature on Bayesian persuasion with multiple agents (and payoff externalities) by analyzing a setting where the number of agents (customers) is random and part of the information signaled. We show that this causes the agents' prior beliefs to be *size-biased* towards larger values of demand, in comparison to the firm's belief.

In general, the firm may send a different (private) signal to each customer, possibly giving them 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 (public) 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 and have lower risk of "leakage" (where customers share their private signals to each other).

Our primary result is that the optimal signaling mechanism is *public*, where a common binary signal ("buy now" or "wait") is sent to all customers. In other words, the optimal mechanism recommends all customers to take the same action. Using this result, we show that the problem of finding the optimal signaling mechanism can be posed as a fractional knapsack problem, yielding an efficient linear time algorithm for computing the optimal signaling mechanism. Under a mild condition on the demand distribution, we show that the optimal signaling mechanism has a threshold structure.

We numerically compare the expected revenue achieved by the optimal mechanism against that achieved by the no-information and the full-information (where we tell each customer the total inventory and demand) mechanisms. Against the two benchmarks, we show that the optimal signaling mechanism achieves a 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 a substantial revenue gain by *committing* to a signaling mechanism, even if the mechanism is not optimal.

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