Dynamic Pricing for Customers with Time-Sensitive Valuations

(Extended Abstract)

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Dynamic pricing has becoming increasingly prevalent in many industries. One of the main advantages of dynamic pricing is that it helps mitigate the risk associated with demand uncertainty (see, for instance, Aviv and Pazgal 2008 and Cachon and Swinney 2011). In this paper, we show that dynamic pricing can play an important role in differentiating between customers over time even in the absence of demand uncertainty. In many settings, especially in fashion and electronic gadget retail, a customer’s willingness-to-pay (or valuation) for the product is time-sensitive and decreases over time. In these situations, customers are not only different in terms of their initial willingness-to-pay for these items when they are first introduced to the market, but they are also different in terms of how rapidly they lose their interest in these products. So, we may have customers who initially value the product at a high level, but then as time progresses, they lose interest in the product completely. And, we may also have customers who initially value the product at a low level, but still remain interested in the product as time progresses. That is, the willingness-to-pay of the lower valuation customers diminishes at a lower rate relative to that of the higher valuation customers. This phenomenon is illustrated in Figure 1.

![Figure 1: Valuation of two customers decreasing over time.](image)

In this paper, we show that when a firm sells to customers who have heterogeneously decreasing valuations, the firm can achieve significant benefits by incorporating dynamic pricing even in the absence of demand uncertainty. This is not the case if customers were homogeneous in their valuation decay rate. In that case, in the absence of demand uncertainty, the firm’s optimal pricing strategy would be to post a fixed price, and dynamic pricing would have no benefit. When customer valuations decrease at different rates, the ranking of customers (in terms of their valuations) changes over time (as in Figure 1). This allows the firm to generate more revenue by revising its initial price to target customers who currently have higher valuations even though they initially had lower valuations.

Formally, we characterize a revenue-optimal selling mechanism for a firm with customers who have heterogeneous valuations that decrease in a heterogeneous fashion as well. We assume that the firm knows the total demand and also knows the customer valuation distribution but does not know the precise valuation of each individual customer. We also include production costs and product holding costs for the firm. In our setting, the firm commits to a price trajectory, and the customers are strategic and select the best time to purchase so as to maximize their individual net...
utility. We assume that customers with higher initial valuation also have a higher rate of valuation decrease. To the best of our knowledge, this setting has not been studied in the literature.

We next describe the main characteristics of this optimal mechanism ignoring the production and holding costs. The optimal mechanism consists of the firm (or seller) posting a series of decreasing prices, which essentially divides the customers into three groups based on their initial valuation. The first group comprises all customers with initial valuations above a threshold (high valuation customers) who purchase the product immediately. The second group consists of all customers with initial valuations below a smaller second threshold (low valuation customers). For these customers, the posted prices are designed in a way to extract their entire surplus. Finally, the third group consists of customers with valuations between the two thresholds (medium valuation customers), who do not purchase the product immediately but purchase before the low valuation customers, and obtain a positive net utility, or surplus.

The low valuation customers in our mechanism play an important role that is in contrast with what occurs in static pricing. In a static pricing policy, all customers with valuations above the price would immediately purchase and those with valuations below the threshold would not purchase. However, in our optimal mechanism, the low valuation customers purchase the product after some delay and the firm is able to extract their entire surplus. In the absence of holding and production costs, the firm sells the product to all customers in this fashion, which can generate significant additional revenue. For instance, we show that the seller can increase his revenue by approximately 25% by employing the optimal mechanism (relative to static pricing) when the initial valuation distribution is uniform and the valuation decay rates are proportional to initial valuations; in fact, three-quarters of this increase is obtained by selling to the low valuation customers.

We next investigate the impact of holding and production costs on the optimal selling mechanism. Both of these costs motivate the seller to reduce the length of the selling period, but in different ways. The presence of production costs motivates the seller to sell fewer units by targeting higher valuation customers. Interestingly, we find that the optimal mechanism here can be obtained from the baseline optimal mechanism (obtained without these costs) in a simple manner: it introduces a cut-off in the customers’ purchase times so that if a customer’s initial valuation is greater than this cut-off, her time of purchase remains the same as that in the baseline optimal mechanism, and otherwise she does not purchase the product at all.

Holding costs motivate the seller to price in a manner so that customers are incentivized to make their purchases earlier (than the baseline case). We find that depending on the holding cost, three types of optimal mechanisms can arise. If the holding cost is larger than a threshold, then the seller finds it too expensive to carry the product and simply posts a fixed price and all customers who purchase the product do so immediately. If the holding cost is moderate (below the previous
threshold and above another lower threshold), then the seller benefits from dynamic pricing but cannot extract the entire surplus of customers with low initial valuations. If the holding cost is below the lower threshold, then the structure of the optimal mechanism is similar to that of the baseline optimal mechanism: there are three distinct groups of customers and the seller can extract the entire surplus of customers with low valuations. Overall, the value of dynamic pricing decreases with increasing holding and production costs.

Finally, we summarize our main technical contribution. In our setting, one of the hurdles in characterizing the optimal selling mechanism is that there is no consistent customer ranking based on customer types. As a result, satisfying the individual rationality and incentive compatibility constraints becomes challenging.\(^1\) Note that when there is a consistent ranking of customers, individual rationality constraints are binding for the lowest customer type that the seller would like to sell the product to, and the mechanism is incentive compatible if the allocation rule is monotone in the type of the customers. In contrast, in our setting, the individual rationality constraint is binding for a group of customers with low initial valuation. Furthermore, the monotonicity of the time of purchase in the initial valuation does not guarantee that the mechanism is incentive compatible. To characterize the optimal mechanism, we first establish necessary and sufficient conditions to have an incentive compatible mechanism. One of these conditions resembles the traditional envelope condition (Myerson 1981). This condition ensures that the mechanism is locally incentive compatible. The other condition called interval condition ensures that the mechanism is globally incentive compatible. We first relax the problem by ignoring the interval condition and characterizing a revenue-optimal mechanism that satisfies the individual rationality constraints and envelope condition. Then, by establishing several additional properties of this mechanism, we show that the mechanism indeed satisfies the interval condition, and thus is optimal.

References


\(^1\) To characterize the optimal mechanism, using the revelation principle, it suffice to focus only on mechanisms in which customers have an incentive to participate, that is, the individual rationality constraints hold, and are willing to reveal their private information to the mechanism designer, that is, the incentive compatibility constraints hold (see, Myerson 1981).