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Competitive markdown timing for perishable and substitutable products ☆

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ABSTRACT

We model as a duopoly two firms selling their fixed stocks of two substitutable items over a selling season. Each firm starts with an initial price, and has the option to decrease the price once. The problem for each firm is to determine *when* to mark its price down in to maximize its revenue. We show that the existence and characterization of a pure-strategy equilibrium depend on the magnitude of the increase in the revenue rate of a firm when its competitor runs out of stock. When the increase is smaller than the change in the revenue rate of the price leader when both firms are in stock for all of the three possible scenarios, neither firm has the incentive to force its rival to run out of stock and if a firm marks its price down after the season starts, its inventory runs out precisely at the end of the season. When the increase is larger than the change of the price leader's revenue rate in one particular scenario, waiting until its rival runs out of inventory may be an equilibrium strategy for the larger firm even though this may lead to leftover inventory for itself. In other cases, there may be no pure-strategy equilibrium in the game. In certain regions of the parameter space, a firm's revenue may be decreasing in its starting inventory which shows that a firm may be better off if it can credibly salvage a portion of its inventory prior to the game. While most of our analysis is for open-loop strategies, in the final part of the paper, we show that the open-loop equilibrium survives as an equilibrium when we consider closed-loop strategies for an important subset of the parameter space.

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1. Introduction

Many companies in various industries face the problem of selling a fixed amount of inventory over a finite horizon. Examples include retailers selling perishable goods such as apparel, electronics and toys, airlines selling a fixed number of airplane seats, and hotels selling a fixed number of rooms. A frequent reason for fixed inventories is the lack of replenishment opportunities due to relatively long replenishment lead times as compared to the length of the selling season. For example, according to a recent survey, average lead time in the apparel and footwear industries is 11 months [3], while the fashion seasons themselves are as short as 2–3 months [28]. This situation leads to retailers ordering most or all of their merchandise prior to the season. For these retailers, pricing is the only control to match supply and demand once they place their orders. According to one estimate by a consulting firm, a typical retailer sells between 40 and 45 percent of its merchandise at a discounted price [35]. A vivid example is J.C. Penney, a major US department store, which generates 73 percent of its revenue from products sold at a discount of 50 percent or more, and only 0.2 percent from goods bought at full price [20]. Long lead times and hard-to-predict demand also cause toy retailers using excessive markdowns to match supply and demand [38]. Markdowns are dominant in the auto industry, where manufacturers introduce a new vintage of a vehicle every year. According to a study by Copeland et al. [5], the price of a new vehicle declines by 9.2 percent over the model year, and half of these declines are driven by promotions to clear the inventory that dealers and factories build up of that model year's vehicles. For example, Ford had 103 days of supply or 27,100 units of 2006 Expeditions at the beginning of July, 2006. The 2007 model was to be launched in September, so the company initiated a promotion in that summer and offered a discount between $5,000 and $6,000 per vehicle to clear its inventory [1].

Markdowns may have a dramatic effect on a retailer's profitability. Many retailers blame excessive markdowns to their recent financial troubles [34]. At the same time, managing markdowns can be challenging since marking the price down too early or too deeply will lead to

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lost revenue, while delaying markdowns or keeping them shallow will lead to liquidating inventory at even lower prices at the end of the season. Due to such challenges, many retailers have begun using markdown optimization software to determine the timing, depth and frequency of their clearance or markdown events. Software vendors that offer markdown optimization solutions include DemandTec, Oracle, Predictix, Revionics and SAS [31].

As in many other areas of business, firms are usually very sensitive to the pricing activities of their competitors. For example, in 2010, Best Buy, the largest electronics retailer in the US, started its holiday sales 10 days earlier than previous years considering competition in addition to its inventory build-up [36]. In the auto industry, competition (and inventory as discussed above) also shapes year-end clearance offers [2].

In this paper, we study a markdown competition game between two firms whose two products are substitutes for each other. Each firm is endowed with a fixed amount of inventory that it needs to sell over a common selling season. We assume that the firms are symmetric except for their starting inventory levels and assume deterministic demands. One firm's demand rate at a given time depends on its own price as well as its competitor's price and stock availability. We assume no particular function to define this dependency, except that the demand is decreasing in own price and increasing in its competitor's and that unilateral price drops are revenue increasing. Each firm starts the selling season with a common high price and has a single chance to switch to a lower one (which is also common) during the season. With this simplification, the game we study is a simple finite horizon timing game, in which each firm's strategy is the time of its markdown. We explore two types of equilibria in this setting. First, we assume that the firms pre-commit themselves to the markdown times at the beginning of the season and use a static game to explore the strategic interactions between the firms. In this case, we identify the *open-loop equilibrium* of the game. While the assumptions regarding exogenous markdown prices and pre-commitment to markdown times may be too restrictive in many practical settings, they may be justified for a limited number of firms that practice what is known as pre-announced or automatic markdowns. In this strategy, the seller announces the future prices (which are usually fixed percentages of the original price) along with the times that these prices will take effect (provided that there is still inventory) in advance. Examples include Land's End Overstocks for fashion apparel, Tesco's Fresh & Easy for groceries and Theater Development Fund's TKTS for theater tickets.

In the final part of the paper, for an important subset of the parameter space, we assume that firms can observe each other's actions throughout the selling season and dynamically decide when to mark the price down. In this case, we use subgame-perfect equilibrium as a solution concept and identify the *closed-loop equilibrium* of the game and show that this coincides with the open-loop equilibrium. That is, for this region of parameter space, the firms do not have any incentive to preempt or wait for each other in marking the prices down during the season; their decisions at the beginning of the season do not change.

We also assume away the stochastic nature of demand in these settings. However, note that the markdown decisions are made after the actual season starts, i.e., when, in practice, a considerable portion of the uncertainty is resolved and accuracy of demand forecast is reasonably high (see, for example, [8]).

We find that the existence of a pure-strategy equilibrium and its characterization critically depend on the maximum demand rate that a firm faces when its competitor runs out of stock (i.e., monopoly demand rate when the price is low) relative to three thresholds. These thresholds are functions of the demand rates and prices and measure the effectiveness of price changes when the competitor is in stock relative to when the competitor is out of stock. If the monopoly demand rate is smaller than all thresholds, there is a pure-strategy equilibrium in the game, and each firm's equilibrium markdown time can be characterized as a function of starting inventory levels and length of the selling season. The equilibrium is one of seven possible equilibria, depending on where the starting inventory levels and the selling season fall in the parameter space. In all equilibria, the larger firm (the firm with the larger starting inventory) always marks its price down earlier than the smaller firm. We show that each firm either (i) marks down the price at the beginning of the season (ii) never marks the price down (iii) marks the price down in the middle of the season at such a time that its inventory runs out precisely at the end of the season. In other words, it is not an equilibrium strategy to change the price after the season starts and still have some leftover inventory at the end of the season, or run out of stock before the season ends.

When the monopoly demand rate is larger than the last threshold but smaller than the first two, a pure-strategy Nash equilibrium still exists. The equilibrium in this case is one of six possible equilibria. Different from the previous case, in one of the equilibria, the larger firm may wait for the smaller firm to exhaust its stock, and switch immediately after, even though this may lead to leftover inventory at the end of the season. We also derive a set of sufficient conditions for the uniqueness of the equilibria in these cases. Finally, we show by examples that if the monopoly demand rate is larger than one of the first two thresholds, a pure-strategy Nash equilibrium may fail to exist.

We show that the three thresholds mentioned above are never exceeded and the uniqueness conditions are easily satisfied if the demand rates originate from two important demand models: linear demand model and attraction demand model.

Under a single-firm setting, the revenue is monotone increasing in the starting inventory level and the length of the selling season. Markdown time, on the other hand, is monotone decreasing in the starting inventory level and increasing in the length of the selling season. One would expect these results to carry to the competitive case. Another intuitive conjecture for the competitive case is that a firm's revenue and markdown time are monotone decreasing in its competitor's starting inventory level. Interestingly, comparative statics results of the competitive game lead to exceptions to these properties. First, firms' payoffs are not monotone increasing in their own starting inventories, particularly when the firms have intermediate levels of starting inventory and when their demands are inelastic to an industry-wide markdown. In this case and under the assumptions of our model, both firms' revenues may be decreasing in their starting inventory levels and they are better off if they can credibly salvage some of their inventory prior to the game. Alternatively, firms will not prefer to have more inventory even if it was free. When one firm is substantially small and the larger firm has an incentive to wait until the smaller firm exhausts its stock, the smaller firm's revenue jumps down as its starting inventory goes up, again breaking the monotonicity of the smaller firm's payoff in its own inventory. In this equilibrium, the larger firm's markdown time is no longer monotone decreasing in the smaller firm's inventory, either.

Under a reasonable assumption that the starting inventory levels of both firms are bounded from below (above) by what they can sell when both firms are charging a high (low) price, we show that the length of the period during which firms charge different prices increases linearly with inventory imbalance (measured as the difference between starting inventory levels) and decreases reciprocally with product substitution (measured as the difference between the demand rates of firms when they charge different prices).

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