

# A Simulation-based Approach to Dynamic Pricing

**Joan Morris**

Sc.B. Applied Mathematics

Brown University

May 1995

Submitted to the

Program in Media Arts & Sciences,

School of Architecture and Planning,

In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Media Arts & Science

At the

Massachusetts Institute of Technology

May, 2001

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## **Abstract**

*By employing dynamic pricing, the act of changing prices over time within a marketplace, sellers have the potential to increase their revenue by selling goods to buyers “at the right time, at the right price.” Software agents have been used in electronic commerce systems to assist buyers, but there is limited use of selling agents in today’s markets. As dynamic pricing systems become necessary as a competitive maneuver and as market mechanisms become large scale and more complex, there is a growing need for pricing agents to be used to automate dynamic pricing, which challenges sellers to improve their understanding of what are the best agent pricing strategies for their marketplaces.*

*This thesis addresses these issues by presenting the Learning Curve Simulator, a market simulator designed for analyzing agent pricing strategies for a market in which a seller has a finite time horizon to sell its inventory. Through an analysis of several pricing strategies using the simulator, I demonstrate how the Learning Curve Simulator can be used as a tool for understanding the relevant factors in determining an effective dynamic pricing strategy. This simulation-based approach to dynamic pricing demonstrates a technique which can lead to the implementation of dynamic pricing strategies in real-world markets.*

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This research was funded in part by Mastercard International, the e-markets Special Interest Group, and the Digital Life Consortium.



# A Simulation-based Approach to Dynamic Pricing

**Joan Morris**

The following people served as readers for this thesis:

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# Abstract

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# Acknowledgements

I would like to thank, first, Pattie Maes, a great advisor and advocate during my two years at the lab and through the Master's thesis process. Simply put, she has inspired not just my research, but me!

Thank you to my thesis readers, Amy Greenwald and Dan Ariely, who both offered challenging perspectives on this work. I particularly want to thank Amy for her enthusiasm for the simulator and for the success of my research.

Thank you to all the Agents, past and present, especially Jim Youll and Sybil Shearin. It has been great to be part of an active research community and I hope we continue to collaborate through the years.

I'm indebted to my UROP, Kaska Dratewska, who ran countless simulation trials in the late night hours for the sake of my paper deadlines! The simulator interface also benefited from her bug testing and feedback.

Finally, thanks to my family and to Mike DiMicco, for your loving support and for all those important things you've taught me over the years.



# 1 Introduction

Today, when a ballpark sells baseball tickets, the park charges the same price for the tickets throughout the season. Yet the demand for tickets changes over time depending on the length of time before the game, the team's success over the season, and unpredictable factors such as the weather. In a best-case scenario, a park sells all of its seats for every game at an optimal fixed ticket price. In a more realistic scenario, some days the park has empty seats and on other days the park is filled with buyers willing to pay more. Nonetheless, today ballparks leave the practice of dynamic pricing to scalpers.

Dynamic pricing, defined as the changing of prices in a marketplace, can be implemented in several different ways. Price discrimination, or personalized pricing, is an intriguing area of dynamic pricing in which sellers charge different segments of customers different prices. While this area is rich with potential, it also has greater risks of customer rejection, as exhibited when Amazon.com experimented with charging customers different prices [2]. In contrast to this approach to dynamic pricing, this body of work focuses on the changing prices over time in a market that makes no assumptions or attempts to segment the buyer population into sub-groups. This perspective on dynamic pricing focuses on how a seller can take advantage of the fluctuations in cumulative buyer demand over time, taking into account a finite time horizon. In this thesis, I refer to this type of changing of prices over time as dynamic pricing.

Cost is perhaps the greatest factor precluding the widespread use of dynamic pricing by ballparks and other markets. In traditional markets, it is expensive to continuously re-price goods, but in digital markets, the costs associated with making frequent, instantaneous price changes are greatly diminished [25]. Moreover, in markets under a finite time horizon, such as ballparks, theaters, seasonal retail stores, rental cars, and other perishable good markets, a clear benefit to

changing prices over time is that one can ensure all inventory is sold. Thus, it seems likely that in the near future, dynamic pricing will become a common competitive maneuver, particularly in markets under a finite time horizon.

A remaining obstacle that hinders widespread dynamic pricing is the difficulty in understanding the complexities price changes introduce into a market. Now that sellers can easily implement frequent adjustments to price, how should they do so? What are the most effective dynamic pricing strategies, and how do they behave in specific markets? I propose that sellers should analyze dynamic pricing algorithms using a market simulator that is capable of simulating many different market scenarios with realistic models of buyer behavior. Using a market simulator, a seller could model its market's characteristics and the behavior of its customers, to develop a pricing strategy that could capture more profit than fixed-price policies.

To illustrate my proposed approach, I present in this thesis the *Learning Curve Simulator*, a platform for running dynamic pricing algorithms in simulated markets. Through an analysis of different pricing strategies under varying market conditions, I demonstrate how, by observing market conditions, a seller can take advantage of fluctuations in buyer demand to earn more revenue and sell more inventory.

## **1.1 Finite Markets**

My investigation of dynamic pricing strategies focuses on an extremely common market type, which I call a *finite market* -- a market with a finite time horizon, seller inventory, and buyer population. Examples of finite markets include event tickets, airlines, hotels, perishable goods, and seasonal retail.

Facing the need to liquidate inventory, sellers in finite markets often choose to sell remaining inventory in a side market where it is referred to as “distressed inventory.” Examples of such markets on-line are LastMinuteTravel.com [24] for airline tickets and FairMarket's

AutoMarkdown [19] for retail. AutoMarkdown runs as a multi-unit Dutch auction [19] in which items are initially offered at a high price and then offered at a progressively lower price, down to a specified minimum, or until all inventory is sold. While AutoMarkdown's pricing strategy is basic and does not respond to demand in the marketplace, it is a good example of how dynamic pricing can achieve a finite market's seller's goal of selling all of the inventory.

I will present strategies in this thesis designed for a finite market where the interplay of time, inventory, and revenue determine the seller's success. While more sophisticated than the pricing strategies of Buy.com and AutoMarkdown, my strategy algorithms are still basic in that they make no assumptions about the behavior of the buyers or the type of buyers in the marketplace. Through incremental adjustments in price, these strategies are designed to adapt and learn the behavior of the marketplace, responding to any type of change. While any price changing strategy can be termed a "dynamic pricing strategy," I also refer to these strategies as "adaptive" because of their ability to observe and adapt to market conditions.

## **1.2 The Ballpark Example**

Returning to the example of a ballpark selling baseball tickets, today when scalpers sell tickets outside the park they are reselling tickets purchased through the park's fixed-price policies. Scalpers adjust their prices on as much as a per ticket basis, responding to changes in the time left before the game, weather changes, and the size of crowd heading from the parking lot toward the park. The mere existence of the scalped ticket market is evidence that dynamic pricing is profitable. So why aren't ballparks adjusting their prices?

There are three barriers to changing prices: 1) the cost of implementing instantaneous price changes, 2) buyer acceptance of unpredictable price changes, and 3) the challenge of developing an appropriate pricing strategy. As markets become increasingly digital, the "menu costs" of making instantaneous price adjustments on a large scale approach zero [25]. There are different

ways of managing buyer expectations when implementing dynamic pricing, and these issues will be addressed in this thesis's Conclusion. To address the third challenge, of making instantaneous *strategic* changes in price, I propose a ballpark, or similar seller, use a market simulator to model their market and analyze which pricing strategy is best for their marketplace. And in the next pages, I demonstrate how this approach would work.

### **Using the Simulator**

A ballpark stands to earn more revenue if it can change its prices in such a way as to take advantage of the fluctuations in buyer demand over time. To understand how this can be done, a ballpark would use the *Learning Curve Simulator* to model its market and the behavior of its buyers. The market conditions: the number of potential game attendees, ticket sellers, seats in the park, and days in the market, define the 'finite' nature of the ballpark's market. The behavior of the buyers is described in the *Learning Curve Simulator* in terms of how the buyer population varies on an individual day and over time. Over time, the amount buyers are willing to pay, referred to as their valuation, can fluctuate. The user can choose different shaped curves to express different valuation over time changes. On a single day, the dispersion between the individual buyers is expressed through several variables, including a variance and distribution of the buyers' demand (buyers vs. price curve). The ballpark sets up these parameters in the simulator to begin an analysis of dynamic pricing in its market.

### **Exploring Market Scenarios**

After setting up the basic ballpark market parameters, the ballpark can compare different combinations of strategies in the simulator. Choosing to compare one fixed price seller against one of the simulator's adaptive pricing strategies allows the ballpark to analyze today's situation where the ballpark offers a fixed price and scalpers adjust their ticket prices over time.

The way the ticket buyers' valuation changes over time is hard to predict when it depends on



external market conditions such as weather and the success of the baseball team. Thus it is important to test the success of any pricing strategy under a variety of unpredicted valuation fluctuations. To do this, the ballpark would run multiple simulation trials under different valuation/time curve shapes, for example decreasing, increasing, mid-dipping, or mid-peaking valuation over time.

The charts in Figure 2.4 present the pricing, revenue and sales results of four different trials, as they would be presented in the simulator's interface. Under the first three trials, the adaptive pricing strategy earns more revenue and sells all the ballpark tickets in the park. The fixed-price strategy sells tickets at a price point that could not sell all the seats in the park. In trial four, the fixed price was at a level that did sell all the tickets and the two strategies performed equally well.

After running a batch of such simulations, a ballpark could adjust different market parameters and continue to run exploratory simulations. In addition to adjusting different market parameters, the ballpark could try different dynamic pricing strategies and fine-tune their behaviors. By also adjusting the price offered by the fixed-price seller, different fixed-prices could be found that earned more revenue than the pricing strategies, but as the ballpark would discover, many of the possible adjustments in market parameters, such as changing the valuation/time curves, would reverse the fixed-price seller's success.

Through working with the simulator, the ballpark would see that using an adaptive pricing strategy ensures a certain amount of success, regardless of the market's behavior. If a perfect prediction of buyer valuation over time could be made, then an optimal fixed price could be chosen, but when that optimal price cannot be chosen, an adaptive pricing strategy demonstrates a better performance under most conditions.

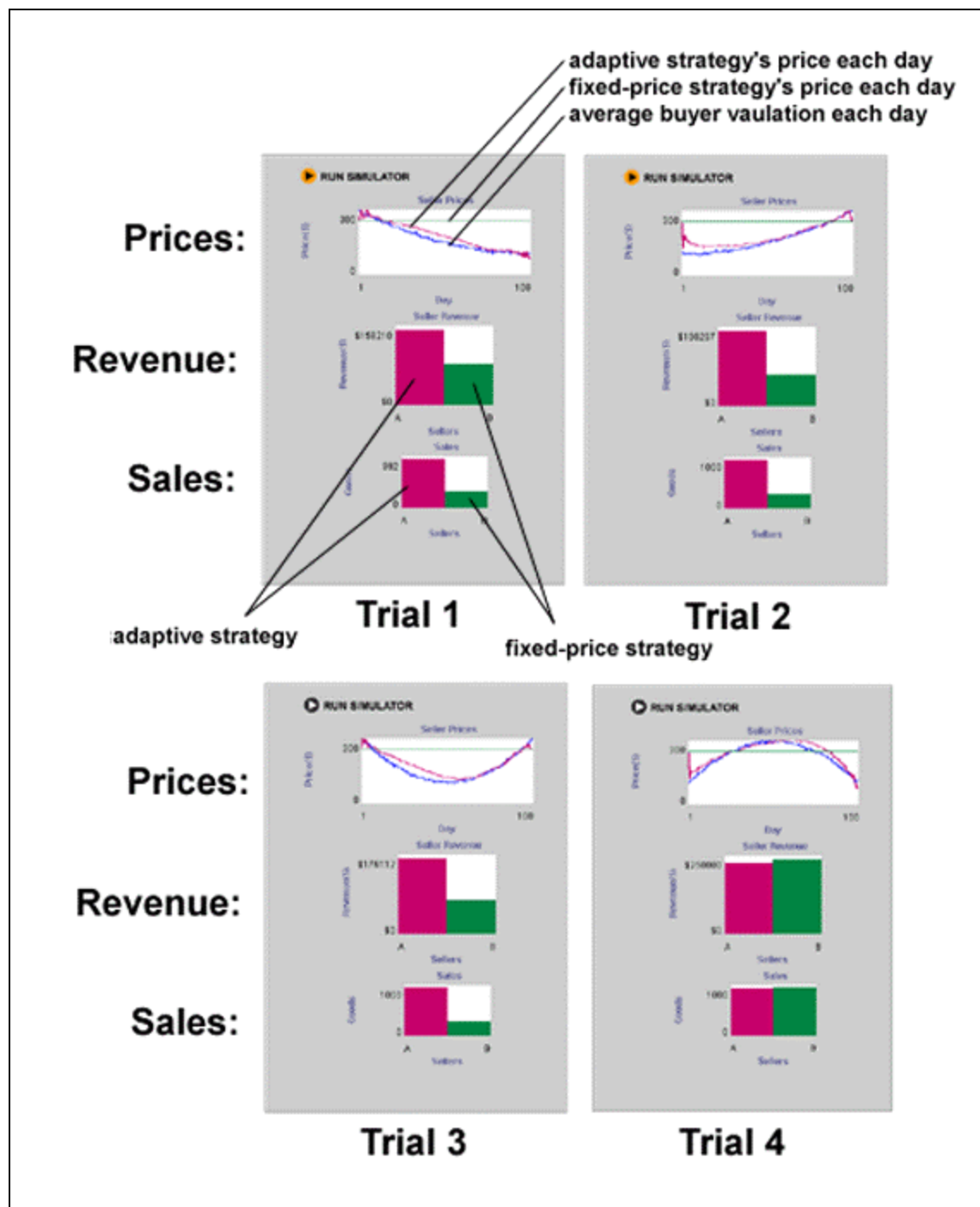


Figure 1.1 Simulator output from three different simulation trials.

One of the goals of this research is to develop a tool that a ballpark, or similar seller in a finite market, could use to explore and understand the conditions for which an adaptive or other dynamic pricing strategy works. By working with the *Learning Curve Simulator*, a ballpark can model its market and test different strategies, to determine an optimal pricing strategy for its specific market conditions. Once an optimal strategy has been determined, a ballpark could take its algorithm and further customize it for the real-world market and eventually deploy the strategy to perform automated price changes in the baseball ticket market.

### **1.3 Overview**

In the following chapter, I will discuss the theoretical underpinnings for this research, with a presentation of related work done in the area of dynamic pricing. In the following chapter, I present the design and implementation of the *Learning Curve Simulator*, from the perspective of the user-interface interaction as well as the backend code design, highlighting how aspects of the simulator are designed to be flexible enough to facilitate future development.

The next two chapters, Strategy Analysis and Usage Analysis, I evaluate the simulator from two perspectives: the simulator as a tool for evaluating pricing strategies and the simulator as a tool to assist real-world sellers in understanding dynamic pricing. My analysis of pricing strategies includes an in-depth analysis of two adaptive pricing strategies termed Goal-Directed and Derivative-Following. These strategies are basic learning algorithms which demonstrate a high amount of success over a fixed-pricing policy. My hope is that in addition to demonstrating the power of a simulation-based approach to strategy analysis, these specific strategies will lay the groundwork for designing more complex algorithms to be deployed in real-world markets. My evaluation analysis of the simulator as a tool for real-world sellers consists of conclusions from meetings with different sellers planning on implementing dynamic pricing. The feedback on the simulator and information about these different sellers' markets highlights some of the challenges in building a general simulator for multiple marketplaces.

This thesis proposes a way of approaching the problem of pricing strategy implementation. We believe dynamic pricing is a powerful idea for increasing revenue in an electronic marketplace, but how should a seller implement effective pricing strategies? In the business strategy magazine Darwin Online, the difficulty and risks of dynamic pricing are summarized with a warning to sellers: “poorly implemented pricing schemes create the potential for competitive price wars and

[16]. The *Learning Curve Simulator* is designed to alleviate these risks of dynamic pricing by providing a mechanism and approach for understanding dynamic markets and analyzing pricing strategies.

## 2 E-Markets & Dynamic Pricing

Before exploring the details of the *Learning Curve Simulator*, it is important to understand the state of today's electronic markets and the previous work done in the area of dynamic pricing.

Electronic markets have dramatically reduced the cost of making changes to price [25], so for the first time sellers are able to realistically make immediate and timely adjustments to price. As evidence of this, several on-line businesses today make automated adjustments in price, as much as every hour.

An example of one such on-line business is Buy.com. As described by [25], Buy.com uses software agents to search competitor's web sites for competing prices, and in response, Buy.com lowers its price to match or beat these prices. Their simple pricing strategy is based on the assumption that their customers are extremely price sensitive and will choose to purchase from the seller offering the lowest price. Not surprisingly, Buy.com has managed to garner enormous sales, but their profits are extremely low, or even negative.

The example of Buy.com highlights two things. First, automated dynamic pricing is a feasible option for companies today. Second, an overly simplistic or incorrect model of buyer behavior can produce undesirable results. Today's economy is ready for dynamic pricing on a more complex scale: more complex in its understanding of buyer behavior and its pricing algorithms. With these changes, sellers stand to increase profits through dynamic price adjustment.

## **2.1 Today's Example: Revenue Management**

The airline industry provides a more sophisticated example of dynamic pricing in today's economy. The airlines use the technique of revenue management to dynamically adjust prices over time by adjusting the number of seats available in each pre-defined fare class, or booking class [5, 21, 24]. Commercial revenue management systems forecast demand, monitor booking activities and, in response, adjust the number of tickets available at each fare level. This method is extremely profitable for the airlines and practiced in other industries such as hotel rooms, the cruise industry, and rental cars. Its success is based on these industries' ability to segment their buyers into different groups with different levels of willingness to pay. Some claim a distinct difference between revenue management and dynamic pricing [4] because of this buyer segmentation, which is not a necessary aspect of dynamic pricing. My investigation of dynamic pricing does not focus on buyer segmentation, or price discrimination, but the airline industry's adjustment of prices over time still demonstrates the potential of earning more revenue by charging "the right customer, the right price, at the right time."

The techniques of revenue management require sellers to make sophisticated assumptions and predictions about the behavior of the marketplace. This limitation was addressed by Gallego & van Ryzin [12] in their discussion of the need to merge the ideas of revenue management with dynamic adjustment of prices, where pricing is determined in response to consumer demand. As the revenue management industry exists today, the prices in each fare class are fixed, yet these price levels influence the market. For example, when the lowest fare class is sold out, the demand for the second-lowest fare class increases. In their work, Gallego & van Ryzin propose a model for blending revenue management, or dynamic programming, with price adjustments based on observed demand, and suggest that this model of price adjustment be applied to new industries, such as the fashion and retail industries.

## 2.2 Buyers in Electronic Markets

While methods exist for using historical data to predict market behavior [21], the potential problem with using previous data to make assumptions about the future, is the risk of being wrong. For example, marketers have made assumption about the behavior of buyers on-line which have been shown to be incorrect.

There is increasing evidence that while the search costs of finding products on the Internet are lower than in the off-line world, there is not a corresponding increase in buyers' sensitivity to prices [10]. Even with tools such as shopbots performing the task of locating goods and comparing prices, buyers seldom purchase from the lowest priced seller, revealing that they have a more complex utility function for that good or vendor. Additionally, when buyers have more information about a product, as they can more easily find in an electronic market, they become even less price sensitive [8]. Another interesting observation of on-line markets is that price dispersion, traditionally thought to be caused by high search costs, can still be high in an environment of low search costs, presumably when buyers have preferences for certain products and sellers [7].

The new purchasing environment created by electronic markets has revealed new and somewhat unpredicted buyer behavior. Initial attempts at providing buyers with shopping assistance (shopbots) and initial use of software agents to adjust prices (Buy.com) both assumed that buyers were extremely price sensitive. Because this has been shown to not be the case, there is a need for more complex tools for buyers [15, 22] *and* for sellers. I propose the *Learning Curve Simulator* as a tool that will allow sellers to deploy dynamic pricing in an electronic marketplace filled with complex buyers.

## 2.3 Theoretical Studies

Earlier work of Gallego & van Ryzin [13] built a theoretical model for calculating optimal prices for finite markets. This model addresses the challenge of dynamic pricing in finite markets, but from a theoretical standpoint. They examine a deterministic version of the problem of pricing under finite time horizons by making the assumption that consumers' demand curves do not change over time. Under these conditions, they conclude that the optimal pricing strategy is “jittery” and requires constant price adjustments, something they considered to be infeasible at their date of publication (1994). They concluded that a fixed-price strategy works “surprisingly well” when the demand curve is known. A “nearly optimal solution” is to have a fixed set of tiered prices that the seller oscillates between, and this is proposed as a more feasible solution than the optimal solution (of continual, incremental price adjustment).

These results can be easily duplicated in the *Learning Curve Simulator*. When the demand curve is known, a best fixed price can be selected to nearly optimize revenue, even under cases of changing demand curves over time. But what my analysis of pricing strategies emphasizes is that one *cannot* assume perfect knowledge of the demand curve, something to which Gallego and van Ryzin concede is more realistic.

In a recent analysis of the automotive industry [4], Biller et al. designed a theoretical model for applying dynamic pricing to a marketplace with unknown changing demand levels. They demonstrate that under fluctuating demand there is always an optimal dynamic pricing strategy which is successful over a fixed-price strategy. The degree of success of the strategy increases depending on the amount of variance among the buyer population and the number of times the seller adjusts prices. Their model [9], focuses on a market with no limits on production, so not “finite,” but these results are similar to the results we have found in the simulator.



## 2.4 Simulation-based Approach

While a theoretical approach to agent pricing strategies could be taken, a theory-based solution is often difficult to apply to a real-world marketplace because of the overly simplifying assumptions that typically need to be made in developing a theoretical model. Simulated marketplaces are able to model more diverse and complex scenarios, rather than the general case. By producing tangible, numerical results, the *Learning Curve Simulator* can be used as a tool for understanding real-world scenarios.

Researchers at IBM have made significant headway [14, 17, 18] in examining the results of buyer and seller agent-driven markets, focusing on markets of information goods. Their analysis of agent-driven markets highlights through simulation some of the potential pitfalls of automated dynamic pricing, such as price wars. In their analysis, they introduced four different agent pricing strategies: game theoretic, derivative following, myopically optimal (dynamic programming), and Q-learning (reinforcement learning). Their game theoretic strategy was used as a benchmark, under the assumption of rational behavior of all buyers and sellers. The complexity of buyer behavior in the *Learning Curve Simulator* prevents the ability to make this assumption of rationality in strategy analysis. Their specific algorithm for the derivative following strategy was adapted for finite markets and will be analyzed in the *Learning Curve Simulator*. Their work has provided a strong background for this investigation of successful strategy development.

Brooks et al. [6] also performed analysis of pricing agents in a simulated market environment and discussed the trade-offs between “exploitation” and “exploration” pricing techniques on the part of the seller. They conclude that when a pricing agent is interested in maximizing revenue over a longer period than the immediate purchase period, a simple learning algorithm works best for markets with high levels of uncertainty. While Brooks examines markets of information goods with no constraints on time or inventory, their use of a simulator to demonstrate the strength of different strategies provides a useful guideline for our analysis.

## 2.5 My Approach

The McKinsey Quarterly [2], a quarterly publication on business strategy, recommends sellers pursue dynamic pricing on-line and start by running different pricing experiments. They state that by making small adjustments in price, sellers can discover the demand levels of their buyers. Despite the abundance of the theoretical studies and optimal pricing strategy conclusions found in the literature, for the real-world seller, making predictions about buyer demand and implementing this as a strategy is far from straightforward, and yet McKinsey's overly simplistic recommendation addresses this difficulty. I propose that the *Learning Curve Simulator* be a model for a practical tool sellers can use to study different pricing strategies, so their exploratory pricing schemes can be more strategic and informed, both by the literature and through first hand experience with a simulated market environment.

As discussed in this chapter, the use of a simulator is a powerful and practical approach to dynamic pricing strategy analysis, and can serve as a platform for modeling the complex behaviors of buyers on-line.

The *Learning Curve Simulator*, as a tool for sellers, addresses the complexities of on-line buyer behavior by providing a rich set of behavior parameters. First, the buyer population in the simulator can be divided into two groups, who each behave according to their own sets of behavior parameters. This allows for the expression of different types of buyer populations within the simulator. To express the dispersion within each group of buyers, the simulator allows for a variance to be indicated for a chosen buyer/price distribution curve. Additionally, price sensitivity is expressed with a selection of the percentage of buyers are comparison shoppers. Preference for a particular type of good or seller is expressed in an option to select a seller as "preferred." Although not a complete or exact model of real-world markets, especially because individual markets contain their own idiosyncrasies, this is a more expressive set of variables than any previous set of simulation-based work for dynamic pricing analysis.

In contrast to the strategies developed by other researchers, the strategies implemented in the *Learning Curve Simulator* are based on machine learning concepts, and thus referred to as ‘adaptive.’ Each of the strategies makes no assumptions about the rationality of market players, but instead makes basic observations and adjustments in price each day.

The following chapter presents the *Learning Curve Simulator* and two adaptive pricing strategies, the Goal-Directed and Derivative-Following strategies, which will lay the groundwork for demonstrating the simulator’s ability to serve as a practical tool for dynamic pricing strategy development.



## 3            **The Learning Curve Simulator**

To present the *Learning Curve Simulator*, this chapter first discusses the simulator's user interface with a description of the user interaction. Next, this chapter covers a high-level description of the back-end code, highlighting the structure of the underlying design. Finally, the two pricing strategies implemented in the simulator are presented, along with their pricing calculations.

### **3.1            Simulator Interaction Design**

The *Learning Curve Simulator's* graphical interface is a Java Swing application, which can run as either a client application or a web applet. It simulates a market based on user-supplied parameters defining a Market Scenario, Buyer Behaviors, and Seller Strategies. The *Learning Curve Simulator's* interface is shown in Figures 4.1 through 4.5. This series of screens illustrates the steps a user takes to set up a model of his/her market and run simulations. Table 4.1 outlines the input parameters collected on each input screen, as discussed below.

Figure 4.1 shows the initial screen of the simulator. At this screen the user selects from a defined scenario to pre-fill the following input screens, or chooses to build a custom market scenario. The first three selections are based on the real-world markets of airline tickets, a grocer selling produce, and a ballpark selling tickets. The remaining selections are designed to illustrate certain strategic results.

#### **The Simulation Cycle**

Before detailing the exact simulator inputs, it is useful to first present how the simulator runs a simulated marketplace based on the inputs. After a user has progressed through the screens in Figures 4.2-4.5, he/she hits the "Run Simulator" button. At that moment, the simulator

sequentially runs through each “day,” or time period, of the market. Each day, a random number of buyers enter the market, based on a uniform distribution of buyer entrance over the entire market. These buyers stay in the market until either they have purchased a good or their lifetime has expired. On a single day, each buyer, in random sequence, searches through the available sellers, in random sequence, and compares the seller’s price with its own reservation price. If the seller’s price is less, a transaction occurs and the buyer leaves the market. If the seller’s price is more, the buyer continues looking. The day ends when each buyer has completed its search through the sellers. At the end of the day, a new reservation price for each buyer is calculated based on the user-provided buyer behavior parameters, and each seller updates its price based on its chosen pricing strategy. If the seller is using a Fixed-Price strategy, there is no change to the price. If the seller is using an adaptive pricing strategy, the seller examines different results from the market, such as how many goods it has sold or how much revenue it has made in the previous day and uses this information to calculate a new price. In this manner, the market progresses until the last day, stopping only if there are no more buyers or no more goods in the market.

The speed of each simulation run depends on the number of buyers in the market who need to search through the sellers. A simulation with 4000 buyers runs in approximately three seconds and the same simulation with 40,000 buyers runs in approximately 30 seconds.

### **Market Scenario**

Now that the process of providing the simulator input parameters is presented. The first series of simulator inputs are the Market Scenario inputs, shown in Figure 4.2. The Market Scenario is used to set the parameters of the finite market: the number of days, buyers, sellers, and goods. It also sets the market mechanism, buyer population segmentation, the costs of the market (cost of production and marginal cost per good), and the initial price offered by the sellers.

The number of days defines the number of periods the sellers can change their prices and the

number of instances buyers can enter the marketplace. The number of sellers in the market determines whether or not this is a monopoly or competitive environment. The number of goods per seller, as compared with the number of buyers, determines which parameter constrains the market: buyers or goods. The choice of constraining parameter effects the outcome of different strategies as will be shown in the analysis section.

The buyer population can be segmented or divided into two groups, either into a 50/50 split or a 75/25 split. By segmenting the buyers, the user then will define separate buyer behavior parameters for each of these groups and they will be joined in one population for the market simulation. The purpose of segmenting the population is to allow for users to express different sub-groups within their customer population.

The sellers' costs are defined as the cost of production and the marginal cost per good. Many finite markets, such as a ballpark, have a marginal cost of zero per good, so the major cost of the market is the initial cost of production. Although an overly simplistic assumption, the costs for each seller in the simulator are considered to be identical. Because it is assumed that margin costs are low (i.e. negligible) and because there is no distinction made between each seller's costs, the results of the simulation are reported in terms of revenue (price \* units sold), not profit (revenue – costs).

The “initial price” input value is the price offered by each of the sellers on the first day of the market. This value can be adjusted on a per seller basis on the Seller Strategies screen.

When setting the market mechanism, the user chooses between Posted-Price and First-Price Auction. A Posted-Price market is the typical market consumers face today in which sellers publicly post prices and buyers view the prices and choose to purchase for that price, or not. The other choice for market mechanism is a very basic auction, termed a First-Price Auction. In this auction, there is one bidder per seller at each instance. When a buyer places a bid equal to its

reservation price, it is compared to the seller's reserve price and if it is higher, then the buyer pays the bid price for the good. There is no competition between the bidders and the bidders do not know the sellers' prices in the marketplace. The purpose of building this auction mechanism was to test different strategies designed for an auction scenario.

### **Buyer Behavior**

After defining the Market Scenario, the user then defines the behavior of the buyers in the market, both in terms of their behavior on a per day basis and their behavior over time. These parameters are shown in the screenshots in Figures 3.3 and 3.4.

The behavior of the buyers on a single day of the market is defined in several ways. First, the buyer population can be segmented into two groups, defined by the Market Scenario on the previous screen, in a ratio of either 50/50 or 75/25. When the buyer population is segmented, there are two tabs in the interface for these two groups, and each of the buyer parameters can be defined for these separate groups. The results of the market simulation will present the combination of the two buyer segments as one population.

For each buyer segment, the dispersion among the buyers' reservation prices each day is defined by the variance and daily buyer/price distribution. The variance sets the range for the spread along the chosen distribution curve. The distribution curves model different types of demand curves: the common decreasing curve, an increasing curve which could apply to a luxury item where more buyers are willing to pay more for the good, a double peaked curve which applies to markets with two-tiers of buyers (such as leisure and business travelers), and a mid-peaking curve which applies to a market in which there is a commonly understood average value for the item.

In addition to modeling the dispersion among buyers each day, the user has the choice of how many buyers will be comparison shoppers. Comparison shoppers are defined as buyers who look at the prices of each seller and buy from the seller with the highest percentage discount below



their reservation price. When a buyer is not a comparison shopper, it will check multiple sellers' prices only until a match and will then immediately purchase.

The final parameter determining the daily behavior of buyers is the designation of certain sellers in the market as "preferred." A preference for a seller can express real-world differentiation among products and sellers, due to higher quality, better product features, and brand loyalty. When a seller is selected as preferred, buyers are willing to pay 20% more for that seller's products. While this percentage mark-up is configurable in the back-end of the simulator, it was designed in this basic form to simplify the interaction with the simulator.

The behavior of the buyers over time is defined by four variables: the lifetime, the minimum and maximum prices, and the valuation curve, each shown in the bottom half of the Buyer Behavior screens, in Figures 3.3 and 3.4. The lifetime parameter indicates how "patient" the buyers are: how many days they are willing to wait in the market, continuously looking for the right price. If the buyer is still looking at the end of its lifetime, it leaves the market without purchasing. The valuation curve choice determines how the buyers' average reservation prices, or valuation, changes over time, by either a flat, decreasing, increasing, mid-dipping, or mid-peaking curve. The minimum and maximum prices define the minimum and maximum values on this valuation/time curve. The buyers' valuation on a single day is a significant factor in how many sales a seller makes, and the more successful sellers are the ones that can effectively follow the changes in the buyers' valuation over time.

### **Seller Strategies**

The final step to setting up the market is to specify which pricing strategy each seller uses, shown in the left pane of the final screenshot, Figure 3.5. The simulator is designed to allow multiple strategies to work within the same market, so a user can compare how a strategy performs compared with other strategies in the marketplace. For simplicity of comparison, a maximum of

four strategies can be presented at one time in the simulator, and only three are shown in Figure 4.5. The three strategies available are Fixed-Price, Goal-Directed, and Derivative-Following. Each of these strategies are discussed and evaluated in the Strategy Analysis chapter.

The user can adjust each strategy by changing the initial price offered by the seller and by choosing to limit the number of goods sold in a single day for each seller. Changing the initial price effects the first day of sales, and of course, every day after in the case of a Fixed-Price strategy. Some of the strategies use this initial price in the pricing calculation, so this initial price also effects the behavior of these strategies over time. Sales can be limited each day to represent actual market limitations to selling an entire inventory in a single day. When the user chooses to limit the sales, that seller can only sell three times the ratio of goods to days. In practice, this constricts the behavior of the sellers, producing less drastic changes in prices because there are less drastic discrepancies in sales between days.

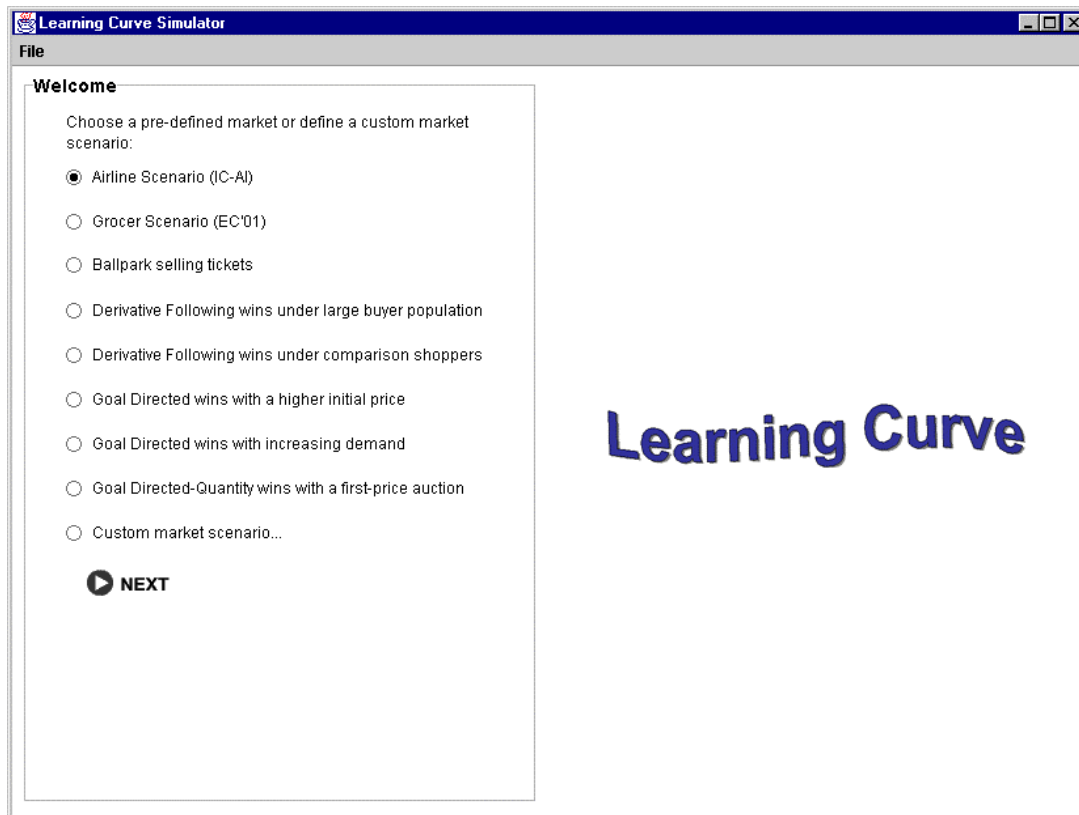


Figure 3.1: Learning Curve Simulator – Choose from a pre-defined scenario

**Learning Curve Simulator**

File

**Market Scenario** | Buyer Behavior | Seller Strategies

**Market**

Number of Days: 80

Number of Buyers: 5000

Market Mechanism: Posted-Price

Segment Buyer Population? Yes, 50%-50%

**Sellers**

Number of Sellers: 5

Number of Goods per Seller: 1000

Fixed Cost (\$): 5000

Marginal Cost per Good (\$): 10

Initial Price (\$): 200

**NEXT**

**SIMULATOR OUTPUTS**

Figure 3.2: Learning Curve Simulator – Defining a market scenario

**Learning Curve Simulator**

File

**Market Scenario** | **Buyer Behavior** | Seller Strategies

**Buyer Segment A** | Buyer Segment B

**Buyer Behavior Each Day**

Price Variance Each Day (+/- \$): 25

Price Distribution (Buyers/Price): ☐ ☐ ☐ ☐ ☒ ☐ ☐

% Comparison Shoppers: 0 25 50 75 100

Preference for Certain Sellers:

☐ Seller A ☐ Seller B ☐ Seller C

☐ Seller D ☐ Seller E

**Buyer Behavior Over Time**

Buyers' Lifetime in Market: 5

Buyers' Min Price (\$): 100 Buyers' Max Price(\$): 300

Change in Buyers' Prices over Time:

☐ ☒ ☐ ☐ ☐

**SIMULATOR OUTPUTS**

Figure 3.3: Learning Curve Simulator – Defining the behavior of buyer population segment A



<b>Simulator Inputs:</b>	<b>Description</b>
<b>Market Scenario:</b>	
Number of Days	Number of periods in the market. Each seller can change its price at the end of a day.
Number of Buyers	The size of the buyer population over the entire market.
Market Mechanism	Posted-Price or First-Price Auction.
Buyer Segmentation	The buyer population can optionally be divided into two groups, either in a 50-50 or 75-25 ratio.
Number of Sellers	Number of sellers.
Number of Goods	Initial inventory for each seller.
Fixed Cost	Cost of producing the inventory
Marginal Cost per Good	The additional cost of selling each good. This is often zero in a finite markets.
Initial Price Offered	The initial price all the sellers will offer in the market. This parameter can be adjusted on a per seller basis on the Seller Strategies screen.
<b>Buyer Behavior:</b>	
Daily Price Distribution	The demand distribution of buyers on a single day. Available choices are normal distribution, positive slope, negative slope, or segmented into a high and low grouping.
Price Variance Per Day	The buyers' reservation prices vary $\pm$ the variance in a single day. The variance determines the range for the daily price distribution.
Percentage Comparison Shoppers	The percentage of the buyer population (0-100%) who compare each seller's offer price and purchase from the seller with the greatest % discount below its reservation price for that seller.
Preference for Certain Sellers	The entire buyer population can have a preference for one or more of the sellers, which is represented by a higher reservation price for that individual seller. This is a method for expressing product and seller differentiation.
Lifetime	Number of days a single buyer will be in market, actively looking for seller. Regardless of lifetime, once a buyer purchases, it leaves the market.
Buyer Valuation over Time	Over the course of the market, the buyers' demand curve will change, and the valuation/time curve expresses how the demand will change over time. The shape of the curve can be either flat, increasing, decreasing, mid-peaking, or mid-dipping over time.
Minimum/Maximum Buyer Prices over Time	The range of prices for the buyer valuation curve. These values are the minimum and maximum reservation prices over the market.
<b>Seller Behavior:</b>	
Seller Strategies	The different pricing strategies sellers use in the market, either Goal-Directed or Derivative-Following. .
Initial Prices	The different prices sellers offer on the first day of the market, before adjusting price through the chosen strategy.
Available Inventory per Day	Amount of inventory a seller can sell in one day. This can be limited to represent shelving costs and to prevent 100% inventory sell-off in a single day.

*Table 3.1: Learning Curve Simulator Inputs*

## Simulator Output

After the simulator runs, the results are presented in the right pane of the interface, as shown in Figure 3.5. These results summarize the market in terms of pricing, revenue, and sales. Additional output detailing each day and each transaction is also saved to a tabbed-delimited file on the user's machine. If the user had clicked 'Run 100 Simulations,' after 100 identical simulations ran, an output file would be created for each simulation, and a summary file would be generated that reported the final revenue and sales of each seller per simulation.

Returning to the visual output presented in the interface, the top chart in Figure 3.5 shows the pricing behavior of each seller on each day in relation to the average reservation price of the buyers. The next two charts report the revenues and sales of each seller. Revenue is the sum of

the sale prices of each good sold. The total sales amount is the amount of inventory sold per seller. The success of the individual strategies is measured by the amount of revenue and sales and the pricing chart is used to understand how the sellers priced their goods and achieved their revenue and sales results. As shown in these results, it is straightforward to see which strategy earned the most revenue and sold more inventory, which makes the pricing chart the most interesting to watch between simulations.

The interface of the *Learning Curve Simulator* allows it to act as a tool for exploring and learning how competitive pricing strategies and buyer behaviors effect the success of dynamic pricing in different markets. To support an exploration process, the simulator's interface is built so that any input parameter in the Market Scenario, Buyer Behaviors, and Seller Strategies can be adjusted and from that input screen, the simulator can be run again. The ease of running, adjusting, and then running again, allows for experimentation and exploration. By producing immediate visual results, this interface is an effective way of exploring and testing different agent strategies.

## 3.2 Simulator Code Design

After outlining the simulator's functionality from the perspective of the interface, the code design is presented here as an overview of the underlying workings of the simulator.

The *Learning Curve Simulator* is built in three tiers: a general market framework, a detailed framework for the "learning curve" aspects of the market, and the graphical user interface. These three tiers are built in Java 1.3, forming the three Java packages: 'marketplace,' 'lc,' and 'gui,' respectively.

Simulator's Java Packages	Core Package Classes
gui	LearningCurveIO
lc	SimulationDriver
marketplace	Engine

Table 3.2: Core Simulator Classes, within each simulator package

The interaction between these three functional tiers is directed by the communication between the core Java classes: 'gui.LearningCurveIO,' 'lc.SimulationDriver,' and 'm' outlined in Table 3.2. When a user interacts with the simulator, he/she interfaces with the Swing interface, the Java object named LearningCurveIO. When the simulator inputs have been gathered, LearningCurveIO passes the inputs to the class SimulationDriver. The SimulationDriver manages the creation of the *Learning Curve* buyers and sellers, and then sends these market players to the core of the simulator, the Engine class. The Engine iterates through each day of the market simulation, managing the matching of buyers and sellers. At the end of each day, the Engine stores information about each successful market transaction and informs the sellers and buyers to update their prices. At the end of the market, the Engine reports the market's results to the SimulationDriver, which sends the results the LearningCurveIO which visually presents these results to the user.

The marketplace and the lc packages contain several additional classes, which are outlined below in Tables 3.3 and 3.4. The classes in each package are categorized by their role in the simulator,

according to whether they are framework pieces, utilities, or players in the market. The ‘marketplace’ classes provide a structure for any type of marketplace, because it assumes nothing about the characteristics or behaviors of the buyers or the sellers. The classes in ‘marketplace’ outline the structure of a market by defining Java interfaces for buyers and sellers which are then implemented in detail in the ‘lc’ package. If another type of market were to be implemented, the ‘marketplace’ package could serve as a starting point and the designer would implement the Java interfaces in the ‘marketplace’ package and any additional classes deemed necessary.

MARKETPLACE PACKAGE	
Java Class	Functional Description
<b>Market Framework</b>	
SimulationState	Framework piece which coordinates the state of the simulator: the current day and which buyers and sellers are actively looking for transacting.
Engine	Framework piece which runs the simulated market. Based on information from the SimulationState, locates buyers and sellers and pairs them for negotiation.
<b>Market Players</b>	
TransactionParty	A generic player in the market (Java interface).
Buyer	A generic buying player (Java interface).
Seller	A generic selling player (Java interface).
Good	The object that is exchanged between market players.
<b>Market Utilities</b>	
SellerStrategy	A generic interface for a seller strategy.
Strategy	A generic strategy of any player.
Lifetime	Gives a player a random lifetime (beg and end date), based on a duration value.
Negotiation	Mechanism for matching up buyers and sellers based on different market mechanisms. It returns the sale price or 0, depending on the result of the negotiation.
Distribution	Generic utility for generating numbers in a specified distribution, based on a histogram distribution model.
Results	Utility for storing the results of the simulation.
Receipt	Utility for storing each sale’s receipt. Receipts are created by sellers and contain all information a seller knows about its sale.
Day	Utility for organizing simulation results by the events of each day.

*Figure 3.3: marketplace Java classes*

The ‘lc’ package defines the specific behavior of the buyers and sellers by implementing Buyer and Seller classes in the ‘marketplace’ package as the LCBuyer and LCSeller classes. The ‘lc’ package is designed so that many different seller strategies can be implemented in the simulator. This is accomplished by defining each strategy as a class which implements the ‘marketplace.SellerStrategy’ interface. This design makes the addition of new strategies trivial.



Table 3.4 lists the classes in the ‘lc’ package, including a complete list of the strategies implemented in the simulator.

LC PACKAGE	
Java Class Name	Functional Description
<b>Learning Curve Players</b>	
LCBuyer	LCBuyer is the specific implementation of a buyer in the <i>Learning Curve Simulator</i> . Each buyer object has different characteristics, such as: an array of reservation prices for each seller, a beginning and ending day in the market, a preference for certain buyers, a designation as a comparison shopper or not. The buyer’s reservation price is calculated each day based on all of its characteristics.
LCSeller	LCSeller is the specific implementation of a seller in the <i>Learning Curve Simulator</i> . Each seller has a certain amount of inventory, a designated strategy, an initial offer price, and its receipts from its sales. Each day, the seller uses its sales receipts and its strategy to calculate a new offer price.
<b>Learning Curve Utilities</b>	
SimulationDriver	The SimulationDriver initializes the simulator by directing the InputVariables to the marketplace.Engine and creating the populations of buyers and sellers.
LearningCurve	This utility is for running the simulator from a command line (vs. the GUI).
InputVariables	This class coordinates all of the input variables for the simulator, gathering them either from the GUI or the command line.
DemandCurve	This utility calculates the average reserve price for the buyer population on a given day, provided the specified shape of the valuation/time curve.
SStrategyFP, SStrategyDF, SStrategyDFA, SStrategyGO, SStrategyGOA, SStrategyGOQ	Each of these classes implements the SellerStrategy interface. These seller strategies determine the reserve price offered by a seller on a given day. The strategies use the sales receipt information of the seller to calculate a new offer price. FP = Fixed-Price DF = Derivative-Following DFA = Derivative-Following, adjusted for market day GO = Goal-Directed (or Goal-Oriented) GOA = Goal-Directed, adjusted for market day GOQ = Goal-Directed, Quantity.

Table 3.4: lc Java classes

### 3.3 Simulator Strategies

The *Learning Curve Simulator* is designed to accommodate any dynamic pricing strategy. The initial analysis of dynamic pricing focuses on adaptive pricing strategies – strategies which make basic observations within a market and respond with basic price adjustments. Presented here are two such strategies, the Goal-Directed and Derivative-Following strategies. They each execute dynamic pricing by making incremental, exploratory adjustments to price each day in an attempt to learn the demand in the marketplace. The key characteristics of these strategies are their relative computational simplicity and the lack of assumptions about the behavior of competitors or buyers.

#### Goal-Directed

The *Goal-Directed* (GD) strategy adjusts its price by attempting to reach the goal of selling the entire inventory by the last day of the market, and not before. By lowering prices when sales are low and raising prices when sales are high, this strategy paces its sales over the market, with the plan of selling to the highest paying buyers on each individual day. Equation 1 presents this strategy calculation.

$$\begin{aligned} \text{price}_{i+1} &= \text{price}_0 + \text{price}_0 * \frac{\sum_{n=1}^i \text{goodsSold}_n - \text{expGoodsSold}_i}{(\text{expGoodsSold}_i)} * \text{scale}_i \\ \text{expGoodsSold}_i &= \left( \frac{\text{initialInventory}}{\text{daysInMarket}} \right) \\ \text{scale}_i &= \frac{\text{daysInMarket}}{2 * (\text{daysInMarket} - i)} \end{aligned}$$

Figure 3.6: Goal-Directed Calculation

The GD calculation has been modified from my previous work [23] with the addition of a scaling factor ( $\text{scale}_i$ , in Figure 3.6). This scaling improves the strategy's ability to make price adjustments at the end of the market. By incorporating in knowledge of the progress through the market, the strategy now has the ability to make dramatic price changes during the last days,

when sales are most important. As presented in [23] and as will be demonstrated below, the GD strategy performs best under high variance among the buyer population and when sales are less critical during the first days of the market.

### **Derivative-Following**

The *Derivative-Following* (DF) strategy adjusts its price by looking at the amount of revenue earned on the previous day as a result of the previous day's price change. If yesterday's price change produced more revenue per good than the previous day, then the strategy makes a similar change in price. If the previous change produced less revenue per good, then the strategy makes an opposing price change. Revenue per good is equivalent to the sale price, except in the case when no goods are sold, so following this calculation, the seller will always sell at the highest price that generates sales.

$$\begin{aligned} \text{price}_{i+1} &= \text{price}_i \pm \text{change}_{i+1} \\ \text{change}_{i+1} &= \text{price}_i * \left( \hat{a} + \left( \frac{\text{daysInMarket} - i}{(\text{daysInMarket} + i) * \hat{a}} \right) \right) \end{aligned}$$

*Equation 3.7: Derivative-Following Calculation*

This strategy calculation, shown in Equation 3.7, is an adjustment of the strategy analyzed by Kephart, et al in [17]. I tailored the DF's performance for a finite market by incorporating a scaling factor which takes into account the day of the market, much like the scaling factor in the GD strategy. Instead of adjusting the price each day by a fixed percentage, the change ( $\text{change}_{i+1}$ , in Figure 3.7) is scaled by a ratio based on the progress through the market. As will be shown in the analysis sections, the DF strategy performs best in the initial days of the market and reacts most strongly to competitive factors. When a market has a high percentage of comparison shoppers, DF sellers generate price wars, particularly when competing with other DF sellers.



## 4 Strategy Analysis

To evaluate the impact of the *Learning Curve Simulator* as a tool for evaluating strategies and as a tool for sellers to understand dynamic pricing, the evaluation consists of two distinct parts. The first evaluation of the simulator, found in this chapter, takes the form of an in-depth analysis of the behavior of the different strategies within the simulator. This analysis compares two strategies, the Goal-Directed (GD) and the Derivative-Following (DF), under different buyer behavior conditions, with the purpose of demonstrating the relevant factors to their success. The second evaluation is a less formal analysis towards understanding how effective the simulator is as a tool for real-world sellers. This analysis follows in the next chapter, Usage Analysis.

The Goal-Directed and Derivative-Following strategies demonstrate just two approaches to dynamic pricing within finite markets, based on the concepts of adaptive learning. Other strategy approaches, such as dynamic programming [3], could be applied to the simulator and the potential of alternative strategy approaches will be addressed in the Conclusion chapter. My hope is that these two strategies will lay the groundwork for designing more complex strategies designed to be deployed in real-world markets.

### 4.1 Analysis Process

The following pages present an analysis of the GD and DF strategies under a small set of changing buyer behavior parameters, presenting the conditions which were found to be most influential over the success of each strategy. Based on the input parameters detailed in Chapter 3 (see Table 3.1), Table 4.1 presents the values used in each evaluation simulation. The values shown in italics varied between simulation trials.

<b>Simulator Inputs:</b>	<b>Values</b>
<b>Market Scenario:</b>	
Number of Days	100
Number of Buyers	<i>Four times as many as the number of goods (4000) or Equal to the number of goods (1000 or 2000)</i>
Market Mechanism	Posted-Price
Buyer Segmentation	None
Number of Sellers	<i>1 (monopoly) or 2 (competition)</i>
Number of Goods	1000/seller
<b>Buyer Behavior:</b>	
Daily Price Distribution	Mid-peaking distribution
Price Variance Per Day	<i>\$0 or ±\$50</i>
Percentage Comparison Shoppers	0% or 100%
Preference for Certain Sellers	No seller preference or one seller preference
Lifetime	<i>1 or 5 days</i>
Buyer Valuation over Time	<i>Increasing, decreasing, mid-peaking, and mid-dipping curves</i>
Minimum/Maximum Buyer Prices over Time	Minimum: \$100 Maximum: \$300
<b>Seller Behavior:</b>	
Seller Strategy	<i>GD or DF</i>
Initial Price	\$200
Available Inventory per Day	3*(initial inventory/days)

*Table 4.1: Simulator Input Values used in my Analysis  
The parameter values in italics varied between different trial simulations.*

The two strategies are first analyzed under monopoly conditions, next under competitive conditions and third under buyer segmentation. In every trial presented, the market contained 100 days and each seller had 1000 goods. For each market trial, the strategies were tested under four different buyer valuation/time curves. The success of the strategies is examined under different types of buyer populations (number of buyers and variance among buyers) in a monopoly setting. Then, an analysis of the strategies under competition is conducted, examining the effect of comparison-shopping and buyer preference for certain sellers.

The simulation results are shown in Tables 4.2-4.8. For each of the pricing charts shown in the tables, the vertical axis represents price – both the price offered by the seller and the price the average buyer is willing to pay – and the horizontal axis plots time across the market. On each chart, the vertical axis ranges from \$0 to \$350 and the horizontal axis ranges from 0 to 99 days. The darkest curve is always the average buyer reservation price and the lighter curves are the prices offered by the sellers. The revenue and sales results below each chart report the averaged results over 100 simulations  $\pm$  one standard deviation.

## 4.2 Monopoly: One Seller in the Market

To provide a baseline for analysis, Table 4.2 contains the results of eight simulations with one seller in the market, first using the GD strategy and then the DF strategy. In each simulation, there is zero variance within the buyers' daily price distribution and many, long-term buyers in the market. The charts illustrate the characteristic behavior of the GD and DF strategies under each of the buyer valuation curves. In these trials, the standard deviations are zero because there is no randomness to the results when there are numerous buyers in the market and there is no variation between the buyers.

Shown in the left column of Table 4.2, the GD strategy follows each buyer valuation curve very closely after a brief oscillation period. If the seller still has inventory to sell on the last days of the market, the GD strategy results in another period of price oscillation in order to sell the remaining inventory. While the strategy succeeds in finding and following the demand curve, this is not always the best approach to the market. For example, in the case of constantly decreasing valuation over time, the GD seller paces its sales to include sales on the worst days of the market. Reflecting this poor behavior, this is the only case in which the GD strategy earned less revenue than the DF strategy.

The DF strategy also successfully follows each buyer valuation curve, but in a pattern of over- and under-shooting, shown in the right column of Table 4.2. When there is no variance in a large buyer population, the DF strategy sells its entire inventory at the halfway point through the market, and depending on the valuation curve, this is often not to the strategy's benefit. Only in the case of decreasing buyer valuation over time, where it is to the seller's advantage to sell during the first half of the market, did the DF strategy outperform the GD strategy.

The effect of variance within the buyer population is shown in Table 4.3. In the sample pricing chart, both strategies adjust their pricing curves to be higher than the average buyer price, thereby

capturing the buyers who are willing to pay the highest prices each day. Again, the DF strategy prevails on the decreasing valuation curve because it does not sell goods at the last, i.e. worst, days of the market, unlike the GD strategy. Comparing these results to the initial case with no price dispersion between the buyers, both strategies produce significantly more revenue for the sellers under each valuation curve because they are able to raise their prices to meet the demand of the buyers willing to pay higher prices on a single day.

Table 4.4 presents the simulation results when there are the same number of buyers in the market as goods (1000) and the buyers each have a lifetime of one day, limiting the number of opportunities a seller has to make a sale. As the results show, under most curves, the GD strategy sells a significantly larger amount of inventory than the DF strategy, but this does not always lead to higher total revenue. The sample pricing chart demonstrates the behavior of the two strategies under the mid-peaking valuation curve. The GD strategy falls far below the buyer valuation curve when sales are slow, and near the end of the market drops the price down to \$1 in an attempt to sell the remaining inventory. While it does manage to sell inventory, it does not do so at the best price! Conversely, the DF strategy follows the curve closely as it has during the previous trials and manages to maximize revenue per seat over the course of the market. Shown in the mid-peak valuation curve, the DF strategy has achieved almost perfect matching of the valuation curve. Examining the revenue results, the DF strategy produces more revenue than the GD strategy except in the case of mid-peaking where the GD strategy managed to sell almost its entire inventory at a mediocre price, while the DF strategy only sold two-thirds of its inventory.

When the market is severely limited in the number of buyers, the contrasting approaches of the strategies demonstrate strengths and weaknesses. The GD overcompensates for the shortage of buyers and sacrifices daily revenue for daily sales. If it can manage to sell its entire inventory, then the total revenue makes up for the sacrifice. The DF strategy, by focusing on revenue per good, consistently makes sales on each day of the market, at the highest possible price which can



eliminate lower-paying buyers. When it is able to sell a large percentage of its inventory, the total resulting revenue is high.

When high variance is coupled with a small buyer population, the results are quite interesting. What is most notable about the results shown in Table 4.5 is that the DF strategy sells only a third of its goods under all valuation curves except the increasing curve. Examining the DF pricing curve, the pricing behavior looks very similar to the pricing under a higher variance (shown in Table 4.3), falling just above the average buyer curve. DF does adjust for the limited number of buyers, and this lack of adjustment costs the seller the majority of its potential sales.

Contrast this result with the performance of the GD strategy. Referring to the sample pricing curve, the GD strategy is able to sell at a relatively high price just before midway through the market because of the higher variance in buyer valuations. Then, when sales slip in the second half of the market, the GD strategy keeps a low price, and finally drastically drops the price to \$1 at the end of the market. Both in sales and total revenue, the GD strategy performs extremely well. Although on average, it is selling at a lower price than the DF strategy, selling over 90% of its revenue produces significantly higher revenue.

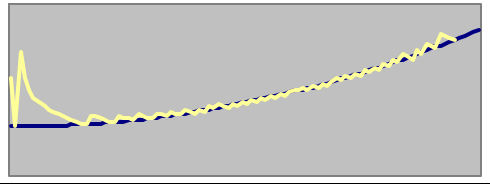
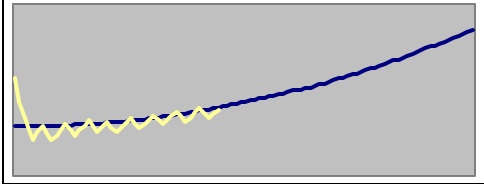
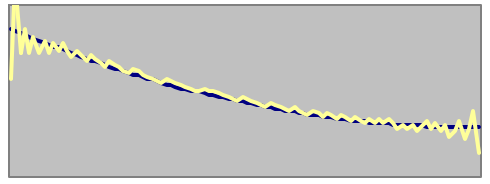
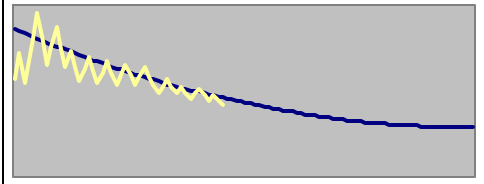
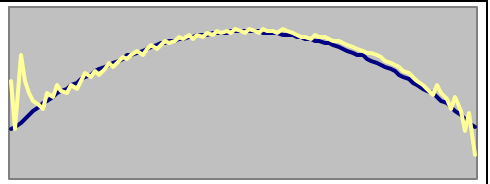
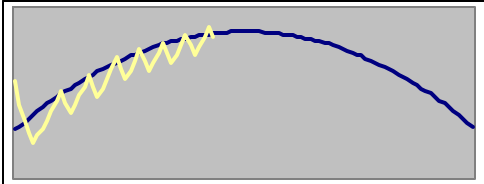
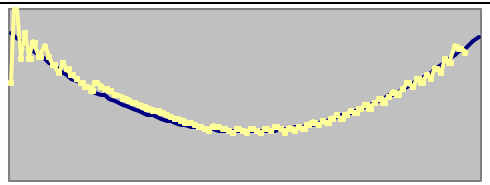
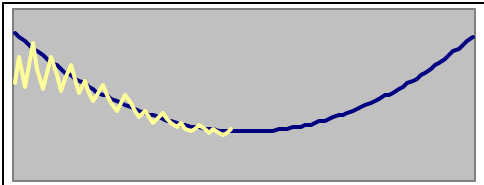
Valuation / Time	Goal-Directed Strategy	Derivative-Following Strategy
	After an initial oscillation period, the GD strategy follows the buyer valuation curve, pacing its sales through the entire market. Incorporated into the GD pricing calculation is an ability for the strategy to perform more drastic price adjustments at the beginning and ending of the market.	The DF strategy follows the buyer valuation curve by over and under-shooting each period. When the market is saturated with buyers, this enables the seller to sell out of inventory half way through the market (as shown by the curve's disappearance).
Increasing		
	Revenue: \$168,320 $\pm$ 0      Sales: 1000 $\pm$ 0	Revenue: \$101,910 $\pm$ 0      Sales: 1000 $\pm$ 0
Decreasing		
	Revenue: \$148,170 $\pm$ 0      Sales: 990 $\pm$ 0	Revenue: \$203,530 $\pm$ 0      Sales: 1000 $\pm$ 0
Mid-Peaking		
	Revenue: \$226,350 $\pm$ 0      Sales: 1000 $\pm$ 0	Revenue: \$196,760 $\pm$ 0      Sales: 1000 $\pm$ 0
Mid-Dipping		
	Revenue: \$159,940 $\pm$ 0      Sales: 1000 $\pm$ 0	Revenue: \$155,710 $\pm$ 0      Sales: 1000 $\pm$ 0

Table 4.2: Simulation results under Monopoly conditions with No Variance and Many, Long-term Buyers  
The darkest curve is the average buyer reservation price on each day (valuation/time). The lighter curve is the price offered by that seller on a particular day.

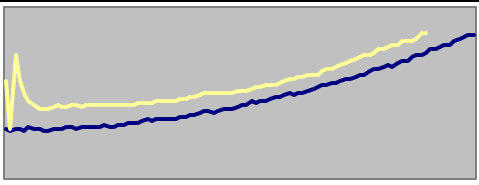
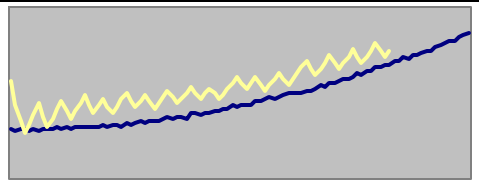
	Goal-Directed Strategy With High Variance		Derivative-Following Strategy With High Variance	
Sample Pricing Chart				
Valuation Curve:	Revenue:	Sales:	Revenue:	Sales:
Increasing	\$199,680 ± 149	1000 ± 0	\$149,036 ± 1089	1000 ± 0
Decreasing	\$208,673 ± 847	994 ± 7	\$228,689 ± 1078	1000 ± 0
Mid-Peaking	\$275,052 ± 601	991 ± 2	\$243,633 ± 1228	1000 ± 0
Mid-Dipping	\$202,006 ± 198	1000 ± 0	\$189,358 ± 739	1000 ± 0

Table 4.3: Monopoly with High Variance and Many, Long-term Buyers

The darkest curve is the average buyer reservation price on each day (valuation/time). The lighter curve is the price offered by that seller on a particular day.

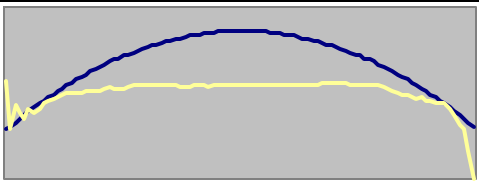
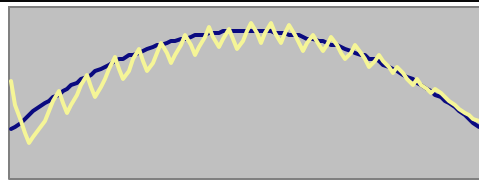
	Goal-Directed Strategy With Few Buyers		Derivative-Following Strategy With Few Buyers	
Sample Pricing Chart				
Valuation Curve:	Revenue:	Sales:	Revenue:	Sales:
Increasing	\$79,176 ± 4598	814 ± 16	\$123112 ± 2690	790 ± 13
Decreasing	\$107,441 ± 2642	811 ± 13	\$111,492 ± 2759	710 ± 15
Mid-Peaking	\$162,147 ± 5530	955 ± 7	\$144,724 ± 3497	641 ± 14
Mid-Dipping	\$66,936 ± 2788	\$740 ± 16	\$120,720 ± 2398	782 ± 12

Table 4.4: Monopoly with No Variance and Few, Short-term Buyers

The darkest curve is the average buyer reservation price on each day (valuation/time). The lighter curve is the price offered by that seller on a particular day.

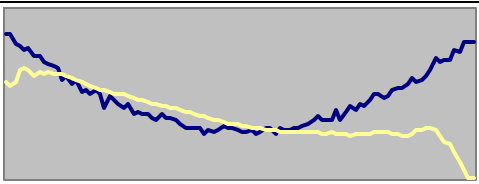
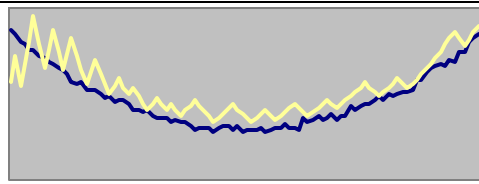
	Goal-Directed Strategy With High Variance & Few Buyers		Derivative-Following Strategy With High Variance & Few Buyers	
Sample Pricing Chart				
Valuation Curve:	Revenue:	Sales:	Revenue:	Sales:
Increasing	\$141,958 ± 4619	999 ± 3	\$189,363 ± 4114	977 ± 22
Decreasing	\$127,302 ± 2107	889 ± 13	\$67,333 ± 4180	328 ± 21
Mid-Peaking	\$207,286 ± 2036	972 ± 5	\$85,747 ± 5860	335 ± 24
Mid-Dipping	\$102,601 ± 4409	907 ± 17	\$75,253 ± 4669	372 ± 25

Table 4.5: Monopoly with High Variance and Few, Short-term Buyers

The darkest curve is the average buyer reservation price on each day (valuation/time). The lighter curve is the price offered by that seller on a particular day.

### 4.3 Competition: Two Sellers in the Market

In a competitive marketplace when sellers compete for market share, adaptive pricing strategies react to the other strategies in the marketplace, not just the buyers' demand. Initially a market scenario is presented in which none of the buyers compare prices across sellers or treat the sellers different. Next the effects of comparison-shopping and seller-preference are presented. As in the monopoly setting, each of the pricing charts in the following tables are based on a 100 day simulation with the buyer valuation ranging from \$100 to \$300, depending on the valuation/time curve. In each of the competitive simulations, there were 2000 buyers, the same number of total goods in the marketplace.

Table 4.6 presents three different competitive pairings: Goal-Directed vs. Fixed-Price, Derivative-Following vs. Fixed-Price, and Goal-Directed vs. Derivative-Following. The actual success of a fixed-price seller depends on the fixed price it chooses. When used as a pricing policy, a "fixed-price strategy" should be optimized based on the predicted behavior of the market [12, 13]. The success of fixed-price strategies are not examined here, so the fixed-price has been chosen to be \$200, the average valuation over time, across all the valuation curves. The fixed-price seller is presented as a way of demonstrating the interplay between the adaptive and fixed-price strategies.

When the Fixed-Price seller is able to sell goods (when its price is below the buyer valuation curve), the GD strategy stops adjusting its price and appears to mimic the Fixed-Price seller, particularly under the increasing and decreasing valuation curves (Table 4.6, left column). The reason the GD strategy stops changing its price is that when the Fixed-Price seller enters the market, the sales are split between the two sellers, and in this case with 2000 buyers (1000 per seller), the GD strategy sells the exact amount it aims to sell each day, making it unnecessary to change the price. If there were more or less buyers in the market, the GD strategy would result in a flat price curve at a higher or lower price point, respectively. Having a Fixed-Price seller in the

market prevents the GD strategy from finding the highest price the buyers are willing to pay, yet in spite of this drawback, under every curve, the GD strategy produces a high amount of revenue and sells almost its entire inventory.

When a DF strategy is paired with a Fixed-Price seller, center column of Table 4.6, it has difficulty finding the buyer demand curve because of the low number of buyers and thus resorts to more frequent, higher oscillations in price. When the Fixed-Price seller is not making any sales, the DF strategy closely follows the buyer curve. This results in the DF strategy selling a much higher percentage of its goods, but at much lower prices than the Fixed-Priced seller. Under some curves this results in higher revenue for DF than for a Fixed-Price seller.

When DF and GD strategies are combined into the same marketplace, they do not respond to each other in a dramatic way. In fact, the individual strategies in the right column of Table 4.6 look much like when these strategies compete against a Fixed-Price seller, except because both strategies are actively selling every day, the strategies never behave as they would with numerous buyers in the marketplace. Each strategy is responding to the lack of buyers in the marketplace – the GD strategy starts to drop prices as sales drop off and the DF strategy keeps raising the price until it no longer makes sales and then dramatically lowers the price again.

When a population of comparison shoppers is added to the marketplace, there is much more interaction between the two strategies. Table 4.7 compares the competitive effects of pairing two Goal-Directed strategies, two Derivative-Following strategies, and one Goal-Directed strategy with one Derivative-Following strategy when 100% of the buyer population compares the prices of the two sellers and purchases from the lowest priced seller. When this trial was run with 75%, 50% and 25% comparison shoppers, the results linearly approached those with no comparison-shopping.

Across the results, the amount of revenue earned by each seller has been dramatically reduced.

Examining the results of the two GD strategies, they behave much as they did in a monopoly setting with limited buyers (Table 4.4), except they do not respond to the high variance in the buyer population. The center column shows the two DF strategies, and as shown most dramatically by the sample pricing curve, when they are paired together, they produce a price war. Especially for the case of increasing valuation over time, the DF strategies drop their prices to \$1. When one GD competes with one DF, there is a modified price war, where prices don't drop as dramatically, but are still forced down by the DF strategy. The DF strategy sells approximately the same amount of inventory as GD, yet earns more revenue than the GD strategy under all valuation curves and increases its revenue as compared to the DF-DF competition. This occurs because the DF strategy does not limit the amount of inventory it sells at the beginning of the market when prices are higher, while the GD strategy spreads out its sales, including selling on the last days of the price war when prices approach zero.

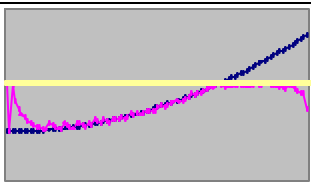
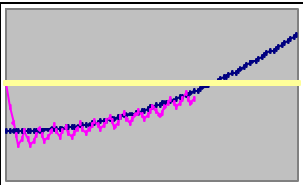
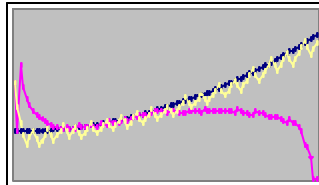
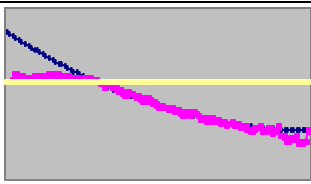
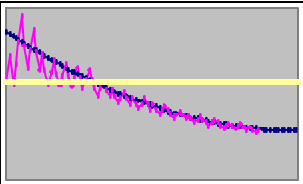
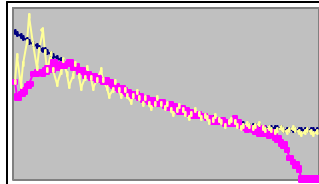
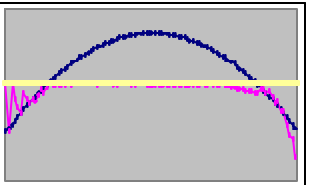
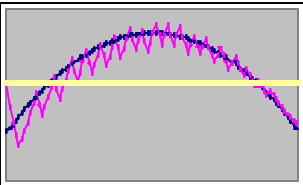
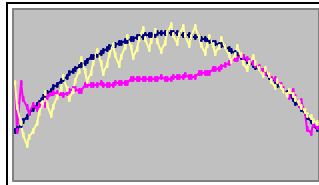
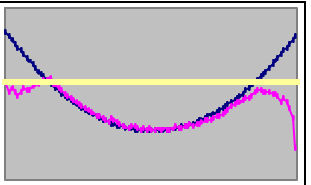
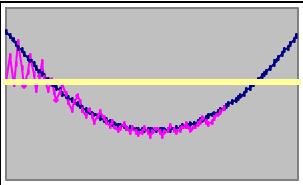
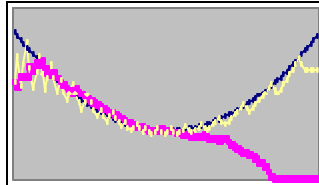
Valuation / Time	Goal-Directed Strategy vs. Fixed Price Strategy		Derivative-Following Strategy vs. Fixed Price Strategy		Goal-Directed Strategy vs. Derivative-Following Strategy	
Increasing						
	<b>GD:</b> \$157,307 ± 5596 <b>Sales: 990 ± 10</b>	<b>FP:</b> \$58,912 ± 3273 <b>Sales: 295 ± 16</b>	<b>DF:</b> \$117,551 ± 1311 <b>Sales: 1000 ± 0</b>	<b>FP:</b> \$116,258 ± 4365 <b>Sales: 581 ± 22</b>	<b>GD:</b> \$113,551 ± 8815 <b>Sales: 926 ± 19</b>	<b>DF:</b> \$139,024 ± 3499 <b>Sales: 964 ± 22</b>
Decreasing						
	<b>GD:</b> \$134,204 ± 3069 <b>Sales: 976 ± 9</b>	<b>FP:</b> \$62,086 ± 3813 <b>Sales: 310 ± 19</b>	<b>DF:</b> \$154,366 ± 1758 <b>Sales: 1000 ± 0</b>	<b>FP:</b> \$75,882 ± 3265 <b>Sales: 379 ± 16</b>	<b>GD:</b> \$121,028 ± 3399 <b>Sales: 884 ± 17</b>	<b>DF:</b> \$145,205 ± 5725 <b>Sales: 922 ± 35</b>
Mid-Peaking						
	<b>GD:</b> \$178,410 ± 4218 <b>Sales: 980 ± 6</b>	<b>FP:</b> \$143,326 ± 4440 <b>Sales: 717 ± 22</b>	<b>DF:</b> \$160,391 ± 5307 <b>Sales: 765 ± 23</b>	<b>FP:</b> \$183000 ± 4691 <b>Sales: 915 ± 23</b>	<b>GD:</b> \$190,593 ± 3397 <b>Sales: 980 ± 6</b>	<b>DF:</b> \$164,719 ± 4025 <b>Sales: 752 ± 19</b>
Mid-Dipping						
	<b>GD:</b> \$144,565 ± 5263 Sales: 987 ± 11	<b>FP:</b> \$58,794 ± 11 <b>Sales: 294 ± 16</b>	<b>DF:</b> \$128,381 ± 1143 Sales: 1000 ± 0	<b>FP:</b> \$92,126 ± 4029 <b>Sales: 461 ± 20</b>	<b>GD:</b> \$77,342 ± 3890 <b>Sales: 809 ± 20</b>	<b>DF:</b> \$146,845 ± 2850 <b>Sales: 988 ± 17</b>

Table 4.6: Competition with No Variance and Few Buyers

The darkest curve is the average price that the buyers are willing to pay on each day (valuation). The lighter curves are the prices offered by the sellers on a particular day. In the right column, the medium colored curve is the GD strategy and the lightest curve is the DF strategy.

When buyers have a preference for a certain seller, the population of buyers considers that seller's product to be more valuable, perhaps because of brand, quality, or reputation. In the simulator, this is modeled by boosting up the reservation price a buyer has for that seller by a fixed percentage, in this case 20%. Table 4.8 shows competition between the GD and the DF when there is a preference for one of the sellers. What we observe is that both strategies are able to charge higher prices at certain points in the market, but the GD strategy is forced to lower its price during the middle portion of the market to ensure it made enough sales. Under both trials, the sellers sold approximately 70-80% of their inventory. While the preferred seller earns more revenue under the different trials, the earnings spread between the two sellers is not nearly as large when there is a preference for the DF seller.

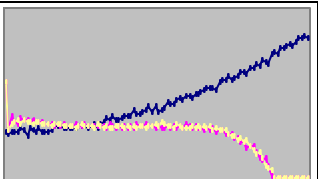
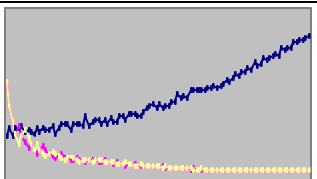
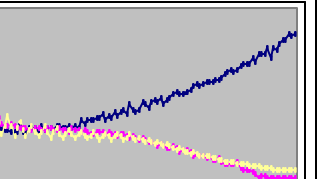
	GD vs. GD With Comparison-Shopping		DF vs. DF With Comparison-Shopping		GD vs. DF With Comparison-Shopping	
Valuation Curve:	GD Revenue:	GD Revenue:	DF Revenue:	DF Revenue:	GD Revenue:	DF Revenue:
Increasing	\$57,881 ± 2220	\$57,881 ± 2220	\$40,532 ± 8211	\$40,532 ± 8211	\$35,639 ± 2831	\$58,713 ± 1856
Decreasing	\$87,058 ± 1875	\$87,058 ± 1875	\$86,512 ± 6549	\$86,512 ± 6549	\$71,826 ± 3564	\$117,151 ± 4074
Mid-Peaking	\$143,472 ± 2837	\$143,472 ± 2837	\$53,273 ± 28,092	\$53,273 ± 28,092	\$57,763 ± 4968	\$96,786 ± 3833
Mid-Dipping	\$63,595 ± 1664	\$63,595 ± 1664	\$63,595 ± 1664	\$63,595 ± 1664	\$50,765 ± 3939	\$80,820 ± 3158
Sample Pricing Chart						

Table 4.7: Competition under Comparison Shopping and High Variance

The darkest curve is the average price that the buyers are willing to pay on each day (valuation). The lighter curves are the prices offered by the sellers on a particular day. In the right column, the medium colored curve is the GD strategy and the lightest curve is the DF strategy.

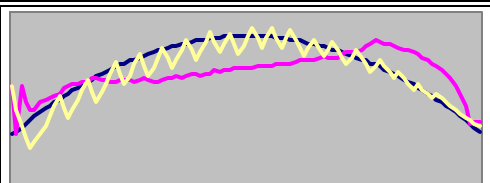
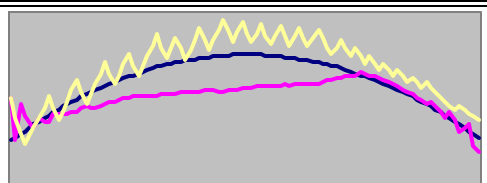
	Goal-Directed vs. Derivative-Following With Preference for GD		Goal-Directed vs. Derivative-Following With Preference for DF	
Valuation Curve:	GD Revenue:	DF Revenue:	GD Revenue:	DF Revenue:
Mid-Peaking	\$208,822 ± 5102	\$157,476 ± 4674	\$190,360 ± 4126	\$212,647 ± 4422
Sample Pricing Chart				

Table 4.8: Competition under a Buyer Preference for Different Sellers

The darkest curve is the average price that the buyers are willing to pay on each day (valuation). The medium colored curve is the GD strategy and the lightest curve is the DF strategy.



### 4.3.1 Further Market Variation: Buyer Segmentation

Up until now the analysis of the strategies has been very controlled with the purpose of discovering which market conditions effect a strategy's success. Now, both to continue the strategy analysis and to demonstrate the richness to which the buyer behavior can be defined, an analysis of the effect of buyer segmentation is presented. Buyer segmentation, or the dividing of the simulator's buyer population into sub-groups, allows for different types of buyers to co-exist in the market. As will be shown, the GoalDirected strategy is better able to handle this type of market diversity. To further illustrate the use of the simulator as an interface for analysis, the results of this analysis are shown as screenshots from the simulator.

Market Scenario	Buyer Behavior	Seller Strategies																		
		<table><thead><tr><th>Strategies</th><th colspan="2">Sellers</th></tr><tr><td></td><th>A</th><th>B</th></tr></thead><tbody><tr><td>Fixed Price</td><td><input type="radio"/></td><td><input type="radio"/></td></tr><tr><td>Goal Directed</td><td><input checked="" type="radio"/></td><td><input type="radio"/></td></tr><tr><td>Goal Directed Quantity</td><td><input type="radio"/></td><td><input type="radio"/></td></tr><tr><td>Derivative Following</td><td><input type="radio"/></td><td><input checked="" type="radio"/></td></tr></tbody></table>	Strategies	Sellers			A	B	Fixed Price	<input type="radio"/>	<input type="radio"/>	Goal Directed	<input checked="" type="radio"/>	<input type="radio"/>	Goal Directed Quantity	<input type="radio"/>	<input type="radio"/>	Derivative Following	<input type="radio"/>	<input checked="" type="radio"/>
Strategies	Sellers																			
	A	B																		
Fixed Price	<input type="radio"/>	<input type="radio"/>																		
Goal Directed	<input checked="" type="radio"/>	<input type="radio"/>																		
Goal Directed Quantity	<input type="radio"/>	<input type="radio"/>																		
Derivative Following	<input type="radio"/>	<input checked="" type="radio"/>																		

Figure 4.9: Seller Strategies used in Trials 1 and 2.

Two trials were run, one with buyer segmentation, Trial 2, and one without, Trial 1. -The market scenario for Trial 1 is presented in Figure 4.10. This is very similar to the market scenario analyzed in the previous sections of this chapter: there are two sellers, 100 days, 1000 goods per seller, and 4000 buyers. In the first trial, there is no buyer segmentation. In Trial 2, there is a 75/25 split to the buyer population, selected from the pull-down menu on the Market Scenario screen (Figure 4.11). The two sellers in the trials each used the GoalDirected and Derivative-Following strategies, as shown in Figure 4.9.

Figure 4.12 shows the input screens for the two segments of the buyer population. Segment A, on the left side of Figure 4.12, is the buyer segment present in both trials. Segment B, on the right side of Figure 4.12, is 25% of the buyer population in Trial 2. Segment A could be described as

an extremely price sensitive population because the buyers have a relatively low variance, they are all comparison shoppers, and they have a long lifetime in the market. Segment B is a less price sensitive or less ‘price aware’ group of buyers: they have a high variance in reservation prices, they do not comparison shop, they only shop for one day, and the maximum average reservation price is higher than Segment A’s (\$350 versus \$300 for Segment A).

Market Scenario		Buyer Behavior	Seller Strategies
<b>Market</b>			
Number of Days:	100		
Number of Buyers:	4000		
Market Mechanism:	Posted-Price		
Segment Buyer Population?	No		
<b>Sellers</b>			
Number of Sellers:	2		
Number of Goods per Seller:	1000		
Fixed Cost (\$):	5000		
Marginal Cost per Good (\$):	10		
Initial Price (\$):	200		

*Figure 4.10: Market Scenario for Trial 1  
The input variables for a market scenario with no buyer segmentation (Trial 1).*

Segment Buyer Population?	Yes, 75%-25%
---------------------------	--------------

*Figure 4.11: Market Scenario for Trial 2  
The change to the input variables for a market scenario with buyer segmentation (Trial 2).*

The results of the two trials are in Figure 4.13. In Trial 1, with only Segment A buyers, the Derivative-Following strategy earns more revenue than the Goal-Directed strategy. In Trial 2, when 75% of the buyers behave according to Segment A’s input parameters and 25% behave according to Segment B’s input parameters, the Goal-Directed strategy earns more revenue than Derivative-Following.

In this second trial, the DF strategy earns less because it has significant difficulty in selling inventory. The DF price curve follows the higher paying, less discriminating customers, but

because this is only 25% of the population, this results in much lower sales for DF and a dominance of the GD strategy. The GD strategy does not focus on the highest paying customers until mid-way through the market when it was making enough sales to do so. Then at the end of the market, the seller strategically lowered its price to sell its remaining inventory to the lower paying customers.

As demonstrated by these results, populating the market with a more complex buyer population results in more complex and unexpected pricing behavior. The success of the individual strategies is highly dependent on the buyer behavior and thus it is important to accurately model a market's real-world buyers. Segmentation of the buyer population allows for a richer and perhaps more accurate description of the buyer population, and this very basic analysis of buyer segmentation shows that breaking the buyer population into distinct groups displays additional strengths (and weaknesses) of different pricing strategies.

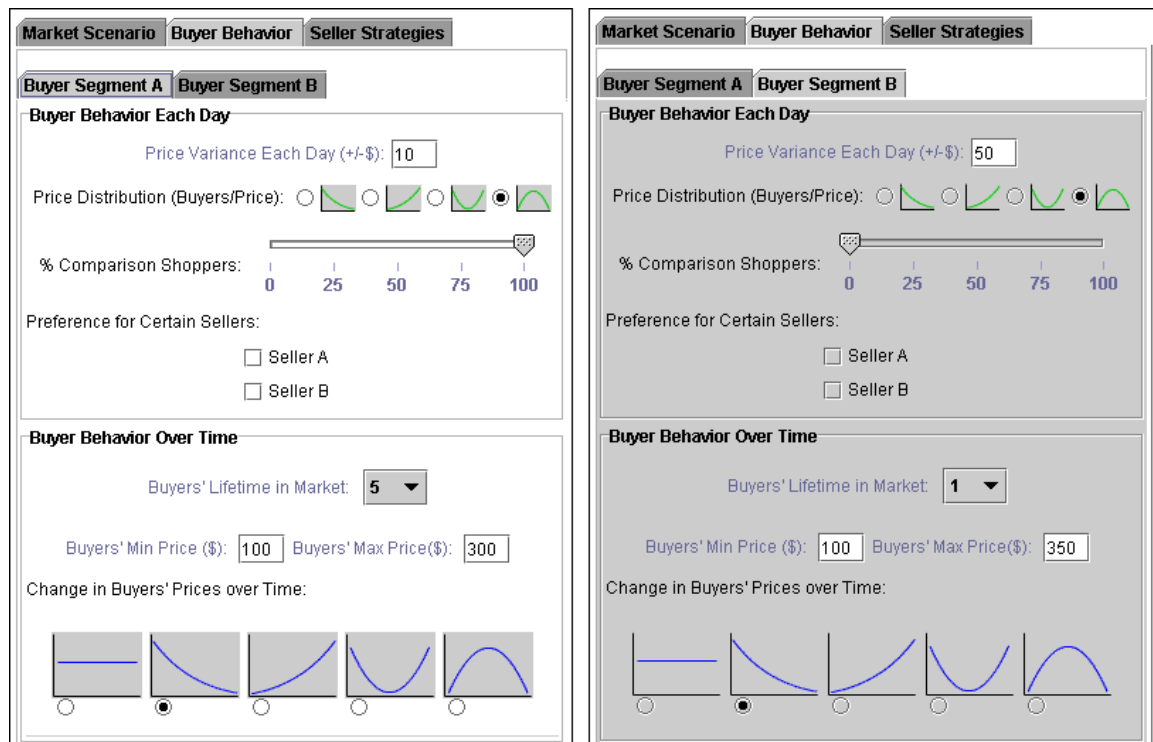


Figure 4.12: Buyer Behavior  
The left pane defines the behavior of Segment A and the right pane defines the behavior of Segment B.

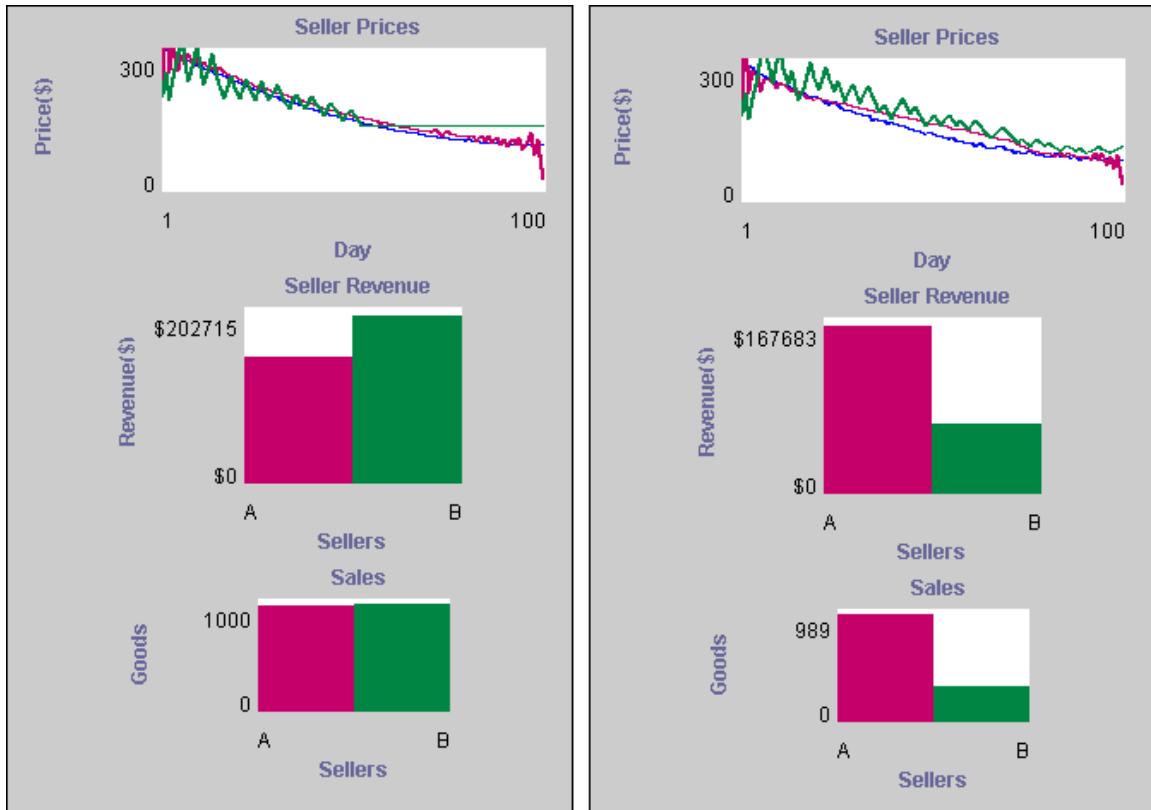


Figure 4.13: Simulator Output

The left pane is the output from Trial 1 (one buyer population) and the right pane is the output from Trial 2 (two differing buyer populations in one market). The pink (on the left) is the Goal-Directed strategy and the green (on the right) is the Derivative-Following strategy.

## 4.4 Strategy Analysis Conclusions

While the Goal-Directed and Derivative-Following strategies are computationally basic, they are surprisingly robust under extremely different market conditions. Under every case presented, excluding the situation of 100% comparison-shopping, the strategies managed to adjust prices in the direction of learning the changing demand in the marketplace, without knowing the true buyer demand or competitors' prices. These strategies point towards some general guidelines for choosing and designing adaptive pricing strategies:

- The Goal-Directed strategy consistently sells all or the majority of its inventory, given any combination of buyer behaviors and competition, at the expense of drastically over- and under-shooting the buyer valuation curve early and late in the market.
- The Derivative-Following strategy consistently sells at the highest price it can on any single day. When there is a relative peak in demand during the first days of the market and there is an abundance of buyers, DF performs very well. If buyer demand peaks at some later time, DF does not space out its sales so as to insure that it sells a large number of goods.
- In a monopoly, the shape of the valuation/time curve has an enormous effect on the success of an individual strategy. Variance among buyer reservation prices and a limited number of buyers requires the adaptive strategies to be more agile. When designing an optimal strategy for a monopoly setting, knowledge about the typical valuation/time curve and the buyer population should be incorporated into the pricing algorithm.
- If buyers are extremely price sensitive (100% comparison-shoppers), adaptive strategies can easily break down into price wars. In particular, the Derivative-Following strategy generated a price war between itself and other adaptive strategies.

- When there is product and seller differentiation (a willingness to pay more for certain seller's products), a carefully designed adaptive strategy can narrow or widen the discrepancy between the sellers' earnings.
- Buyer segmentation introduces complexities which can reverse the successes of a given strategy. This highlights the importance of accurate modeling of a buyer population.

As dynamic pricing is deployed in markets, it is important to understand the interplay of different pricing strategies. Deck, et al. in [11] compared two simple pricing strategies, price matching and price cutting, and combined them into one simulated market setting, demonstrating that both strategies were weakened in a mixed strategy marketplace. The strategies presented here, while neither price matching nor cutting, produced mixed results. When there was no comparison-shopping, the DF and GD strategies did not significantly effect each other's behavior or success because these algorithms are not tied to competitor prices. But in the market with comparison-shoppers (Table 4.7), the two strategies began to affect each other. The presence of a DF strategy hurt the success of the GD strategy while the presence of the GD strategy improved the success of the DF strategy over when it competed with another DF strategy.

Returning to the scenario of a ballpark selling baseball tickets, what dynamic pricing strategy should a ballpark apply to its market to sell tickets at the highest demand levels while still filling the park? Based on the market conditions of a ballpark (monopoly, high variance among the buyers, and a low marginal cost per seat in the park), I would recommend using a strategy similar to the Goal-Directed strategy. The Goal-Directed strategy's strength is its focus on selling the entire inventory, sometimes at lower prices, which is a good approach under low marginal costs. The Goal-Directed strategy also adjusts easily under high buyer variance, as shown in Table 4.3. Under the conditions in Table 4.3, the GD strategy performs well under each valuation/time curve. Actual market data from ballparks could provide us an accurate valuation/time curve

estimate to further inform a strategy choice. If one assumes the baseball ticket valuation curve does not continuously decrease over time, then selling all the inventory at the beginning of the market is to the ballpark's disadvantage, which a Fixed-Price policy or Derivative-Following strategy does not protect against.

While the Goal-Directed calculation used in this analysis has not been optimized for the baseball ticket market, the process of modeling a market and determining which adaptive strategy is most successful is a useful exercise. The *Learning Curve Simulator* provides a mechanism for analyzing pricing strategies, making the process of understanding and modeling a market a straightforward task rather than a highly elusive problem.





## 5 Usage Analysis

In addition to building the *Learning Curve Simulator* for analyzing specific dynamic pricing strategies, a secondary goal of this research is to create a tool that real-world sellers can use to understand the potential impact of dynamic pricing on their markets. To evaluate the *Learning Curve Simulator* in terms of its effectiveness as a tool for sellers, I conducted two informal workshops during the MIT Media Lab's ThingsThatThink Consortium meeting, held in May 2001. Between eight and ten lab industry sponsors attended each workshop. After demonstrating the usage of the *Learning Curve Simulator*, the sponsors and I explored different market scenarios with the simulator, comparing a Fixed-Price strategy, the Goal-Directed strategy, and the Derivative-Following strategy. Afterward, we discussed specific issues relevant to their markets and explored how those factors would affect the results in the simulator.

### 5.1 Simulator as an Interface

The simulator interface received lots of positive feedback, both from people who had used market simulators before and those who had not. Sponsors described the simulator as “clear” and “uncluttered,” with a good “separ

Suggested improvements for the interface comprised requests for additional features such as the ability to save a specific scenario and to compare results across simulation runs. Although not demonstrated during the workshop, both of these actions can be done with the current simulator by accessing the output file generated during each simulation. Comparative analysis can then be done by hand, outside of the simulator application, by accessing the output file from a spreadsheet application.

Other users requested adding mouse-over tool tips or hyperlinks that would explain more about each variable in the simulator. If the simulator were to be released for general use, this would be

an excellent additional feature.

## **5.2 Simulator as a Tool**

About half of the sponsors I spoke to stated that the simulator would be useful to their companies, as it exists today. Several of them plan to access the simulator on-line or install it at their company. They plan for employees involved in pricing decisions to use the simulator as a learning tool. This was an extremely positive response, but there was still a desire among these sellers for changes to the simulator.

Each sponsor I spoke to said the simulator would require more buyer behavior parameters to accurately describe their market. Two specific types of buyer behavior mentioned by sellers were “brand loyalty” and “different types of buyers.” The current buyer behavior parameter “preference for a certain sellers” is meant to express brand loyalty, but based on this feedback, perhaps it does not do so clearly or effectively enough. While the request for different types of buyers is vague, after this workshop I attempted to create that feature by adding the ability to segment the buyer population into two distinct populations. This feature allows for a richer description of the buyer population by creating two separate groups, which behave according to two sets of buyer behavior parameters.

From talking to these sellers about their markets, my conclusion is that a general market simulator cannot accurately model a company’s market, because of the unique factors and perspectives each company has. Instead, a general simulator is able to offer a higher level of understanding about the effects of dynamic pricing. For a simulator to be a true reflection of a market and thus be a tool the company can use to accurately predict the effect of a dynamic pricing strategy in their own market place, a domain expert would need to incorporate historical and other market data into the simulator’s modeling of buyer behavior.

What I found to be most interesting when talking with sellers were the barriers they described towards deploying dynamic pricing in their market. While it was a goal of each company I met with, it was not something that could be implemented in the near future. For example, I spoke with American Greetings about their season card division. Dynamic pricing is of great interest to them, but they currently have several obstacles to implementation. First, they print the retail price on all of their cards and then sell the cards in lots to retail stores at fixed prices. It is part of their sales practice to always *oversell* the cards to retail stores, with the agreement that these stores are able to return any unsold inventory for a full refund after the card's season. American Greetings then sorts through the returned cards and puts a portion of the cards into storage for next year's season. To preserve brand equity, it is a priority of American Greetings to never sell out of the seasonal cards (Valentine's Day cards, for example).

By implementing dynamic pricing, American Greetings would be able to fine-tune the amount of cards shipped to each retail store and then adjust the cards' prices to ensure that all inventory was sold by the last day, but not before the last day. A strategy similar to the Goal-Directed strategy might work for them because of its emphasis on inventory control. The company's current inefficiency of accepting returned inventory and storing cards for the next year could be eliminated with an effective dynamic pricing strategy.

While American Greetings sees the potential of dynamic pricing, they identify barriers to implementation as 1) the current printing of prices on cards and 2) the current arrangement where retail stores control the retail price, not American Greetings.

As a final observation, none of the sellers I spoke to criticized the limitation of the simulator only modeling finite markets or the constrained set of seller strategies. Real-world markets will have constraints on their parameters, whether or not they are related to a finite time horizon, and a finite market is a specific way of expressing these constraints. During the workshops, I presented

only two pricing strategies, explaining that any strategy could be designed and implemented in the simulator. The two we evaluated generated enough discussion and interest that I would suggest that, when a company is performing a similar analysis of dynamic pricing options, two strategies allow for enough diversity to understand the factors of dynamic pricing, without overwhelming the analysis process.

## 6 Conclusion

Dynamic pricing will likely become a common competitive maneuver in the near future and because of this, sellers need to be equipped with an understanding of how different pricing strategies will play out in their marketplaces. A common type of market is one with a finite time horizon, and it is in this market type that a seller has great potential to gain through adjustments to price over time. In this thesis, I have presented a tool, the *Learning Curve Simulator*, for modeling finite markets and for testing dynamic pricing strategies. By using such a simulator, sellers can gain an understanding of dynamic pricing and of the different factors contributing to successful dynamic pricing strategies.

There are several open issues in the deployment of dynamic pricing, for which the *Learning Curve Simulator* can contribute towards solving. The following sections highlight some of these issues in electronic markets and how a simulation-based approach can facilitate their solution.

### 6.1 Further Strategy Development

The adaptive pricing strategies implemented in this body of work illustrate one type of approach to designing pricing strategies. There are many potential approaches to strategy development and the simulator can serve as a platform for testing such strategies.

An effective technique for optimal pricing is dynamic programming [3] which, like revenue management, makes assumptions about the marketplace to forecast and make optimal decisions, taking into account time and inventory constraints. By considering the problem of pricing in a market to be a multi-armed bandit allocation problem [20] and simplifying the strategy decision to a finite number of decision variables, a strategy could be developed and tested in the *Learning Curve Simulator* which found an optimal pricing solution for each market scenario. Although, as discussed earlier, a drawback to this approach is the number of required market behavior

assumptions, such as the shape of the buyer valuation/time curve. Another drawback is that to deploy an optimal solution, the calculation is often times too computationally intense for a real-world setting [21]. But these drawbacks do not preclude the benefit of understanding how dynamic programming strategies perform in a market and the *Learning Curve Simulator* can provide the mechanism to do that.

## **6.2 More Realistic Buyer Behavior**

As requested by the sellers who worked with the simulator, to make the simulator more effective it needs more parameters to describe the behavior of buyers. In addition to the behaviors these sellers suggested, there are additional behaviors that will occur in markets in response to the introduction of dynamic pricing, and these behaviors should be modeled in order to understand the impact of different pricing strategies. Just as leisure travelers often purchase airline tickets more than twenty-one days in advance to receive a discounted fare, when sellers implement dynamic pricing into new markets, discount-seeking buyers will work within the pricing rules to receive a lower price. If the pricing strategy is not easily decipherable, buyers may change their behavior in response to seeing prices change. For example, buyers sensitive to changing prices may wait on a purchase if prices are falling or choose to buy immediately if prices are increasing. The effect of this type of behavior on a strategy's success could be evaluated in a simulator that accurately modeled the different ways in which buyers respond to dynamic pricing.

## **6.3 Buyer Response**

Amazon.com's foray into dynamic pricing illustrated, perhaps too clearly, the risk of a negative buyer response to buyer pricing. Amazon.com charged new customers less for a DVD than loyal customers, and this initiated a widely publicized negative response from their customers.

There are several theories as to how Amazon.com could have avoided this backlash. One proposal is that Amazon.com could have customized the entire sales package, including delivery

time, to create a qualitatively, versus quantitatively, better package [16]. While this would help disguise the dynamic pricing, this would not have changed the basic fact that Amazon.com gave benefits to new customers, not old ones. Another suggestion is that Amazon.com practice better customer relations, through better follow-up and explanation of their pricing [2]. Again, I see this as a patch to the problem that customers are upset that Amazon.com is discriminating against their loyal customers.

My proposed recommendation for sellers implementing dynamic pricing is to publish or make known the parameters by which the sellers change prices. Airlines and other industries such as hotels and rental cars employ complex pricing strategies – while the strategies themselves are not revealed, the rule that prices change over time and over type of traveler is well understood by consumers and does not raise objections. Personalized pricing, or price discrimination, is more complex than simply changing prices over time (as shown by Amazon.com). But today, when sellers offer a discount to customers who sign-up for a particular promotion, customers understand this rule and either elect to put themselves in that discounted customer segment, or not. When rules are public, strategies will have to take into account the movement of buyers from the non-discounted segment to the other, but this can be accommodated for with accurate modeling of the movement of buyers between segments. While the current version of the *Learning Curve Simulator* is not designed to model different buyer reactions to dynamic pricing, a market simulator can be useful in understanding the potential outcomes of a negative response to a pricing strategy or of a shift of buyers between different population segments.

## **6.4 Market Types**

This thesis focused on finite markets with posted-prices, only briefly covering an auction implementation. This constraint on the analysis does not limit the impact of the simulator as a tool for understanding markets and dynamic pricing strategies. The lessons learned from finite markets can be extended to markets with non-perishable goods, such as the automotive industry

[4, 9]. Pricing strategies could be designed to have knowledge of production and distribution decisions and by changing prices could improve the entire supply chain.

Electronic markets allow for geographically distributed markets, and a by-product of this distribution and the ability to make instantaneous price changes, is that auctions have become an extremely popular market mechanism for selling products. While tempting to enter auction markets to sell goods, sellers should proceed with caution when deploying dynamic pricing strategies in these markets. Consumers behave differently in markets in which they name their own prices and affect the sale price of the item [1]. Before developing a pricing strategy for an auction, a seller should gather an understanding of how their customers will behave within the chosen auction type. The *Learning Curve Simulator* could serve as a platform for modeling this buyer behavior and studying the effects of this behavior on different auction pricing strategies.



# References

1. Ariely, D. and Simonson, I. "The Psychology of On-line Auctions (Working Paper)." 2001.
2. Baker, W.L., Lin, E., Marn, M.V. and Zawada, C.C. "Getting Prices Right on the Web." *The McKinsey Quarterly*. (Number 2). 2001.
3. Bellman, R.E. *Dynamic Programming*. Princeton University Press, Princeton, 1957.
4. Biller, S., Chan, L.M.A., Simchi-Levi, D. and Swann, J. "Dynamic Pricing and the Direct-to-Customer Model in the Automotive Industry." *GM Research & Development Center*, 2000.
5. Boyd, E.A. "Airline Alliance Revenue Management." *OR/MS Today*. (October 1998). 1998.
6. Brooks, C.H., Fay, S., Das, R., MacKie-Mason, J., Kephart, J. and Durfee, E. "Automated Strategy Searches in an Electronic Goods Market: Learning and Complex Price Schedules." Proceedings of the *ACM Conference on Electronic Commerce (EC '99)*, Denver, CO (November 1999).
7. Brynjolfsson, E. and Smith, M. "The Great Equalizer? Consumer Choice at Internet Shopbots (Working Paper)." July 2000.
8. Carmon, Z. and Ariely, D. "Focusing On The Forgone: How Value Can Appear So Different To Buyers And Sellers." *Journal of Consumer Research*. (27 (3)). 360-370. 2000.
9. Chan, L.M.A., Simchi-Levi, D. and Swann, J. "Flexible Pricing Strategies to Improve Supply Chain Performance (Working Paper)." Northwestern University, 2000.

10. Clay, K., Krishnan, R. and Wolff, E. "Pricing Strategies on the Web: Evidence from the Online Book Industry." Proceedings of the *2nd ACM Conference on Electronic Commerce (EC '00)*, Minneapolis, Minnesota (October 2000), 44-55.
11. Deck, C.A. and Wilson, B.J. "Interactions of Automated Pricing Algorithms: An Experimental Investigation." Proceedings of the *2nd ACM Conference on Electronic Commerce (EC '00)*, Minneapolis, Minnesota (October 2000), 77-85.
12. Gallego, G. and van Ryzin, G. "A Multiproduct Dynamic Pricing Problem and Its Applications to Network Yield Management." *Operations Research*. vol. 45 (1). 24-41. 1997.
13. Gallego, G. and van Ryzin, G. "Optimal Dynamic Pricing of Inventories with Stochastic Demand Over Finite Horizons." *Management Science*. vol. 40 (8). 999-1020. 1994.
14. Greenwald, A., Kephart, J.O. and Tesauro, G.J. "Strategic Pricebot Dynamics." Proceedings of the *ACM Conference on Electronic Commerce (EC '99)*, Denver, CO (November 1999).
15. Guttman, R. and Maes, P. "Agent-mediated Integrative Negotiation for Retail Electronic Commerce." Proceedings of the *Workshop on Agent Mediated Electronic Trading (AMET'98)*, Minneapolis, Minnesota (May 1998).
16. Kalin, S. "How Low Can You Go?" *Darwin Online*. (April 2001). 2001.
17. Kephart, J., Hanson, J. and Greenwald, A. "Dynamic Pricing by Software Agents." *Computer Networks*. vol. 32 (6). 731-752. 2000.
18. Kephart, J.O. and Greenwald, A. "Shopbot Economics." Proceedings of the *Fifth European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertainty*, (July 1999).

19. Keskinocak, P. and Tayur, S. "Quantitative Analysis for Internet-Enabled Supply Chains." *Interfaces, Special issue on Operations Research in the e-Business Era*. vol. 31 (March/April 2001). 2001.
20. Leloup, B. and Deveaux, L. "Dynamic Pricing on the Internet: Theory and Simulations." *ENS de Cachan, GRID, NR 00-14*. 2000.
21. McGill, J.I. and van Ryzin, G. "Revenue Management: Research Overview and Prospects." *Transportation Science*. vol. 33 (No. 2 (May 1999)). p. 233-256. 1999.
22. Morris, J. and Maes, P. "Sardine: An Agent-facilitated Airline Ticket Bidding System." *Proceedings of the Fourth International Conference on Autonomous Agents (Agents 2000)*, Barcelona, Catalonia, Spain (June 2000).
23. Morris, J., Maes, P. and Greenwald, A. "Learning Curve: Analysis of an Agent Pricing Strategy Under Varying Conditions." *Proceedings of the Conference on Artificial Intelligence*, Las Vegas, NV (June 2001).
24. Smith, B.C., Gunther, D.P., Rao, B.V. and Ratliff, R.M. "e-Commerce and Operations Research in Airline Planning, Marketing, and Distribution." *Interfaces, Special issue on Operations Research in the e-Business Era*. vol. 31 (March/April 2001). 2001.
25. Smith, M., Bailey, J. and Brynjolfsson, E. "Understanding Digital Markets: Review and Assessment." in *Understanding the Digital Economy*, Brynjolfsson, E. and Kahin, B. eds., MIT Press, Cambridge, MA, 2000.