Variable Pricing in Oligopoly Markets*

I. Introduction

Firms continuously vary the prices of their products in the marketplace. These variations sometimes exhibit consistent patterns, such as higher-priced products having greater price variability. For example, in the grocery industry, more expensive stores tend to have more frequent price changes (Information Resources Inc. 1993). Similarly, with airlines, the lower-priced, low-frills Southwest Airlines has less price variability than the major national carriers American Airlines and Delta. In telephone services, the large national long-distance carriers are more expensive and have more variable pricing than discount carriers such as 10-10-220 or bigzoo.com.

From these examples, one can conceptualize a firm as making a choice of an average price and price variability as part of its strategic pricing decision. In the simplest case, consider a 2 × 2 matrix of high or low average prices versus high or low price variability. Which quadrant should a firm select? How will its decision be affected by a competitor’s quadrant choice? Our goal is to provide answers to these questions.

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Behavioral research has found that consumers respond to variability in prices in addition to price levels. We show that this finding can explain why some firms vary their prices more frequently than others. We examine pricing strategies composed of an average price and price variability and employ logit market share models to analyze equilibrium pricing strategies in an oligopoly. Two competing logit specifications termed price sensitivity and payoff sensitivity are considered and are shown to yield contradictory implications for pricing policy. From three empirical studies on restaurant choice, we find that the price sensitivity model is the better model.
There is more than one explanation for price variability. It has been explained as the temporal enactment of a mixed-strategy Nash equilibrium. The latter occurs, for example, due to heterogeneity in customer information (Variance 1980) or heterogeneity in customer loyalty (Raju, Srinivasan, and Lal 1990). Price variability has also been explained as emerging from a pure-strategy Nash equilibrium. This can occur when national brands competing against private labels and each other use variable pricing to prevent competitive encroachment (Lal 1990). We believe that, in addition, one needs to examine behavioral research, which has shown that consumers respond to price variability as well as average price levels.

Our approach is to study the effect of price variability on consumer behavior. Research has shown that variability reduces consumers’ sensitivity to price and nonprice attribute differences between brands. In examining the strategic consequences of behavioral findings, our approach is similar to the spirit of normative pricing models in the reference price literature that show, for example, that cyclical pricing strategies can be optimal under specified circumstances by manipulating reference price effects (Greenleaf 1995; Kopalle, Rao, and Assuncao 1996). However, our analysis diverges from dynamic models of pricing in that the behavioral motivation is different and variability is random rather than deterministic.

We utilize the logit model that has been used extensively for obtaining equilibrium pricing policies under oligopoly (Anderson, de Palma, and Thisse 1992). Logit models are based on a utility maximizing framework and are consistent with the main economic approaches to describing demand for differentiated products as well as with psychological choice theory. Logical consistency requirements that market shares should be nonnegative and should sum to unity are automatically satisfied (Naert and Bultez 1973). Finally, there is a long history of the use of the logit in econometric and analytical studies in marketing (e.g., Guadagni and Little 1983).

The task of obtaining the optimal pricing policy should be relatively straightforward except that it is intertwined with the problem of determining the correct specification of the logit model. Two alternative logit specifications are considered. The first, termed payoff sensitivity, finds support in the economics and psychology literatures. In it, sensitivity to product differences, both in quality and price, decreases with price variability. The second specification, termed price sensitivity, is grounded in reference price research. In this specification, only the sensitivity to price differences decreases in the variability of prices.

We derive optimal pricing strategies under both specifications. Since sensitivity declines in variability for both specifications, one would hope to find similar implications for pricing. For the average price level, the two speci-

1. Logit market share models must be used with caution when optimizing over product attributes due to the problem of corner solutions (Grucza and Sudharshan 1991). However, there is no problem in evaluating pricing policies (Basu and Nguyen 1998).
fications indeed provide the same insight, namely, higher-quality firms should charge higher prices. However, for the price variability component of the pricing strategy, pricing implications under the two specifications are diametrically opposite. Under the price sensitivity specification, higher-quality firms adopt high price variability, while lower-quality firms adopt zero price variability. Under the payoff sensitivity specification, it is the reverse.

To obtain empirical support for one specification versus the other, three studies were conducted. The context was a choice of restaurants by participants. Experiments using restaurant settings (e.g., Gneezy, Haruvy, and Yafe 2004) or choices over restaurants (e.g., Ofek, Yildiz, and Haruvy 2003) are popular since participants are generally familiar with such settings and choices. Results were consistent with the price sensitivity specification. The implications of this for pricing are discussed.

The article is organized as follows. Section II discusses background literature and the two logit specifications. Section III contains the analysis that provides the strategic pricing results for both specifications. In Section IV, the experiments and the empirical results are described. Finally, in Section V, we provide conclusions and directions for future research.

II. Behavioral Underpinnings

This section describes two logit specifications that differ in their explanation of how variability in price affects choice probabilities. The specifications are referred to as the payoff sensitivity specification and the price sensitivity specification. Each finds significant support in the literature, as we discuss below.

First, some terminology should be clarified. Consider the simplified case of two firms, 1 and 2, with products that are valued at $V_1^* > V_2^*$, by the market and priced at $P_1$ and $P_2$, respectively. We will call firm 2 the higher-quality firm since $V_2 > V_1$. The “price difference” is $|P_1 - P_2|$. By payoffs, we mean $V_1 - R_1$ for firm 1 and $V_2 - R_2$ for firm 2, and, by “payoff difference,” we mean $|(V_1 - R_1) - (V_2 - R_2)|$. If consumers are more sensitive to price differences, it means that the lower-price firm benefits in getting a larger market share, and when consumers are more sensitive to payoff differences, it means that the firm with the higher payoff benefits more.

A. Payoff Sensitivity Specification

The idea that variability moderates sensitivity to payoff differences is well established. Studies in psychology and economics have shown that sensitivity to payoffs is reduced with higher payoff variability (for reviews, see Lee [1971]; Vulkan [2000]). A simplified exposition of various probability matching studies is the following. Participants are paid for a correct prediction as to which of two possible outcomes will occur, say, heads or tails of a tossed coin that is biased to give heads with a certain probability. Following each
prediction, the outcome is observed. While the optimal response is to always predict the more common outcome, the literature reveals that decision makers tend to "probability match." That is, if the probability of the more common outcome is 0.7, that outcome will be predicted in 70% of the trials. Based on the findings of probability matching, Erev, Bereby-Meyer, and Roth (1999) proposed a learning model in which sensitivity to expected payoffs of alternative choices declines in the variability of past payoffs. The Erev et al. model has been used to explain a variety of puzzling phenomena, from probabilistic punishment in law enforcement (Perry, Erev, and Haruvy 2002) to casino gambling (Haruvy, Erev, and Sonsino 2001).

Equation (1) is the choice function of the Erev et al. formulation that we adopt as our payoff sensitivity specification. The probability of household $i$ buying brand $j \in \{1, 2, \ldots, J\}$ at time $t$ with expected valuation (or quality) $V_{ij}$ and expected price $P_{ij}$ is given by

$$Pr_{ij} = \frac{1}{\sum_{m=1,2,\ldots,J} \exp \left[ \gamma (V_{im} - P_{im} - V_{ij} + P_{ij})/S_i(s_{i1}, \ldots, s_{ih}) \right]} ,$$

where the composite variability measure $S_i(s_{i1}, \ldots, s_{ih})$ is positive and increasing in each brand-specific variability measure $s_{ij}$ and $\gamma$ is a scaling parameter. Consumers make decisions based on their expected price for a product, which, in turn, depends on their past observation of the distribution of prices. In this specification, sensitivity to product differences, both in quality and price, decreases in the variability of overall payoff derived from these products. In the limit, an adaptive updating process (see Erev et al. 1999) results in $S_i(s_{i1}, \ldots, s_{ih})$ converging to the true underlying variability $S(s_1, \ldots, s_J)$, expected price $P_{ij}$ converging to the true average price $\bar{P}_j$, and $V_{ij}$ converging to the true quality $V_j$, which is assumed here to be the same for all households. In equilibrium, the market share for brand $j \in \{1, 2, \ldots, J\}$ with quality $V_j$ and average price $\bar{P}_j$ is given by

$$MS_j = \frac{1}{\sum_{m=1,2,\ldots,J} \exp \left[ \gamma (V_{im} - \bar{P}_m - V_j + \bar{P}_j)/S(s_1, \ldots, s_J) \right]} ,$$

Note that this share equation is not a demand function since the overall demand for the relevant choices is fixed at one. A proper demand function should have overall demand falling in the price of the options. To get a proper demand function, while preserving the brand choice structure, one would need to account for the probability of no purchase in the category.

Following Chintagunta (1993), we allow for the probability of opting out of the category, denoted by $P^\text{out}(V_1, \ldots, V_J, \bar{P}_1, \ldots, \bar{P}_J)$. Demand is then equal to $D_j = MS_j \times (1 - P^\text{out})$, where $P^\text{out}$ is strictly increasing in all $V_j$'s, strictly decreasing in all $\bar{P}_j$'s, and is not a function of $s_1, \ldots, s_J$. The independence of the opting out option from the price variability means that the probability of choosing the category is not a function of the price distribution of each
option in the category. It also means that the addition or omission of $P_{out}$ in the maximization function does not affect the first-order conditions with respect to $s_j$.

The dynamic nature of the Erev et al. model ensures that unchosen alternatives do not influence choice. This is because of the dynamic updating of both the reference price and variance according to the realized outcomes (prices in our case). As such, if a consumer does not visit restaurant $j$ out of 1,000 restaurants, its price and price variability will never enter either the reference price or the perceived variance. Similarly, if a restaurant is rarely chosen, its price and price variability will have a miniscule effect on the consumer’s estimates. This solution to the “representative measure” is typically chosen to deal with category-level reference prices (Biehal and Chakravarti 1983; Briesch, Krishnamurthi, and Raj 1997).

### B. Price Sensitivity Specification

Winer (1989), Mazumdar and Jun (1992), Kalyanaram and Little (1994), and Han, Gupta, and Lehman (2001) show that higher price variability increases the range of prices that consumers find acceptable. This translates to reduced price sensitivity in the presence of high price variability. Our second specification is consistent with the reference price literature. A reference price is an internal standard against which observed prices are compared (Kalyanaram and Winer 1995; Raman and Bass 2002). The literature review by Kalyanaram and Winer (1995) shows that there is good empirical support for the existence of reference prices. Less consensus exists on the correct form they should take, that is, contextual or temporal, category level or brand level, and so forth. We use a variant of the specification used by Kalyanaram and Little (1994) and Han et al. (2001). In these papers, brand-level variability for household $i$, $s^2_{ijt}$, is defined as the dynamically smoothed variance of past brand prices relative to a reference price. That is,

$$R_{ijt} = \lambda_{\text{ref}}(t)R_{ij,t-1} + (1 - \lambda_{\text{ref}}(t))P_{ijt} - \lambda_{\text{vol}}(t)(P_{ij,t-1} - R_{ij,t-1})^2,$$

$$s^2_{ijt} = \lambda_{\text{vol}}(t)s^2_{ij,t-1} + (1 - \lambda_{\text{vol}}(t))(P_{ij,t-1} - R_{ij,t-1})^2,$$

where $R_{ij,t-1}$ is household $i$’s reference price for brand $j$ at time $t$ and is a function of past observed prices. The adjustment weights $\lambda_{\text{vol}}(t)$ and $\lambda_{\text{vol}}(t)$ may be constants (Kalyanaram and Little 1994; Han et al. 2001) or they may be time dependent. One example of a time-varying adjustment weight is that of fictitious play where the adjustment weight equals $t/(t - 1)$ (Fudenberg and Levine 1998).

Kalyanaram and Little (1994) proposed that the difference of price and reference price should be rescaled by its standard deviation. That is, consumers are sensitive not to the absolute distance of price from the reference price but to the number of standard deviations between the price and reference price.
Following the logit framework adopted by Kalyanaram and Little (1994), the probability of a household $i$ buying brand $j$ at time $t$ is given by

$$
Pr_{ijt} = \frac{\exp(x_i \beta_j - (\gamma_e + \gamma_f + \gamma_g)(P_{ijt} - R_{ijt})/s_{ijt})}{\sum_{m=1,2,...,n} \exp(x_m \beta_m - (\gamma_e + \gamma_f + \gamma_g)(P_{imt} - R_{imt})/s_{imt})},
$$

where $x_{ijt}$ is a vector of household- and brand-specific variables, including brand loyalty, brand constants, advertising, and feature and display, and $\beta_j$ is the vector of corresponding coefficients. Thus, $x_i \beta_j = V^t$ is the household’s valuation of brand $j$ at time $t$. The parameters $\gamma_e$, $\gamma_f$, and $\gamma_g$ are coefficients on the price and differ depending on whether price is perceived to be a gain, a loss, or in an acceptable range vis-à-vis the reference price. We replace these by a single parameter $\gamma$ to be consistent with the payoff sensitivity specification. Finally, we assume consumer homogeneity and adopt category-level reference price and variability measures that are composed of the past prices of all brands, so that $R_j = R, \forall j$, and $S = S(s_1, s_2, \ldots, s_J)$. The brand subscript may then be dropped from equation (3), resulting in

$$S_j^2 = \lambda_{vol}(t)S_{j-1}^2 + (1 - \lambda_{vol}(t))(P_{j1} - R_{j-1})^2. \quad (6)$$

In equilibrium, this converges to a value we denote by $S_j^2$. With these modifications to (5), the market share in equilibrium is determined by the aggregate logit model

$$MS_j = \frac{1}{\sum_{m=1,2,...,n} \exp(V_m - V_j + \gamma(P_j - \bar{P}_{jm})/S(s_1, \ldots, s_j))}. \quad (7)$$

As in the previous section, we construct a proper demand function by multiplying market share by $(1 - P_{mom})$. This specification models that consumers become less sensitive to price differences when prices are more variable in the environment. Hence, it is called the price sensitivity specification.

### III. Optimal Pricing Policies

In this section, we derive the pricing policies for $J \geq 2$ firms under both specifications. The optimal average prices have the usual property: under both specifications, for any pair of firms $i$ and $j$, the higher-quality firm will charge a higher price and leave a greater payoff. Thus, (a) if $V_j > V_i$, then $\bar{P}_j > \bar{P}_i$ and $V_j - \bar{P}_j > V_i - \bar{P}_i$, and (b) if $V_j = V_i$, then $\bar{P}_j = \bar{P}_i$. Next, we consider optimal price variability.
Variable Pricing Strategies in Oligopoly Markets

A. Payoff Sensitivity Specification

Each firm $j$ maximizes its profits with respect to its average price $\bar{P}_j$ and variability $s_j$. Thus,

$$\max_{\bar{P}, s_j} \pi_j = \frac{(1 - P^\text{out})(\bar{P}_j - c_j)}{1 + \sum_{m \neq j} \exp \left[ \gamma(V_m - V_j + \bar{P}_j - \bar{P}_m)/S(s_1, \ldots, s_J) \right]}.$$  \hspace{1cm} (8)

We can state the following results with respect to price variability.

**Proposition 1.** Under the payoff sensitivity specification, (a) for the highest-quality firm, the optimal variability is zero, (b) for the lowest-quality firm, maximum variability is optimal, and (c) there exists a cutoff quality such that all firms with lower quality find it optimal to have maximum variability and all firms with higher quality find it optimal to have zero variability.

The intuition is as follows. Overall sensitivity to payoffs is lowered by increased variability in price. Since higher-quality firms provide a larger payoff, they benefit from high sensitivity and should therefore pursue low price variability. The lower-quality firms benefit from decreased sensitivity and therefore prefer to pursue a high-variability strategy.

The price changes should have as high variability as possible for the low-quality firms within the confines of the available technology. In a grocery store, price changes may occur at the rate of once a week, while on the Internet, it is possible for them to change several times a day. Airline prices, for example, are extremely variable. It should be noted that although price changes, such as those for an airline pricing, are generated by some deterministic algorithm, they appear to be random from the customer’s perspective, hence, satisfying the requirement of random variability.

B. Price Sensitivity Specification

Recalling equation (7), each firm $j$ maximizes its profits with respect to its average price $P_j$ and variability $s_j$. Thus,

$$\max_{\bar{P}_j, s_j} \pi_j = \frac{(1 - P^\text{out})(\bar{P}_j - c_j)}{1 + \sum_{m \neq j} \exp \left[ \gamma(V_m - V_j + \bar{P}_j - \bar{P}_m)/S(s_1, \ldots, s_J) \right]}.$$  \hspace{1cm} (9)

In contrast to the previous specification, the optimal price variability strategy is as follows.

**Proposition 2.** Under the price sensitivity specification, (a) for the highest-quality firm, the maximum variability is optimal, (b) for the lowest-quality firm, zero variability is optimal, and (c) there exists a cutoff quality such that all firms with lower quality find it optimal to have zero variability and all firms with higher quality find it optimal to have maximum variability.

The intuition is as follows. In this specification, only sensitivity to prices is lowered by increased variability in price. As such, the high-quality firm, which is also the higher-price firm, benefits from low sensitivity to price and
therefore pursues high price variability. The lower-quality firm is also the low-
price firm, and benefits from increased sensitivity to price. Therefore, it prefers
to pursue a low-variability pricing strategy.

The explanation can also be rephrased as follows. The formation of category-
level reference prices helps the firms with lower-quality, lower-priced brands
and hurts the firms owning higher-quality, higher-priced brands. Thus, higher-
quality, higher-priced brands should oppose the formation of a stable reference
price by making prices variable. Lower-quality, lower-priced brands should
therefore oppose variability.

C. The Relationship between Variability and Market Shares under
Different Specifications

The two specifications generate contradictory implications. In the price sensi-
tivity case, the higher-quality firm prefers high price variability. This is reversed
for the payoff sensitivity specification. We need to distinguish the correct spec-
ification. Although the preceding results have normative and descriptive value,
they are not well suited for hypothesis testing through experimentation. The
following result, which is testable using only consumer responses, is thus useful.

**Proposition 3.** Let MS denote the market share of the highest-quality
firm. Then, (a) MS(high variability, payoff sensitivity specification) < MS(low
variability, payoff sensitivity specification), (b) MS(high variability, price sen-
itivity specification) > MS(low variability, price sensitivity specification),
and (c) the market share of the lowest-quality firm has the reverse ordering.

The explanation is straightforward. In the payoff sensitivity specification,
when there is no price variability, consumers are perfectly sensitive to payoffs
and choose the dominant choice with probability 1. When price variability is
infinite, consumers have zero sensitivity to payoffs and make their choices
randomly with equal probability. In the price sensitivity specification, with low
price variability, consumers are more sensitive to prices. Since the higher-quality
choices have higher prices, they are less likely to be chosen. As price variability
approaches infinity, price considerations will diminish to zero and choice will
be determined solely on the bases of nonprice attributes, favoring the high-
quality firm.

Proposition 3 yields clear hypotheses to test between the specifications. In
a two-firm setting, let firm 2 be the higher-quality firm. Then:

**Hypothesis 1.** Firm 2's market share is increasing in price variability
(True → price sensitivity explanation supported).

**Hypothesis 2.** Firm 2's market share is decreasing in price variability
(True → payoff sensitivity explanation supported).

IV. Experimental Investigation

The setting is a choice between two restaurants that differ on the attributes of
service quality, food quality, décor, and price; one choice is higher quality and
higher price, and the other choice is lower quality and lower price.
Proposition 3 gives distinct empirical predictions for each model. Thus, an experimental approach can sort out the better specification. However, different scenarios can be observed in practice. For example, following the Erev et al. (1999) framework, price may be realized each time following choice so that decision makers learn expected payoffs and payoff volatility through the updating of expected prices. Alternatively, prices may be known in advance. Or, if there is perfect recall of past prices, the average price and price variability can be computed. It is useful to focus on these cases separately because they all occur in practice. Thus, we perform three experimental studies. Each of the three studies has two conditions, high variability and low variability, but they differ on the information structure that decision makers are given.

In study 1, participants choose in each round between two restaurants whose quality attributes are known but whose price is realized only after selection. This can be the case in real-life consumption decisions when, deciding on which restaurant to pursue, the consumer does not have the menus of both restaurants in front of her. Rather, she recalls the past price of dinner at each restaurant and makes choices based on that recollection.\(^2\)

In some settings, decision makers may know the prices in advance of making their choice (e.g., Kalyanaram and Little 1994). To compare the specifications in that setting, we conduct study 2, where decision makers know the restaurant prices in advance of their choice in each round. Note that since prices are known, the model does not specify a dynamic for learning.

Finally, study 3 verifies that the results extend to settings where the decision maker knows average prices and price variability in advance. Participants are given a single choice between two restaurants where they know all attributes and prices they have paid in the past with certainty.

### A. Methodology for Study 1

Thirty participants were recruited by signs around campus informing them of an experiment in decision making in which they could win cash and prizes. They were randomly assigned to two variability conditions—low and high variability. Participants were informed that they would face choices between vouchers for one of two restaurants. For each restaurant they would know the Zagat ratings over food quality, service quality, and décor but not price.

\(^2\) That price is noisy because of changing menu prices (e.g., fish is typically sold at “market price”), changing menu items (“the special” can vary from day to day), and consumption variability (the consumer does not get the exact same meal, appetizer, and drink each time). The consumer updates his noisy estimate of what the expected price would be. With many observations, this estimate will approach the average dinner price at the restaurant.
TABLE 1  Participants’ Stated Valuations

<table>
<thead>
<tr>
<th></th>
<th>Low Variability (N = 15)</th>
<th>High Variability (N = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restaurant 1</td>
<td>Restaurant 2</td>
<td>Restaurant 1</td>
</tr>
<tr>
<td>Average willingness to pay ($)</td>
<td>10.97</td>
<td>5.93</td>
</tr>
</tbody>
</table>

The price for the chosen restaurant was displayed after making the choice. Prices for both restaurants would vary from round to round. It was stressed that choices would determine the earnings of the participants. Participants were told that each voucher would cover the approximate price of a full dinner.

The ratings were on food quality, décor, and service quality on the Zagat.com scale, ranging from 1 to 30 (the higher the number the better). Participants were informed that Zagat.com is a respected and widely used online restaurant critic and were assured that the ratings given in the experiment were the actual Zagat.com ratings.

Prior to the experiment, participants were given a short questionnaire that asked them to state their willingness to pay for a meal at four restaurants whose ratings were given, including the two that would be later used in the experiment. We wanted to verify that the quality of restaurant 2 was perceived to be significantly higher. Participants’ stated valuations for dinner at these two restaurants are reported in table 1 (participants are sorted by their subsequent assignment to the low or high variability condition).

For all participants, stated valuations of restaurant 2 exceeded their valuations for restaurant 1 by at least $2. Although the participants in the high-variability treatment appear to have a higher average valuation for restaurant 2, this difference is caused mainly due to one participant and is not significant (the two-tail t-test has a p-value of 0.15). Likewise, the difference between the two groups is not significant for the valuation of restaurant 1 (the p-value is 0.77).

Once participants completed the questionnaire, they continued with the actual experiment. Their attention was directed to the computer screen in front of them. The computer screen had two clickable buttons, each labeled by the Zagat ratings of the restaurant it represented. Participants were told to click on one of these two buttons according to their preferences over restaurant vouchers. Following each choice, participants were notified of the exact price they would pay for the voucher they chose. Prices varied from one trial to the next according to a preprogrammed distribution. The price distributions were as follows:

**Condition 1 (the low-variability condition):**
- Price(restaurant 1) = Uniform[1.5, 2.5].
- Price(restaurant 2) = Uniform[2.5, 3.5].

**Condition 2 (the high-variability condition):**
- Price(restaurant 1) = Uniform[0, 4].
- Price(restaurant 2) = Price(restaurant 1) + Uniform[1, 5].
Participants were faced with 200 trials. They were told that at the end of the experiment only one round would be picked to determine the payment. Each participant would be given a voucher for his choice of restaurant for one round only, plus $5 show-up fee, minus the price of that restaurant in that round. Although participants were not told the names of the restaurants, they were assured that all restaurants were within a short driving or walking distance from campus.

B. Results of Study 1

Regardless of the number of trials, one can observe from figure 1 that for the higher-quality restaurant, MS(high variability) > MS(low variability). Referring back to proposition 3, this observation is consistent with the price sensitivity specification but inconsistent with the payoff sensitivity specification. From figure 1, it also appears that when variability is low, participants choose the higher-quality restaurant only about half the time. That is, participants behave as if their payoffs are the same for both restaurants. This is in contrast to the restaurant valuations participants had stated in their preexperiment survey—all of which exceeded the price difference between the restaurants in the actual experiment. In a sense, once participants observed the prices of the restaurants
in the experiment, they quickly determined these prices to be “fair” and adjusted their references accordingly. In contrast, in the high-variability condition, participants had greater difficulty forming accurate references and so reliance on the restaurant attributes was greater.

We can test these observations statistically. First, dynamic specifications for reference price, perceived variability, and expected prices for each restaurant are required for both models.

The following three dynamic updating equations were applied:

\[ R_t = \lambda_{ref} R_{t-1} + (1 - \lambda_{ref}) P_t, \]  

(10)

\[ S_t^2 = \lambda_{vol} S_{t-1}^2 + (1 - \lambda_{vol})(P_{t-1} - R_{t-1})^2, \]  

(11)

\[ P_{jt} = \begin{cases} 
\lambda_{price} P_{jt-1} + (1 - \lambda_{price})P_{t-1} & \text{if restaurant } j \text{ chosen in trial } t-1, \\
\lambda_{price} P_{jt-1} & \text{otherwise}, 
\end{cases} \]  

(12)

where \( R_t \) is the reference price at trial \( t \), \( S_t \) is the perceived variability at trial \( t \), \( P_{jt} \) is expected price for restaurant \( j \) at trial \( t \), \( P_t \) is actual price paid for the brand chosen at trial \( t \), \( \Delta V \) is the estimate for \( V_j - V_t \), \( \gamma \) is the coefficient on price, \( \lambda_{vol} \) is the adjustment parameter for variability, \( \lambda_{ref} \) is the adjustment parameter for reference price, \( \lambda_{price} \) is the adjustment parameter for expected price, and \( \sigma \) is an individual random effect parameter.

To capture heterogeneity among individuals, we allow for an individual random effect \( \epsilon \sim N(0, \sigma^2) \). The probability of choosing brand 1 at trial \( t \) is then given by the following expressions under three different scenarios.

**Benchmark:**

\[ \Pr_{it} = \frac{1}{1 + \exp(\Delta V + \epsilon + \gamma(P_{it} - P_{t}))}. \]  

(13)

**Payoff sensitivity specification:**

\[ \Pr_{it} = \frac{1}{1 + \exp((\Delta V + \epsilon + \gamma(P_{it} - P_{t})/S_t))}. \]  

(14)

**Price sensitivity specification:**

\[ \Pr_{it} = \frac{1}{1 + \exp(\Delta V + \epsilon + \gamma(P_{it} - P_{t})/S_t)}. \]  

(15)

To get the two models nested in the benchmark model, we set \( S_0 = 1 \). Initial reference price is set at the midpoint of 2.5, which is generally selected
as the reference of insufficient reason. Initial expected prices are set at the true means. Likelihood maximization yields the estimates given in table 2.

All parameter estimates except $\lambda_{\text{price}}$ are significantly different from 0 at the 5% level using likelihood ratio tests. That $\lambda_{\text{price}}$ is equal to zero means that updating of expected price is instantaneous. In addition, $\lambda_{\text{ref}}$ and $\lambda_{\text{vol}}$ are also significantly different from one.

From the log-likelihood and Akaike Information Criterion (AIC) results, the price sensitivity specification gives the best improvement in fit over the benchmark. The chi-square $p$-value is less than 0.0001 for the likelihood ratio test between the baseline and price sensitivity model with two degrees of freedom due to the two parameter restrictions. The improvement of the payoff sensitivity specification is significant with a $p$-value of 0.0008.

### C. Methodology for Study 2

In some repeated shopping activities, from grocery choices to shopping for clothes or small appliances, direct price comparison is feasible. The setting in study 2 captures decision-making behavior in such settings.

A fresh sample of 30 participants was recruited. As in study 1, participants were assigned to low- and high-variability groups. The instructions were similar to the instructions of study 1, with the following exceptions: (1) restaurant prices were displayed before making a choice, (2) restaurant 2’s voucher price was greater than that of restaurant 1 in each round, (3) participants were given a third choice of “Neither,” and (4) the number of rounds was reduced to 100.

Participants were given Zagat.com ratings and a price for each restaurant in each round. The ratings were the same as those used in study 1 and remained unchanged from round to round, but prices varied according to the following distribution:

**Condition 1** (the low-variability condition):
- Price(restaurant 1) = Uniform[1.5, 2.5].
- Price(restaurant 2) = Uniform[0.5, 1.5].

**Condition 2** (the high-variability condition):
- Price(restaurant 1) = Uniform[0, 4].
- Price(restaurant 2) = Price(restaurant 1) + Uniform[0.5, 1.5].

---

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Benchmark</th>
<th>Payoff Sensitivity</th>
<th>Price Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$</td>
<td>.398</td>
<td>.388</td>
<td>.410</td>
</tr>
<tr>
<td>$\Delta V$</td>
<td>1.383</td>
<td>1.394</td>
<td>2.034</td>
</tr>
<tr>
<td>$\lambda_{\text{price}}$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$\lambda_{\text{ref}}$</td>
<td>.951</td>
<td>.984</td>
<td></td>
</tr>
<tr>
<td>$\lambda_{\text{vol}}$</td>
<td>.997</td>
<td>.719</td>
<td></td>
</tr>
<tr>
<td>$\sigma$</td>
<td>2.200</td>
<td>2.145</td>
<td>2.430</td>
</tr>
<tr>
<td>Log-likelihood</td>
<td>$-1,931.39$</td>
<td>$-1,924.31$</td>
<td>$-1,893.86$</td>
</tr>
<tr>
<td>AIC</td>
<td>3,870.78</td>
<td>3,860.62</td>
<td>3,799.72</td>
</tr>
</tbody>
</table>
Note that restaurant 2 is always higher priced than restaurant 1. Also note that the average price difference between the two restaurants and the distribution of that difference are identical between the two conditions of study 2. This identical distribution of the difference in price implies identical market shares for the two conditions, given the utility function, in the absence of price variability or payoff variability effects.

D. Results of Study 2

Figure 2 shows that the patterns for the high-variability condition are similar to those of study 1, with the high-quality restaurant preferred over the low-quality restaurant (the proportions do not add up to one because of the opting out choice). Over time, as in study 1, participants experience a mild, yet relatively flat, learning to increase their choice of restaurant 2.

With the low-variability condition, the results are quite different, as shown in figure 3. Participants’ reference prices were adjusted to such an extent that their preferences over the restaurants reversed. The majority now prefer restaurant 1. This reversal is consistent with a strong reference price effect (Kalyanaram and Little 1994) but is not captured by our price sensitivity model without an explicit accounting for reference price effects in the utility function.

E. Discussion of Study 2

The feature that the price of restaurant 2 is always greater than the price of restaurant 1, that this relationship is stated in the instructions, and that these
two prices are prominently displayed next to each other results in a strong formation of preferences and in a preference reversal due to increased variability. That is, when variability is low, restaurant 1 looks much more attractive due to its low price. However, when variability is high, price plays a lesser role in the decision and restaurant 2 appears more attractive. This suggests that restaurant 2 benefits from higher variability—lending support to a price sensitivity explanation.

F. Methodology for Study 3

One hundred participants were given a survey in which they were given a choice of dinner at one of two restaurants. As before, they were given a list of three attributes—food quality, décor, and service. In addition, price information was displayed as a series of prices that participants were told had been paid for dinner in the past. These past prices were either in the high-variability condition or the low-variability condition (see table 3 for the choice descriptions). The average restaurant prices were $10.50 and $16.40, these were obtained from the survey of the participants of study 1 and excluded an outlier.

In addition to eliciting restaurant choices, participants stated the importance weight for each of the attributes, including price, such that the weights sum up to 100. This was done to ensure that higher variability does not make the price less salient in the study, a potential effect that might confound the findings.

We allowed for two different dining situations. In the first, we asked par-
TABLE 3 Choice Descriptions for Study 3

<table>
<thead>
<tr>
<th></th>
<th>Restaurant 1</th>
<th>Restaurant 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low variability:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food quality</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>Décor</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Service rating</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Prices ($) that participants were told had been paid for dinner in the past</td>
<td>10.57, 10.83, 10.23, 10.41, 10.25, 10.63, 11.05, 10.74, 10.13, 10.11</td>
<td>17.09, 15.87, 16.89, 16.79, 15.46, 15.43, 16.61, 16.17, 17.20</td>
</tr>
<tr>
<td><strong>High variability:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food quality</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>Décor</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Service rating</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Prices ($) that participants were told had been paid for dinner in the past</td>
<td>8.12, 7.62, 7.48, 7.78, 13.49, 8.49, 7.03, 14.24, 15.31, 15.41</td>
<td>23.74, 20.13, 22.18, 7.83, 7.76, 11.65, 9.63, 23.71, 25.22, 12.19</td>
</tr>
</tbody>
</table>

Participants to imagine dining alone. In the second, we asked them to imagine dining with a friend, with each paying individually. The reason is that people can display different consumption patterns when dining in social settings than in private consumptions (e.g., Glance and Huberman 1994; Gneezy et al. 2004). For example, there may be greater price sensitivity when dining alone than in company. We eliminated responses from those who indicated that they ate less than two dinners a month at a restaurant, leaving 50 responses in the high-variability condition and 44 in the low-variability condition. The results are shown in table 4.

G. Results of Study 3

In the “dining alone” scenario, we find that 88.6% of the students in the low-variability condition chose restaurant 1 (the lower-quality restaurant). In sharp contrast, 68.0% of the students in the high-variability condition chose restaurant 1. The difference was significant with a chi-square $p$-value of 0.017. As expected, the high-variability condition did not make the price less salient. The importance weight on price was 31.77 in the low-variability condition and 31.06 in the high-variability condition. The difference was not significant (the $p$-value was 0.423).

In the “dining with a friend” scenario, 34.1% of the students in the low-variability condition chose restaurant 1. In contrast, 22.0% of the students in the high-variability condition chose restaurant 1. However, the difference was not significant (the chi-square $p$-value was 0.191). As before, the importance weights appear not to be affected by the condition (they are, however, different between the scenarios). The importance weight on price was 22.61 in the low-variability condition and 24.44 in the high-variability condition. The difference was not significant (the $p$-value was 0.280).
Table 4  Percent Choosing Restaurant 1

<table>
<thead>
<tr>
<th></th>
<th>Low Variability (%)</th>
<th>High Variability (%)</th>
<th>( \chi^2 )</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dining alone</td>
<td>88.6</td>
<td>68.0</td>
<td></td>
<td>.017</td>
</tr>
<tr>
<td>Dining with friend</td>
<td>34.1</td>
<td>22.0</td>
<td></td>
<td>.191</td>
</tr>
<tr>
<td>( N )</td>
<td>44</td>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ H. \quad \text{Study 3: Discussion} \]

When dining alone, the majority of participants chose the lower-priced restaurant. As variability increases, the choice becomes more uniformly divided. This is consistent with both price sensitivity and payoff sensitivity models.

When dining with a friend, the majority chose the higher-price, higher-quality restaurant. This choice became more predominant when variability increased. Recall from proposition 3 that the payoff sensitivity model predicts that higher variability should benefit the lower-quality restaurant. This is clearly not the case. Instead, we find support for the price sensitivity model, which predicts that high-price variability should benefit the higher-priced restaurant. Hence, this study, like the previous two, is consistent with the price sensitivity model.

\[ V. \quad \text{Conclusions} \]

We examined equilibrium pricing strategies composed of an average price and variability in prices rather than a fixed price point. This enrichment of the pricing strategy space is important because behavioral studies have shown that consumers respond to price variability. We investigated competitive pricing strategies by building on these behavioral findings and showing that they can have important strategic implications. If a fixed price with zero variability is optimal, then this will emerge in equilibrium since it is encompassed in the larger strategy space. But a firm facing competitors that employ the broader pricing repertoire will make suboptimal pricing decisions if it ignores the price variability options available to it.

Price variability affects consumer sensitivity to price and product differences. This conclusion arises from two streams of literature. However, slight differences in behavioral specifications in the literatures were found to cause diametrically opposite pricing implications for firms. In the “payoff sensitivity” specification, as variability increases, consumer attention to quality and price differences falls. Hence, lower-quality, lower-priced firms can compete better. In the “price sensitivity” specification, as variability increases, consumer attention to price differences falls. Hence, higher-quality, higher-priced firms can maintain their market share advantage.

We ran three experimental studies to determine the correct specification. Each study had two conditions, high variability and low variability, but they differed on the information structure that decision makers were given. In the
first, participants had to learn both prices and variability. In the second, they had to learn only variability. In the third, they had all the information. All three studies indicated that price variability affects choice probabilities and that it does so in a way that benefits the higher-priced restaurant. The findings support the price sensitivity specification as the better model in predictive ability and in explanatory power.

The examples of grocery store, airline, and telephone pricing policies in the introduction are in accordance with our experimental results. The higher-quality, higher-priced product appears to strongly benefit from higher price variation. This lends face validity to the price sensitivity specification.

The effect of variability on consumer behavior would benefit from additional investigation. For example, do the findings hold when the attributes of the product are uncertain and variable? As a final remark, one should also account for the costs associated with high price variability. These include higher operating costs in inventory control and warehouse handling, higher personnel costs, and higher advertising expenses (Ortmeyer, Quelch, and Salmon 1991).

Appendix

Proofs

Proof of proposition 1. Starting with the objective function,

$$\max_{p_i, s_j} \pi_j = (1 - P^{\text{out}}) \frac{\bar{P}_j - c}{1 + \sum_{s_{s_j}} \exp \left[ \left( \frac{\gamma (V_m - V_j + \bar{P}_j - \bar{P}_n)}{S(s_1, \ldots, s_J)} \right) \right]}. \tag{A1}$$

The partial derivative with respect to variability is

$$\frac{\partial \pi_j}{\partial s_j} = (1 - P^{\text{out}}) \times \left\{ \frac{\gamma (\partial S/\partial s_j)(\bar{P}_j - c)}{S(s_1, \ldots, s_J)} \right\} \times$$

$$\frac{\sum (V_m - V_j + \bar{P}_j - \bar{P}_n) \exp \left[ \left( \frac{\gamma (V_m - V_j + \bar{P}_j - \bar{P}_n)}{S(s_1, \ldots, s_J)} \right) \right]}{(1 + \sum_{s_{s_j}} \exp \left[ \left( \frac{\gamma (V_m - V_j + \bar{P}_j - \bar{P}_n)}{S(s_1, \ldots, s_J)} \right) \right]^2} \geq 0.$$

$$\Rightarrow \sum_{s_{s_j}} (V_m - V_j + \bar{P}_j - \bar{P}_n) \exp \left[ \left( \frac{\gamma (V_m - V_j + \bar{P}_j - \bar{P}_n)}{S(s_1, \ldots, s_J)} \right) \right] \geq 0. \tag{A2}$$

Renumber firms in order of their quality so that $V_j > \ldots > V_n > \ldots > V_i$. We know that $V_j - B_j > \ldots > V_n - P_n > \ldots > V_i - P_i$.  

(a) For the highest-quality firm, $V_n - V_i - P_n + B_n < 0$, $\forall n$. Hence, the sign of the

3. As long as cost differences are small relative to the quality differences, the analysis remains unaffected by cost heterogeneity. The results can also be shown to hold for preference heterogeneity. Details are available from the authors.

4. The extended derivation is available from the authors.
left-hand side in (A2) must be negative. The optimal variability is thus zero for the
highest-quality firm.

(b) For the lowest-quality firm, \(V_m - P_m + P_i > 0, \forall \ m\). Hence, the left-hand side
is positive and maximum variability is optimal.

(c) For each higher-quality firm, the left-hand side becomes less negative. And, by
\(a\) and \(b\), the left-hand side must go from negative to positive. Hence, there is an
intermediate firm with firms above it for whom the left-hand side is positive and firms
below it for whom it is negative. QED.

Proof of proposition 2. Starting again with the objective function,

\[
\max \pi = \frac{(1 - P^{\text{min}})(\bar{P}_j - c)}{1 + \sum_{i \neq j} \exp \left[ V_i - V_j + (\gamma(\bar{P}_j - \bar{P}_m)/S(s_1, \ldots, s_j) \right]}
\]  

(A3)

The partial derivative with respect to variability is

\[
\frac{\partial \pi}{\partial s_j} = \left( \gamma k_j(\bar{P}_j - c)/S(s_1, \ldots, s_j) \right)^2 \times \frac{\sum_{n \neq j} (\bar{P}_j - \bar{P}_n) \exp \left[ V_i - V_j + (\gamma(\bar{P}_j - \bar{P}_m)/S(s_1, \ldots, s_j) \right] \right) \left( > \right) 0
\]

\[
= \sum_{n \neq j} (\bar{P}_j - \bar{P}_n) \exp \left[ V_i - V_j + (\gamma(\bar{P}_j - \bar{P}_m)/S(s_1, \ldots, s_j) \right] \left( > \right) 0.
\]

(A4)

Re-number firms in order of their quality so that \(V_i > \ldots > V_m > \ldots > V_i\). We know that
\(P_i > \ldots > P_m > \ldots > P_i\). Then, we have the following:

(a) For the highest-quality firm, \(P_i - P_m > 0, \forall \ m\). Hence, the sign of the left-hand
side in (A4) must be positive. Maximum variability is thus optimal for the firm with
the highest quality.

(b) For the lowest-quality firm, \(P_i - P_m < 0, \forall \ m\). Hence, the left-hand side is negative
and zero variability is optimal.

(c) For each higher-quality firm, the left-hand side becomes less positive. And by
\(a\) and \(b\), the left-hand side must go from positive to negative. Hence, there is an
intermediate firm with firms above it for whom the left-hand side is negative and firms
below it for whom it is positive. QED.

Proof of proposition 3. Re-number firms in order of their quality so that \(V_i > \ldots > V_m > \ldots > V_i\).

(a) For specification 1, we know from the proof of proposition 1 that when
\(V_i - P_i > \ldots > V_m - P_m > \ldots > V_i - P_i\), then (i) \(\partial \pi / \partial s_j = [(P_i - c)]^2 \partial MS_j / \partial s_j < 0\) for the
highest-quality firm, which then implies that \(\partial MS_j / \partial s_j < 0\) and (ii) \(\partial \pi / \partial s_j = [(P_i - c)]^2 \partial MS_j / \partial s_j > 0\) for the lowest-quality firm, which implies that \(\partial MS_j / \partial s_j > 0\).

(b) For specification 2, we know that when \(P_i > \ldots > P_m > \ldots > P_i\), then (i) \(\partial \pi / \partial s_j = [(P_i - c)]^2 \partial MS_j / \partial s_j > 0\) for the highest-quality firm, which implies that \(\partial MS_j / \partial s_j > 0\) and (ii) \(\partial \pi / \partial s_j = [(P_i - c)]^2 \partial MS_j / \partial s_j < 0\) for the lowest-quality firm, which implies that \(\partial MS_j / \partial s_j < 0\). QED
References


