MANAGEMENT SCIENCE
Vol. 51, No. 2, February 2005, pp. 195–207
ISSN 0025-1909 | EISSN 1526-5501 | 05 | 5102 | 0195

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DOI 10.1287/mnsc.1040.0318

An Experimental Investigation of the Impact of Information on Competitive Decision Making

Charles Abramson
College of Business Administration, California State University, Long Beach, California 90840, cabramso@csulb.edu

Imran S. Currim
Graduate School of Management, University of California, Irvine, California 92697-3125, iscurrim@uci.edu

Rakesh Sarin
John E. Anderson Graduate School of Management, University of California, Los Angeles, California 90095-1481, rakesh.sarin@anderson.ucla.edu

Managers often employ market response models as decision aids and historical information of competitors' market outcomes to aid their competitive decisions in oligopolistic settings. However, little is known about how access to a decision aid or the availability of competitors' market outcomes impact a firm's competitive decisions (e.g., prices) or market outcomes resulting from those decisions (e.g., profits), or how managers make these decisions across such informational conditions. Hence, the objective of this paper is twofold. First, we investigate whether access to a decision aid and historical information of competitors' outcomes yields more- or less-competitive decisions and outcomes. Second, we determine which learning constructs, such as choice reinforcement and beliefs about projected profits, best explain competitive actions across various information conditions. We find that relative to the availability of competitive information, access to a decision aid has a larger effect on lowering prices and profits. We also find that in two-firm markets, price competition is even more intense than in five-firm markets. Similarly, the availability of market share information leads to more aggressive pricing even when profits are held constant. Finally, we outline the implications of our findings in making managerial resource allocations to market research endeavors.

Key words: experimental game theory; competitive decision making; information
History: Accepted by Christopher Tang, interdisciplinary management research and applications; received March 2002. This paper was with the authors 9 months for 3 revisions.

1. Introduction

Consider an industry where a handful of firms compete in a fixed market. All firms simultaneously make a decision at the beginning of a period (e.g., set prices), observe outcomes for the period (e.g., profits), and then make their decision for the next period (e.g., set prices again). An example of such an industry is health care, where several firms routinely compete to provide health care to employees of large institutions. Each firm sets its price for the year (monthly premium) and, having observed the outcome, sets its price for the next year.

Managers often employ market response models (decision aids) and historical information of their competitors' market outcomes to assist in their decisions, such as in the oligopolistic setting described above (Hanssens et al. 2001, Lilien et al. 1992). Information from decision aids and on competitors' outcomes can both impact decisions, but in very different ways. Managers can use historical information of competitors' market outcomes to help predict competitors' actions. Model-based decision aids, however, can help managers assess what customers' responses will be to actions taken by their firm, as well as their competitors. However, very little is known about (a) how access to these decision aids or information impacts competitive decisions (e.g., prices) and the market outcomes resulting from those decisions (e.g., profits) and (b) how managers make decisions under various information conditions.

In competitive settings, several types of information about competitors could influence a firm's decisions. These include information about competitors' past decisions, the outcomes of those decisions, and the firm's ability to analyze the impact of those decisions on its own profits. In this paper, we vary the availability of information on competitors' outcomes by making it public or private and the capability of firms to predict their outcome based on competitors' actions by providing a model (decision aid) or no model.

Managers make decisions in an attempt to maximize their firm's profits. In a competitive setting, the attractiveness of a strategy is influenced by competitors' actions. Because it is not known in advance what competitors will do, a manager resorts to heuristics

or decision rules to maximize profits. For example, a manager may rely on a strategy that has yielded high profits in the past (Erev and Roth 1998). A proactive manager may also formulate expectations about the competitors' future actions based on their past behavior and choose a strategy based on these expectations (Camerer and Ho 1999).

The objective of this paper is twofold. First, following a conceptual framework of the impact of information on competitive decisions, we investigate whether access to a model-based decision aid and to historical information on competitive outcomes yields more- or less-competitive decisions and outcomes. We consider two possible settings: one in which competing firms offer differentiated products and another in which they offer products that are undifferentiated. Second, we investigate how managers make such decisions, that is, the role of decision heuristics such as choice reinforcement and beliefs about projected profits in explaining competitive decisions under various information conditions. We conduct three experiments using a price-setting game in a health care context, wherein managers of five hypothetical firms (or two firms in Experiment 3) make pricing decisions over an eight-period time horizon.

We chose a time horizon of eight periods because it corresponded to 8 weeks of the 10-week executive MBA class in which the experiments were conducted. Large employers, including the University of California, only allow health care insurance providers to change plan characteristics, such as price, once a year. Based on the proposed plan characteristics, employees choose a plan during an open enrollment period. Thus, each pricing decision (and its corresponding market response) is equivalent to one year in our game. In future research, it would be valuable to study pricing behavior over a longer time horizon.

It might appear that consideration of one decision variable, such as price, is a simplification that is not representative of a real decision environment. However, in the health care industry, it is common for large employers to require certain health plans (e.g., health maintenance organizations) to standardize benefits each year. This facilitates plan comparisons by employees who are primarily concerned with price and plan reputation. Our experiments are, therefore, representative of real-world contexts where price is the primary decision variable. Further, the complexity of our games is generally higher than those usually employed in experimental games in economics, yet our games are tractable enough to allow us to draw conclusions regarding the competitive behavior of firms under alternative conditions.

2. A Brief Literature Review

When considering the effects of market response models on managerial decision making, the studies most likely to come to mind are the now classic laboratory (Chakravarti et al. 1979, 1981; McIntyre 1982) and field studies (Fudge and Lodish 1977) assessing the efficacy of judgment-based models in aiding decision making. The objective of those studies was to assess whether a judgment-based model helped managers achieve a higher level of sales and profits, improved prediction of market outcomes, etc. *across* a number of periods in a *noncompetitive* setting.[1] Our objectives are different. We are interested in assessing the impact of access to a decision aid based on market data, as well as information and industry factors on the *evolution* of prices and profits in *competitive* settings.

Our method of data collection was inspired by a pioneering study of the effects of information on managerial decisions conducted by Glazer et al. (1992). In that paper, students who were enrolled in an advanced course in strategic marketing made several managerial decisions (e.g., pricing, advertising, sales force, R&D, etc.) across nine periods in the context of the MARKSTRAT (Larreche and Gatignon 1977) game. The objective of this work was to study the effects of information (e.g., from consumer surveys, brand attribute ratings, perceptual maps, and advertising experiments) on managerial decisions. In contrast, we wish to study the effects of differing levels of access to a model-based decision aid and to competitors' profits on firms' prices, profits, and quality of decision making. Further, we are interested in explaining managers' competitive decisions and investigating whether variables such as choice reinforcement and belief-based projected profits are useful in explaining price variation.

A second stream of research related to our work is behavioral game theory (Camerer 2003). In behavioral game theory, the processes of reasoning that players employ in analyzing a game and in choosing a strategy are uncovered through careful experimental design and observation of their choices. Erev and Roth (1998) and Camerer and Ho (1999), for example, propose learning models to study how players choose among strategies based on their own past experiences and on their beliefs about opponents' behavior. Camerer and Ho (1999) provide a unifying framework in which choice reinforcement and belief-based learning models become special cases of their experience-weighted attraction (EWA) model.

3. Conceptual Framework and Hypotheses

The key objective of this paper is to investigate the effects of availability of a decision aid (model) and of market information about competitors' profits (public information) on the competitive behavior

[1] By this, we mean that the assessed tools do not explicitly account for competitors' actions.

Table 1 Summary of Aggregate-Level Results for Experiments 1–3

	Hypotheses and results	Supported by observations	Level of support
Experiment 1			
Hypothesis 1	Model-based decision aids lead to lower prices.	Yes	$p < 0.001$
	• Models (public information) lead to lower prices.	Yes	$p < 0.017$
	• Models (private information) lead to lower prices.	Yes	$p < 0.001$
Hypothesis 2	Model-based decision aids lead to higher decision quality.	Yes	$p < 0.001$
	• Models (public information) lead to higher decision quality.	Yes	$p < 0.026$
	• Models (private information) lead to higher decision quality.	Yes	$p < 0.001$
Hypothesis 3	Public information leads to lower prices.	Partial	
	• Public information (model) leads to lower prices.	No	
	• Public information (no-model) leads to lower prices.	Yes	$p < 0.010$
Hypothesis 4	Public information leads to higher decision quality.	Partial	
	• Public information (model) leads to higher decision quality.	No	
	• Public information (no-model) leads to higher decision quality.	Yes	$p < 0.009$
Experiment 2			
Hypothesis 5	Differential access (model) leads to higher profits.	Partial	
	• Model (differentiated markets) leads to higher profits.	No	
	• Model (undifferentiated markets) leads to higher profits.	Yes	$p < 0.003$
Hypothesis 6	Higher Decision Quality Index is achieved in undifferentiated markets.	Yes	$p < 0.003$
	• Higher Decision Quality Index is achieved in undifferentiated markets (model).	Yes	$p < 0.001$
	• Higher Decision Quality Index is achieved in undifferentiated markets (no-model).	No	
Experiment 3			
Hypothesis 7	Fewer firms lead to higher prices.	No	
Hypothesis 8	Information on market share leads to lower prices.	Yes	$p < 0.001$

(prices) and outcomes (profits) of firms. Both decision aids and market information improve the quality of decisions but perform different functions. Decision aids help in optimization so that a firm can choose the best price provided it correctly predicts competitors' prices. Market information about competitors' profits helps a firm to predict what prices the competitors are likely to choose. Both types of information resolve some uncertainty. For individual decisions, additional information that resolves some uncertainty about future outcomes is always desirable. The value of such information is therefore positive, and, in theory, any additional information would be preferred. For competitive decisions, however, the impact of information on realized outcomes is more complex. Stigler (1964), for example, argues that public information may encourage collusion and therefore has an adverse effect on the competitiveness of a market. Recently, Vega-Redondo (1997) has advanced a contrary argument. He uses a game-theoretic framework to show that public information might increase the competitiveness of a market. The finding that increased information can lead to more intense competition has also been shown in other game-theoretic papers (Clarke 1983; Vives 1984; Gal-Or 1985, 1986; Hornig and Stadler 2004; Zhu 2004; see Tirole 1988, p. 364 for additional references).

If a decision aid and information on competitors' outcomes is available to all firms, then competitiveness will increase. This is especially so when the number of firms is large and each offers differentiated products. When only a few firms in the industry have access to a decision aid (differential access), these firms will have an advantage and the potential to earn higher profits. In an undifferentiated market, where the optimal price is the same for all firms, the decision-making task is simpler, and firms are likely to set prices closer to the optimal price.

Our hypotheses, stated below (and summarized in Table 1), are based on the generalized message distilled from the literature. We note that our hypotheses will likely hold only when there are a small number of periods (e.g., the eight periods of our games), and, in the long run, pricing behavior may be more complex. Firms might engage in aggressive pricing at first, but decreasing profits could induce them to raise prices. However, the short-run behavior of firms is still of interest to managers.

Hypothesis 1. *Model-based decision aids* (*versus no model*) *lead to lower prices*.

This hypothesis implies that prices set using a decision aid (model condition) will be lower than those that use no decision aid (no model condition). Under the no-model condition, prices and profits are higher, as firms might not realize the benefits of unilateral price cuts. Under the model condition, such benefits are made transparent, and firms are likely to set lower prices. It may seem that the decision aid offers an informational advantage, and, therefore,

firms working under this condition should be able to profit from it; however, if all firms have access to the decision aid, all can realize the benefits of unilateral price cuts, so the result is a more competitive market with lower prices and profits.

Hypothesis 2. *Model-based decision aids lead to higher decision quality.*

The quality of a decision by a given firm in a given period depends on two factors. One is its ability to predict the prices its competitors will set in the upcoming period. The second is its ability to compute its optimal price based on the prices set by its competitors. The Decision Quality Index measures the quality of decisions made by firms working under a given condition (model versus no model, for example) and ranges from 0 to 1. Specifically, a Decision Quality Index of, say, 0.8 would mean that the firm achieved 80% of its maximum possible profit for the period.

$$\text{Decision Quality Index} = \frac{\text{actual profit} - \text{minimum potential profit}}{\text{maximum potential profit} - \text{minimum potential profit}}.$$

Using a decision aid, a profit-maximizing clairvoyant who could predict opponents' actions perfectly would have a Decision Quality Index of 1. Note that even a clairvoyant might not achieve a Decision Quality Index of 1 without a decision aid. This is because, in spite of perfect information on competitors' actions, one may not be able to compute the optimal price without the decision aid. A more stringent measure of decision quality is the proportion of times a chosen price was the best price to set. This measure is akin to measuring batting performance by home runs. We will report the results for this measure of decision quality as well.

Hypothesis 3. *Making information on firms' decisions and outcomes public leads to lower prices.*

There has been some evidence that a greater knowledge of a competitor's performance in price-setting games leads to more aggressive pricing behavior (Armstrong and Collopy 1996, Griffith and Rust 1997). Huck et al. (1999) find that knowledge of a competitor's performance results in more competitive decisions regarding order quantities; however, Huck et al. did not study the effect on prices. They studied the effects of the availability of knowledge of competitors' profits on prices but found that the differences are not statistically significant (Huck et al. 2000). On the other hand, Stigler (1964) makes the general argument that more information on competitors leads to less intense competition (possibly collusion) and hence higher prices. As a result, the effect of public information on the competitiveness of decisions is unclear. We hypothesize, however, that managers with knowledge of their competitors' profits will demonstrate a tendency toward more aggressive pricing. If there were several firms in the industry, each with its own unique optimal price, collusion would be difficult. Further, experienced managers tend to be competitive and are eager to exploit the advantage of a unilateral price cut especially when the number of competitors is large.

Hypothesis 4. *Making information on firms' decisions and outcomes public leads to higher decision quality.*

We anticipate that the decision quality of managers working with information on competitors' decisions and outcomes (public information condition) will be higher because players learn of each other's profits and prices and, therefore, will be able to more accurately assess their competitors' intentions. When information on competitors' profits is unknown (private information condition), however, it is more difficult for a player to predict competitors' price-setting behavior. The effect of public information on the quality of decisions has not been assessed in prior work to the best of our knowledge.

Hypothesis 5. *Firms that have differential access to a decision aid will make higher profits.*

Hypothesis 1 requires that all firms in a market either do or do not have access to the model-based decision aid. In contrast, under the differential access condition of Hypothesis 5, some firms in a market have access to the decision aid while others do not; consequently, a decision aid is a potential source of competitive advantage. Hypothesis 5 may not hold if opponents are making correct choices (i.e., close to their respective Nash levels) or if the firm's actions reveal the information. In general, however, Hypothesis 5 is likely to hold when differential information can be exploited (e.g., when opponents make incorrect choices because of their lack of information).

Hypothesis 6. *Higher decision quality is achieved in undifferentiated markets.*

When firms within an industry are undifferentiated, an effective strategy for one of them will also be effective for any of the others. Because firms know this, it is easy for them to learn from each other's successes and failures. Hypothesis 6 is based on the premise that players competing in undifferentiated markets will end up learning from each other and will thus attain a higher Decision Quality Index. In contrast, the respective Nash prices and profit functions differ across firms in a differentiated market; therefore, the rate of learning is slower.

Hypothesis 7. *Fewer firms lead to higher prices.*

When the number of firms is large, each with its own distinct optimal price, cooperation becomes difficult. Hypothesis 7 is based on the premise that with only two firms, each may likely see the advantage of setting higher prices (Scherer and Ross 1990). In a variety of games, including the type we employ in our study, the propensity to collude or cooperate is higher when there are only two players than when there are several (Camerer 2003).

Hypothesis 8. *Information on market share leads to lower prices*.

Even when the goal is as specific as profit maximization, information on firms' outcomes leads firms to compete aggressively to seek a greater market share (Buzzell et al. 1975, Szymanski et al. 1993). The consequence is lower prices. Without this information, firms may still attempt to achieve a greater market share, but not as aggressively as when the information is made vivid.

4. Overview of the Experimental Market Game

A total of 224 executive MBA students participated in three experiments to investigate how managers would set prices in a competitive environment: 126 students participated in Experiment 1, 56 students participated in Experiment 2, and 42 students participated in Experiment 3. The average work experience was 14.5 years, and the average age was 38. Each student represented a firm in an industry comprised of five firms (Beta, Delta, Gamma, Sigma, and Theta). In one treatment of Experiment 3, an industry was comprised of only two firms. Beta represented a low-cost, staff model health maintenance organization (HMO); Delta and Gamma represented moderate-cost, traditional HMOs; Sigma represented a higher-cost indemnity insurance plan, and Theta represented a higher-cost, preferred provider organization (PPO). Assignment of students to a firm was random. For all experiments, each firm had the simple task of setting the monthly premium that it would charge for the upcoming period. They were restricted to choosing from one of seven price levels, which varied in increments of \$50 from \$400 to \$700. Based on the prices submitted by the five firms, we computed the profits accrued to each firm and informed them of the results. Firms then set prices for the next period. The game went on for eight periods. A period in the game corresponded to a meeting of the class (once a week); therefore, students had sufficient time (seven days) to analyze the results of previous round(s) before determining their prices for the next period. At the beginning of the game, participants were given information on the cost structure of their respective firms and their customer profiles (e.g., age distribution). Subjects did not know the identities of the students representing the other firms.

This game was motivated by the University of California's health care benefits program. The payoff matrix underlying the game was constructed utilizing the coefficient values from a multinomial logit model of consumer choice, estimated on the actual health care plan choices of University of California employees between 1993 and 1996 (Abramson et al. 1998).

Two factors determined the expected cost of providing health care coverage to those who chose a firm's plan: the degree of flexibility a plan offered and the enrollees' age. Each firm knew its degree of flexibility, which was specified in advance, but the age distribution of those enrolled in a plan depended on the prices set by all firms and the resulting probability that an enrollee would choose a particular firm's plan. At the end of each period, the age distribution of a firm's clients was provided. The revenues accrued to a firm in a given period were based on the price, flexibility, age, and plan-age interaction. A logit model was used to compute the probability of a choice by a consumer i for health plan j (firm j) at time t. The expected revenue for a firm was simply the product of the price set by the firm and the probability of choice summed over all customers. The details of the logit model were not given to the subjects, but the factors that determined probability of choice (price, flexibility, age) were explained to them. When the model was made available, a player could simply plug in the firm's price and the competitors' prices and examine the resulting profit. When the model was not available, a player learned the profit implications of the firm's pricing strategy over time and did not have the opportunity to do a "what-if" analysis by varying prices prior to their actually being set. Because each player had a different potential for making profits, subjects were instructed at the beginning of the game that their performance in the game would be evaluated relative to their profit potential and would contribute to their course grade.

Our game involved a relatively simple decision, which is typical in a competitive environment, yet the setting was realistic enough for our executive subjects to become invested in the decision task. The use of actual data produced reasonable and believable numbers in the payoff matrix; however, players were primarily concerned with the payoffs they would realize, not with the process that generated the payoff matrix. The payoff matrix of our game resembled a prisoner's dilemma, with a Nash equilibrium that was Pareto dominated by a collusive outcome. The payoff matrix for the two-firm market used in Experiment 3 is given in Table 2. For the five-firm market, the basic structure of the payoff matrix was similar to that of

Table 2 Payoff Matrix for Two-Firm Market

	Firm 2's price						
	400	**450**[c]	500	550	600	650	700
Firm 1's price							
400	35,908[a]	39,835	43,282	46,190	48,558	50,431	51,876
	14,654[b]	14,684	13,833	12,429	10,762	9047	7430
450	37,164	42,202	46,830	50,895	54,325	57,120	59,330
	17,790	18,260	17,589	16,120	14,194	12,100	10,047
500[c]	36,674	**42,696**	48,496	53,825	58,508	62,461	65,682
	21,054	**22,157**	21,866	20,494	18,407	15,958	13,436
550	34,683	41,419	48,229	54,790	60,820	66,122	70,598
	24,293	26,210	26,525	25,472	23,398	20,693	17,721
600	31,565	38,649	46,162	53,761	61,084	67,816	73,737
	27,356	30,226	31,366	30,892	29,078	26,302	22,978
650	27,758	34,799	42,614	50,905	59,292	67,378	74,814
	30,125	34,021	36,160	36,523	35,261	32,684	29,205
700	23,684	30,332	38,029	46,576	55,645	64,822	73,671
	32,524	37,448	40,688	42,096	41,681	39,630	36,290

[a] Profit of Firm 1.
[b] Profit of Firm 2.
[c] Nash Price.

the two-firm market; however, the number of entries was 7^5. For the scenario using the model and public information, a player could access the complete payoff matrix. There were three key characteristics of the payoff matrix: (1) the Nash equilibrium was unique, (2) the cooperative solution in which each firm set the highest price yielded the highest industry profit, and (3) the firms generally were able to earn higher profits by undercutting competitors' high prices.

4.1. Experiment 1

Experiment 1 was designed as a 2×2 matrix (see Table 3) to assess the impact of a model-based decision aid (either all firms had access or none did) and information on competitors' profits (public versus private information) on prices, profits, and decision quality. Each market replication consisted of five firms in a differentiated market. The unique Nash equilibrium prices and associated profits for each of the five firms are given in Table 4. Subjects were told that they were to maximize their profits with respect to their own profit potential and that optimal prices and profits differed across firms.

Table 3 Number of Subjects and Design for Experiment 1

		Information on competitors' profits	
		Public	Private
Access to model-based decision aid	Model	32*	30
	No-model	34**	30

* Six teams with five players each and an additional team with three dummy players.
** Six teams with five players each and an additional team with one dummy player.

Each firm set its price for the current period to one of the seven possible levels ($400, $450, $500, $550, $600, $650, or $700).[2] Each firm was informed either of its own profits (private information condition) or all firms' profits (public information condition) and was then asked to set prices for the next period. For both information conditions (public and private), each firm knew the prices set by the other firms. The game terminated at the end of the eighth period. All subjects were aware that the game would last for eight periods and that they were to maximize their firm's cumulative profits by the end of the eighth period.

4.1.1. Model vs. No-Model–Based Decision Aid. Under the model condition, all firms within an industry were given access to a profit simulator (decision aid). This piece of software allowed them to access preselected cells of the payoff matrix underlying the game. This allowed them to assess how much profit they (as well as their competitors if they were assigned to the model/public information scenario) would earn for any given combination of prices. If players were able to anticipate their competitors' actions, they could easily determine their most profitable pricing strategy. The decision aid provided an expected value of the profit the manager would make if he or she correctly predicted the competitors' actions. In principle, a patient and knowledgeable player could identify the Nash equilibrium with the help of the decision aid.

[2] These amounts include a $400 employer contribution. Thus, the net monthly premium paid by an employee for health care insurance could vary between $0 and $300.

Table 4 Nash Prices and Profits at Prices in Experiment 1

	Beta	Delta	Gamma	Sigma	Theta
Nash price	\$400	\$500	\$450	\$600	\$550
Nash profits/period	\$3,155	\$26,959	\$29,659	\$10,913	\$8,442

4.1.2. Public vs. Private Information on Competitors' Profits. Players with information on their competitors' profits were said to be operating under the "public information" condition, and those without such information were operating under the "private information" condition. By using this second variable, evidence could be gathered on the relative magnitude of both effects, which has important implications for how firms should devote resources to various market research endeavors such as building decision aids and collecting information on competitors' profitability.

4.1.3. Results. A summary of the aggregate results as they relate to Hypotheses 1–4 is presented in Table 5 (the table includes results of one-tailed t-tests of statistical significance). In Figure 1, prices, profits and Decision Quality Index are plotted for each of the eight periods of the game for each combination of conditions (model, no model, public information, private information) in Experiment 1.

A clear result is that firms using the decision aid start out with higher initial prices and higher initial profits; however, both prices and profits decline rapidly toward competitive equilibrium levels (Figure 1). This same pattern occurs for both the public and private information conditions.[3] A detailed firm-by-firm analysis, not reported here, reveals a similar pattern. For example, the average price for firm Delta converges to its Nash equilibrium price of \$500 and average profits of approximately \$27,000 (Delta's Nash profits). Hypothesis 1 is supported by these results. Subjects using the model set lower prices than those without the model (Table 5). Without the model, the benefits of a unilateral price cut were not transparent, at least within the eight periods for which the subjects played the game. Access to the decision aid led to higher decision quality. This result holds for both the public and private information conditions (Table 5). Thus, Hypothesis 2 is also supported. Further, with respect to our more stringent measure of decision quality, the proportion of times firms chose the best price was significantly higher when they used a decision aid when information on competitors' decisions was both public (31.65% versus 21.71%, $p < 0.01$) and private (47.44% versus 24.31%, $p < 0.01$).

[3] Note that in Figure 1, the mean Decision Quality Index for the model and no-model groups under public information are the same in the last period, yet the no-model group earned higher profits. This is because the groups not using the model set much higher prices in the last period relative to the group using the model. If all firms in a fixed market set higher prices, then profits would be higher. Decision quality is not necessarily positively correlated to profit, because it measures how close a manager came to choosing the most profitable price level for a particular period of play *given the actions taken by competitors during that period.*

Table 5 Prices and Decision Quality Index Under Model vs. No-Model and Public vs. Private Information Conditions in Experiment 1

	Public	Private	*p*-value
Model	530	526	n.s. (H3)
(all players)	0.86	0.93	n.s. (H4)
No-model	546	564	0.01 (H3)
(all players)	0.83	0.77	0.009 (H4)
p-value	0.017 (H1)	0.001 (H1)	
	0.026 (H2)	0.001 (H2)	

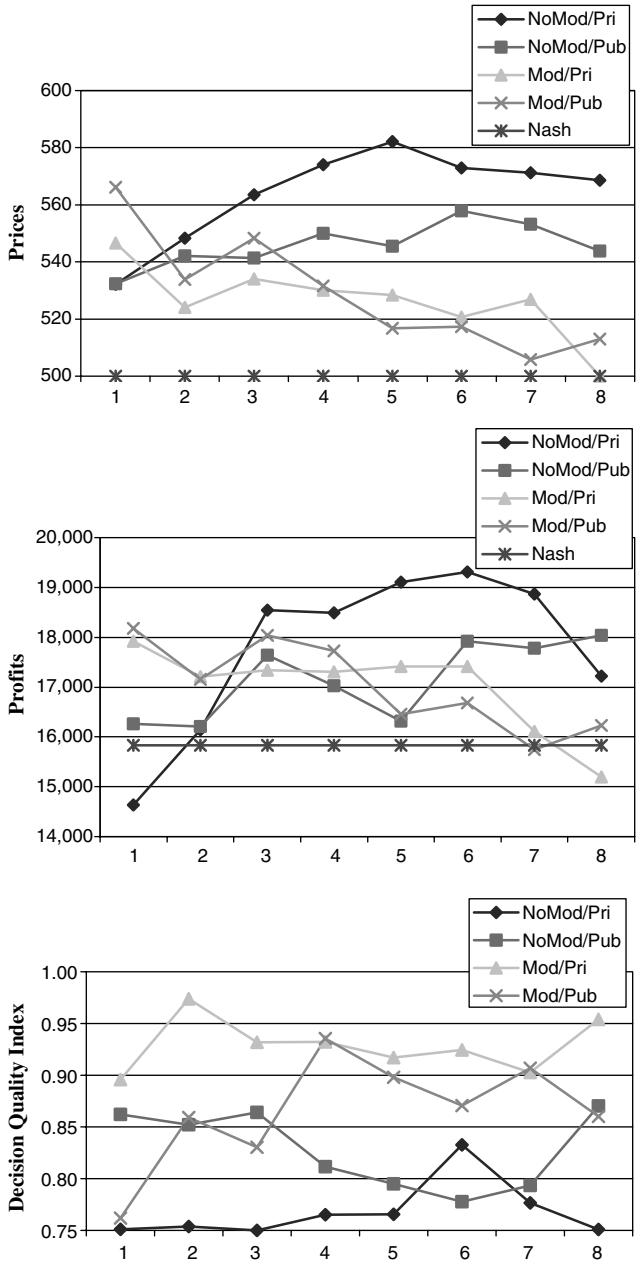
Note. Prices under model vs. no-model conditions refer to Hypothesis 1. Decision Quality Index under model vs. no-model conditions refers to Hypothesis 2. Prices under public vs. private information conditions refer to Hypothesis 3. Decision Quality Index under public vs. private information conditions refers to Hypothesis 4. The statistical test is conducted by each firm's price (or Decision Quality Index value) in each session and comparing these prices (or Decision Quality Index values) across conditions (model vs. no-model; public vs. private).

Hypothesis 3, which states that public information leads to lower prices, is supported when there was no decision aid available (Table 5). With the use of a decision aid, the impact of information (public versus private) is insignificant, and prices and profits converge to the Nash equilibrium levels regardless (Figure 1). A possible explanation for this result is that under the model condition, players can experiment by examining alternative price scenarios both for themselves and for their competitors, and the results they obtain are the primary determinants of their decision. Thus, competitors' profits perform a secondary role, because prices that are more frequently selected are presumably more profitable for competitors. The incremental contribution of public information over private information in the differentiated market is therefore small. For the no-model condition, however, players only have information on past results; therefore, that knowledge plays an important role in the prices they set (Figure 1).

The results that pertain to Hypothesis 4 are rather interesting. As anticipated, players with knowledge of their competitors' profits achieve a higher level of decision quality, but only under the no-model condition (Table 5). Surprisingly, for the model condition, players with public information ended up with a Decision Quality Index below that of players working with only private information. When firms have access to a decision aid, it is possible that information regarding competitors' financial success has a distracting effect (Glazer et al. 1992). In the absence of knowledge of competitors' profits, one concentrates on figuring out what is the best price for one's own firm.

An analysis of variance reveals that the decision aid variable (model/no model) had a greater effect

Figure 1 **Prices, Profits, and Decision Quality Index for Each of Eight Periods and Four Conditions of Experiment 1**



on prices and decision quality than the information variable (public/private; Table 5, Figure 1). Further, there is an interaction effect that dampens the sum of individual effects of the decision aid and public information on both prices and decision quality. For the model condition, the relative impact of the type of information (public versus private) was small, as the ability to evaluate one's own profits under alternative scenarios dominated the knowledge of others' profits in setting prices (Table 5, Figure 1). Only in the absence of a decision aid does the impact of public versus private information appear to be substantial (Table 5, Figure 1). For the model condition, all firms within an industry have the capability to analyze the impact of competitors' actions on their own performance. This knowledge leads to a rapid convergence of prices to their competitive equilibrium positions even in the relatively short span of eight periods. Public information, however, seems to have two counterbalancing forces; more information led to better planning but, in the presence of a decision aid, might have a distracting effect.

The results of Experiment 1 may be good news to theorists who study rationality in markets, but the message is pessimistic for managers. The general message is that access to a decision aid for analyzing opponents' actions leads to outcomes that are more competitive and less profitable for the industry and for individual firms. Access to the model makes collusion possible, but it also makes the benefits of unilateral price cuts transparent; and, in fact, the latter motive seemed dominant in our setting. It is conceivable that collusion is not possible in a five-firm market. In Experiment 3, we will use a two-firm market to further test whether players engage in implicit collusive practices. Access to the model is, however, shared equally in Experiment 1.

Next, we examine whether market response models (decision aids) are a source of competitive advantage when only a few players in the industry possess this capability.

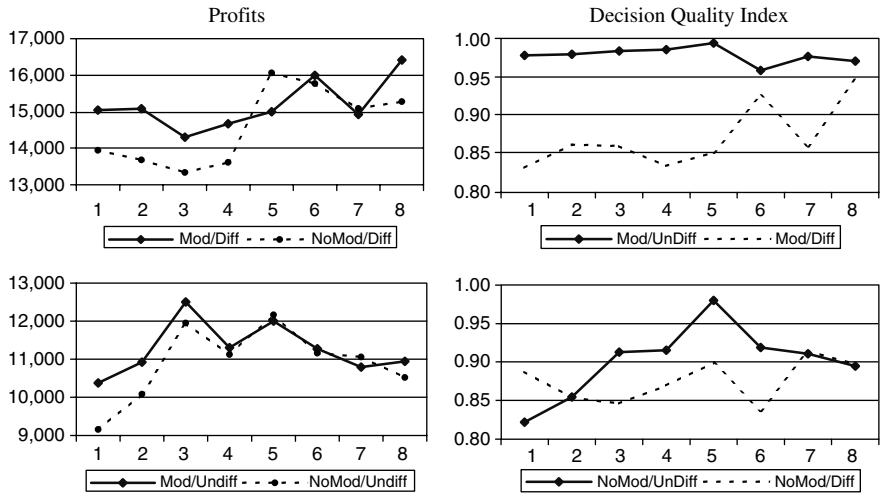
4.2. Experiment 2

In Experiment 2, we assessed the impact of selective access to a decision aid (some firms had access and others did not) in differentiated and undifferentiated market settings. Because the type of information available (public versus private) played a minor role in Experiment 1, we set the information condition for all cases in Experiment 2 to public information.

The subjects in this experiment were 56 executive MBA students. Each market replication consisted of five students (firms). Students did not know the identities of the other players in their market replication but were aware that two firms were given access to a decision aid and three were not. They were instructed not to communicate their identities or their results to the other players. For the differentiated market, the Nash equilibrium prices and profits were kept at the same levels as in Experiment 1. For the differentiated market, the unique, static Nash equilibrium occurred at the same price level for each firm ($600), and if two or more players set the same price, they earned the same level of profits.

4.2.1. Results. For both differentiated and undifferentiated markets, profits for firms with access to the decision aid were generally higher than for firms without access, but not significantly so (Figure 2). While the difference in profits was statistically significant in the undifferentiated market ($p < 0.003$), the

Figure 2 **Profits and Decision Quality Index for Each of Eight Periods and Two Conditions of Experiment 2**



difference was small in magnitude (Table 6). Consequently, Hypothesis 5 is partially supported. An additional noteworthy finding emerges in a detailed analysis: As much of the profit advantage to firms with the model (in both the differentiated and undifferentiated conditions) occurs in the initial periods of play and diminishes or disappears in the last few periods (Figure 2). It is possible that even without knowing the identities of the players that had access to the decision aid, managers learned from one another through market signals (price and profit history) and, over time, learned to make decisions that were more profitable. The advantage given by the decision aid may therefore be short lived, as one ends up sharing the information indirectly through one's actions.

We note that the absolute levels of prices and profits cannot be compared across differentiated and undifferentiated markets, but decision quality can. In undifferentiated markets, the Decision Quality Index is higher than in differentiated markets (Table 6). A particularly striking result is that, for an undifferentiated market, firms with access to the model achieved a Decision Quality Index close to 0.98 and maintained a high level of decision quality over the eight periods of the game (Figure 2). Hypothesis 6 is therefore supported by our data. Further, with respect to our more stringent measure of decision quality, the proportion of times firms chose the best price was significantly higher for those that had access to a decision aid than for those who did not, when markets were both differentiated (42.71% versus 32.61%, $p < 0.05$) and undifferentiated (41.25% versus 29.17%, $p < 0.05$).

Table 6 **Profits (Model vs. No-Model) and Decision Quality Index (Differentiated vs. Undifferentiated) in Experiment 2**

		Industry type		
		Differentiated	Undifferentiated	*p*-value
Differential access to model-based decision aid	Model (2 players)	15155, 0.87	11477, 0.98	0.001 (H6)
	No-Model (3 players)	14550, 0.87	10992, 0.90	0.161 (H6)
	p-value	n.s. (H5)	0.003 (H5)	

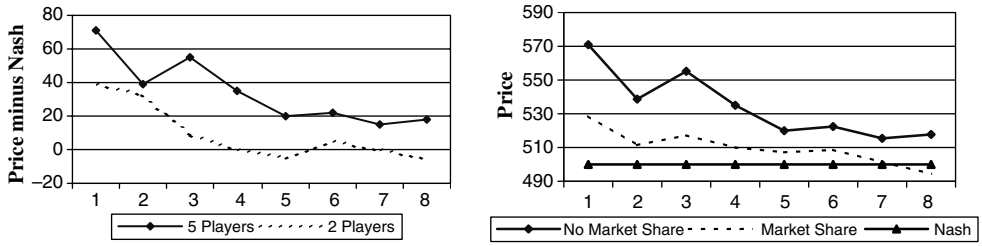
Note. Profits under model vs. no-model conditions refer to Hypothesis 5. Decision Quality Index under differentiated vs. undifferentiated conditions refers to Hypothesis 6.

In Experiments 1 and 2, the industry was comprised of five firms, and only profit information was provided to each firm. In Experiment 3, we introduced two variations—one designed to induce cooperation and another designed to accelerate competition. The first variation used a two-firm market to see whether firms engage in implicit collusion by setting higher prices. The second variation provided firms with market share information along with profits realized. Even though the firms were supposed to maximize total profits over the eight periods, the market share information may have induced them to use more aggressive pricing strategies.

4.3. Experiment 3

In Experiment 3, all players had access to a decision aid and to information on competitors' decisions (model/public information scenario). We examined pricing behavior in a two-firm market and assessed the impact of market share information on the evolution of price in a five-firm market. The subjects in this experiment were 42 executive MBA students. There were six market replications of two-firm markets (model/public information (without market share) scenario). The payoff matrix for the two-firm market is given in Table 2. In addition, there were six replications of five-firm markets in which each firm was given information on prices, profits, and market share for all firms at the end of each period (model/public information (including market share) scenario).

Figure 3 **Pricing Behavior in Each of Eight Periods and Two Conditions of Experiment 3**



*Data for 5 players are taken from Experiment 1.

*Data for No Market Share are taken from Experiment 1.

The results from the two-player markets in Experiment 3 can be compared with those of the five-player markets in Experiment 1 (Figure 1, model/public information scenario). To do this, we use the difference between the observed price and the Nash price in each period. This is because absolute levels of prices in two-firm and five-firm markets are not directly comparable. Prices in five-firm markets with market share information in Experiment 3 can be directly compared to five-firm markets in Experiment 1 (without market share information) for the model/public information scenario.

4.3.1. Results. The results for Experiment 3 are shown in Figure 3. In Figure 3, the data for the bold line on each graph are taken from Experiment 1 and the data for the dotted line on each graph are taken from Experiment 3. In the two-player setting (left-hand panel in Figure 3), firms used aggressive pricing, and the price differential with respect to Nash prices converged rather rapidly to zero (after three periods). In the five-firm setting, the price differential was generally higher and stayed positive. Therefore, Hypothesis 7 is rejected. The difference in mean price and Nash price was 9.5 for the two-player setting and 30 for the five-player setting. The more intense competition, which resulted in lower prices in the two-player setting, could be attributed to the competitive nature of our subjects, who occupy executive positions. The transparency and simplicity could potentially induce cooperation, as we conjectured in Hypothesis 7; indeed, there could be conditions under which one might observe collusive behavior. Experienced managers, however, tend to be more competitive in nature. Hence, they can easily see the benefits of aggressive pricing in simple games.

Evolution of prices in five-firm markets both with and without market share information is shown in Figure 3 (right panel). The mean price when no market share information was provided ($530) was significantly higher ($p < 0.001$) than the mean price when it was provided ($510). As seen in Figure 3, information on market share resulted in more competitive behavior, which, in turn, resulted in lower prices and faster convergence to Nash prices. Hypothesis 8 is, therefore, supported by our data.

In the analysis above, we used the convenient benchmark of the Nash solution (competitive equilibrium). The Nash solution is a useful benchmark for theoretical analysis and for studying market behavior; however, comparison of actual results to the Nash solution provides little insight into the behavior of individual players. A majority of our subjects were not aware of what a Nash solution was and were unlikely to be engaged in a single-minded pursuit of their respective static Nash price. They were more likely to be interested in figuring out, as best as they could, the pricing strategy that yielded their firm the most profit. We have collected data on the price-setting behavior of 224 managers for eight consecutive periods across a variety of industry and information conditions (Experiments 1, 2, and 3). It is likely that managers use strategies that have worked well for them in the past. They are also likely to engage in prospective thinking and to choose their actions based on their beliefs about competitors' actions. The EWA model, which we examine next and which was proposed by Camerer and Ho (1999), can shed some light on managers' motivations.

4.4. Experience-Weighted Attraction (EWA) Model

Camerer and Ho (1999) proposed an EWA model that incorporates both choice reinforcement (i.e., strategies yielding higher profits in the past will tend to be chosen more often) and belief learning (i.e., the expected profit of choosing a strategy if others choose based on their past behavior). We briefly describe this model and estimate its parameters for the price-setting games of Experiments 1, 2, and 3.

There are two key variables in the EWA model that are updated after each period of play. The first variable is $A_i^j(t)$, which in our context is the attractiveness of price level j to manager i after period t has taken place. The second variable is an experience weight $N(t)$, which is the weight placed on previous attractions relative to recent payoffs in updating the attractions. The experience weight is updated at the end of each period as follows:

$$N(t) = \rho N(t-1) + 1, \quad t \geq 1,$$

where ρ is a depreciation rate for the past experience. The initial value of experience weight, $N(0)$, is estimated from the data.

The attractiveness, $A_i^j(t)$, is updated as follows:

$$A_i^j(t) = \phi N(t-1)A_i^j(t-1) + \pi_i(s_i^j, s_{-i}(t))/N(t),$$

if player i chose strategy j in period t; otherwise,

$$A_i^j(t) = \phi N(t-1)A_i^j(t-1) + \delta\pi_i(s_i^j, s_{-i}(t))/N(t),$$

where δ is the discount factor applied to the hypothetical payoffs of strategies not chosen compared to the actual profits realized; ϕ discounts the previous attraction, and $\pi_i(s_i^j, s_{-i}(t))$ is the profit available to player i by choosing strategy j in period t when other players chose strategies s_{-i}. The profit available to player i by choosing strategy j in period t will be a function of strategies chosen by other players. Initial attractions $A_i^j(0)$ are estimated from the data.

The attractiveness levels are inputs to the computation of probability of choice. We use a logit model:

$$P_i^j(t+1) = \frac{\exp(A_i^j(t))}{\sum_J \exp(A_i^j(t))}.$$

The objective is to find the values of the parameters of the model so that log likelihood is maximized; that is, find $A_i^j(0)$, $N(0)$, ϕ, ρ, and δ to maximize

$$\mathrm{LL} = \ln\left[\prod_T \prod_I \prod_J P_i^j(t)^{Y_i^j(t)}\right],$$

where $Y_i^j(t)$ equals 1 if player i chose strategy j in period t, and 0 otherwise.

4.4.1. Results. The results of fitting the EWA model to the 10 cells of Experiments 1, 2, and 3 are reported in Table 7. In our estimation, we assumed that all players in each market condition had the same parameter values, including initial attractions. We reported the number of observations in each cell, N, the log likelihood measure (LL), the BIC (Bayesian Information Center) measure, the initial experience weight $N(0)$, the attraction discount ϕ, the experience discount ρ, and the imagination factor δ. We have not reported the initial attractions for simplicity in presentation.

Note that the imagination factor δ across all 10 cells in Table 7 is quite small. This means that the payoffs of the strategies not chosen receive low weights in updating the attractions. Alternatively, the payoffs of the strategies actually chosen receive high weights, implying that players care most about their realized payoffs. In some of our scenarios (no-model condition), the players can only guess the payoffs of strategies not chosen. Note that in updating attractions, all strategies (chosen or not) receive a contribution of δ times the payoff. The chosen strategy receives an additional contribution of $(1-\delta)$ times its payoff.

Table 7 Fit and Parameter Estimates of Experience-Weighted Attraction (EWA) Model

Experiment 1		Experiment 2		Experiment 3	
Model/public		Model/differentiated		Market share info	
N	206	N	82	N	210
LL	−331.13	LL	−101.56	LL	−358.63
BIC	−351.773	BIC	−119.19	BIC	−386.14
	Estimate		Estimate		Estimate
$N(0)$	2.679	$N(0)$	5.540	$N(0)$	22.28
ϕ	0.649	ϕ	1.038	ϕ	0.448
ρ	0.627	ρ	0.820	ρ	0.184
δ	0.068	δ	0.001	δ	0.099
No-model/public		No-model/differentiated		Two-player markets	
N	226	N	112	N	84
LL	−320.129	LL	−130.17	LL	−109.21
BIC	−347.232	BIC	−153.76	BIC	−126.93
	Estimate		Estimate		Estimate
$N(0)$	1.238	$N(0)$	1.061	$N(0)$	1.065
ϕ	0.321	ϕ	0.620	ϕ	1.062
ρ	0.481	ρ	0.600	ρ	0.000
δ	0.051	δ	0.064	δ	0.000
Model/private		Model/undifferentiated			
N	204	N	60		
LL	−260.47	LL	−62.11		
BIC	−287.06	BIC	−78.49		
	Estimate		Estimate		
$N(0)$	0.000	$N(0)$	13.532		
ϕ	0.430	ϕ	0.977		
ρ	0.309	ρ	0.926		
δ	0.090	δ	0.000		
No-model/private		No-model/undifferentiated			
N	191	N	100		
LL	−294.81	LL	−120.73		
BIC	−321.07	BIC	−139.15		
	Estimate		Estimate		
$N(0)$	1.960	$N(0)$	1.764		
ϕ	0.420	ϕ	0.821		
ρ	0.490	ρ	0.433		
δ	0.064	δ	0.218		

Note. Initial attractions are not reported to simplify the table presentation.

Parameter ϕ discounts the previous attraction and varies from 0.32 to 0.64 in Experiment 1, from 0.62 to 1.03 in Experiment 2, and from 0.448 to 1.062 in Experiment 3. The experience discount ρ varies from 0.30 to 0.63 in Experiment 1, from 0.43 to 0.98 in Experiment 2, and from 0.0 to 0.184 in Experiment 3. Thus, both ϕ and ρ tend to be larger in Experiment 2. Because ϕ and ρ generally have reasonable magnitudes (i.e., not close to 0), both previous attraction and previous experience are relevant in updating attractions.

Finally, $N(0)$ represents the weight given to initial attractions. In one of our 10 cases, $N(0)$ is 0, reflecting that the actual payoff experience is all that counts in that case and not the levels of initial attraction. In two cases in Experiment 2 and one case in Experiment 3, $N(0)$ is high, which means that the influence of the initial attractions persists.

In some of our cases, δ is close to 0 and ϕ and ρ are of approximately the same order of magnitude.

In these cases, attractions are weighted averages of previous attraction and realized payoff, with weights $\phi N(t-1)/[\phi N(t-1)+1]$ and $1/[\phi N(t-1)+1]$. Thus, strategies are reinforced by their previous payoffs in a weighted average manner. For example, if $N(0)=1$, then in Period 1 of updating the chosen strategy, $A(0)$ is weighted by $\phi/(\phi+1)$, and the current payoff is weighted by $1/(\phi+1)$. Similarly, in Period 2 the updated attraction of the chosen strategy will be the weighted sum of $A(1)$ and its payoff, where the weights are $\phi(\phi+1)/[\phi(\phi+1)+1]$ and $1/[\phi(\phi+1)+1]$. In these cases, players seem to be using weighted averages rather than accumulations for updating attractions.

In general, however, weighted average reinforcement for updating attractions is inadequate. For example, in the case for which $\phi=0.821$, $\rho=0.433$, and $\delta=0.218$ (Table 7, no-model/undifferentiated market scenario), a more complex learning rule that incorporates both reinforcement of actual past payoffs and hypothetical past payoffs of strategies not chosen provides a better fit to describe how players are behaving. In the EWA model, one does not have to guess the appropriate learning model (reinforcement, belief-based, or hybrid), as the estimated parameters reveal the appropriate learning rules.

Note that $N(0)$ is higher when using the decision aid than without it when information is made public (six of eight cases in Table 7). This means that pregame experience is higher when players have access to a decision aid. Further, ρ and ϕ are also higher for the model/public information scenario than for the no-model/public information scenario. This means that both previous experience and previous attraction are given a larger weight when updating attractions. In Experiment 2, $N(0)$ is higher for the undifferentiated setting than for the differentiated setting for both the model and no-model conditions. The simpler setting of the undifferentiated case (i.e., identical profit function and Nash price for all players) leads to a higher level of pregame experience.

In Experiment 3, note that the baseline condition for the five-player/no-market share setting is precisely the model/public setting of Experiment 1. The parameter estimates for the EWA model are given in Table 7. It seems that for two-player markets, players used cumulative choice reinforcement. Under the market share condition, strength of initial attraction was high and the payoffs for strategies not chosen were given low weights.

5. Concluding Remarks

In this paper, we have investigated the impact of information on firms' decisions and the resulting market outcomes. Two types of information are considered. One is access to a model-based decision aid and the other is the publication of firm-specific data. Management scientists often invest in building models (decision aids) to reduce uncertainty and to optimize profits. However, we know very little about the effects of using such models in competitive settings. In addition, as noted by Huck et al. (2000), the commission of the European Union considers the publication of firm-specific data to be anticompetitive, whereas U.S. authorities do not object to such information. It is an empirical question of whether information increases, decreases, or has no effect on competition.

Broadly speaking, access to a decision aid was primary in its effect on prices and profits, and the type of information available (public versus private) was secondary in its effect. When all firms had access to a decision aid, they competed on price, and both individual firms' and industry profits tended to be lower compared to when no firm had access to the model. If, however, only a few firms in the industry had access to the model, then firms with access to the model made higher profits. This competitive advantage, however, may be short lived as one ends up sharing the information with others indirectly through one's actions. We also find that in two-firm markets, price competition was even more intense than in five-firm markets. Similarly, even when total profits were held constant, information on market share led to more competitive behavior, with observed prices closer to Nash equilibrium prices.

Our subjects, middle and senior managers drawn from a variety of firms in southern California, are inherently competitive. When we placed them in conditions aimed at increasing competition, they responded as expected. On the other hand, when we placed them in conditions designed to reduce competition, they did not. Information, such as on competitors' profits and decision aids that allow managers to ask "what if" questions about the effects of decision variables on outcomes, increased their level of competitiveness. This suggests that as information technology and decision aids become more pervasive in organizations, competition will intensify. There may, of course, be conditions under which managers may collude, especially if they are confident of the cooperation or reciprocity of their competitors/collaborators.

The key conclusion drawn from our study is that competitive behavior is robust and that the tendency to move toward Nash equilibrium is rather powerful. We have identified conditions under which competition is more intense, leading to observed mean prices close to Nash prices. Our results are applicable to and are consistent with real competitive environments observed in a variety of settings. Carly Fiorina, CEO of Hewlett-Packard Company (HP), blamed poor earnings in the fiscal third quarter of 2003 on HP's own overly aggressive pricing actions. Though HP is just one case, overzealous discounting to gain

market share even when it hurts gross margins is not uncommon in many consumer-product markets. Airlines, long-distance telecommunications providers, and retailers exhibit aggressive pricing behavior. Collusive practices are also observed in the energy sector, but only for short durations.

Our results also suggest that differential access to models or research can be beneficial. Capital One, for example, took advantage of differential information on customer creditworthiness to segment customers and to differentiate itself from the competition. Public information made available through government rules and regulations, technology (scanners), or third-party information providers (ARS, IRI, Nielsen) is likely to enhance competition. Finally, competition is more transparent in undifferentiated markets. For example, price competition is intense for many commodity products. In contrast, in differentiated markets, firms are able to charge relatively higher prices within reason.

There are several possibilities for future research. First, we studied only one decision variable (i.e., price). Future work could employ several variables that include price, product features, advertising, etc. Second, it would be useful to study managerial decision making over a larger number of periods to investigate whether our findings apply to horizons involving longer time periods. In the long run, prices may converge to Nash prices, or they may show some other pattern (e.g., falling prices at first, which then rise because of low profitability). Third, could there be an exposure effect from access to the decision aid independent of usage? How might firms that use the decision aid more differ on decisions and market outcomes from firms that use the decision aid less? Similarly, what would be the result if some players had access to the model but no one was aware how many players had access? Finally, it may be worthwhile to add other constructs, such as "experimentation," and "mimicry" to the EWA model. This would involve generalizing the choice reinforcement variable so that strategies more similar to strategies chosen in the past were also (partially) reinforced. Mimicry or imitation could be incorporated in updating of EWA attraction. We hope our work will motivate such efforts.

Acknowledgments

The authors thank the participants of the UCI/UCLA/USC Marketing Conference for their helpful comments. They also acknowledge the helpful comments of the two reviewers and the associate editor on earlier drafts.

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