



2006

Experimental economics methodologies and applications: price competition among gasoline stations

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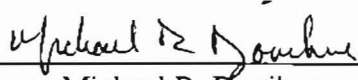
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EXPERIMENTAL ECONOMICS METHODOLOGIES AND APPLICATIONS:
PRICE COMPETITION AMONG GASOLINE STATIONS

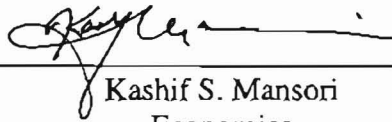
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May 2, 2003

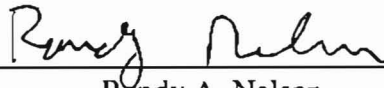
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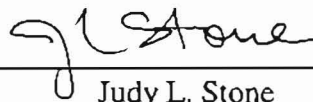
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Abstract

Experimental economics is the newest tool available to improve the research of economists. The first chapter reviews the methods that experimentation employs. The review is important for understanding the construction and running of experiments as well as the criticisms. The second chapter illustrates the methods through an example experiment of the Allais Paradox. The third chapter develops an original experiment involving the pricing decisions of gasoline by owners of adjacent gasoline stations. Anecdotal evidence shows that gas stations located in close proximity to one another often have different prices. This result contradicts existing oligopoly and duopoly theory. An experiment is developed to examine a new set of assumptions that more accurately reflect consumer and firm behavior. The results reflect that a more accurate characterization of behavioral tendencies not only satisfies the observed evidence but the dynamics of duopolies as well. The final chapter addresses the criticisms of experimentation within economics and concludes that careful experimentation can add a tremendous amount to economic research.

Acknowledgements

As with any project of this magnitude, it could never have been completed without the time and energy of many people. I would like to express my gratitude to Professor Michael Donihue who has been indispensable throughout the entire project. His time, guidance, comments, and enthusiasm are deeply appreciated. The feedback and comments provided by Professors Kashif Mansori and Randy Nelson who served as second readers on the project were of tremendous help. Thanks are due to Professor Jason Long for his assistance working with game theory and to Professor James Meehan for his aid with utility theory; a special thanks to them both for the use of their classes. I am indebted to Keith McLaughlin for the considerable time and effort that he spent making the computerization of this project possible. The Senior Scholar committee and the Office of the Dean of Faculty are thanked for the opportunity to participate in such a program and the monetary support without which this project would never have been possible. Finally, to my parents, I am grateful for your continued support of my academic tangents, your assistance in the revision of ideas, and your encouragement throughout this endeavor.

for my parents

CHAPTER 1

The Discipline of Experimental Economics

Some disciplines are inherently experimental, but others (including economics) are not.

– Daniel Friedman and Shyam Sunder

Experimental economics is the most recent tool to emerge in the field of economics. The increased focus on experimentation and the greater usefulness of the results have propelled the tremendous growth of experimental economics over the past thirty years. The elements of experimental economics must be understood in order to examine how experiments contribute to research. The focus of this chapter is to define experimental economics, relate its importance within the larger discipline of economics, investigate the methodologies used in experimental economics, and identify some special considerations for field-specific experiments.

1.1 Defining Experimental Economics

Economics, unlike the natural sciences, has only recently come to rely on experiments to supply deeper insights into research. Previously, economics has only relied on empirical work while the natural sciences have always relied on both empirical and experimental evidence. Experiments have a wide array of uses, not limited to theorists because of the applicability of the results to other disciplines. Within economics, experiments have gained importance because they help economists modify and improve existing theory. The ability for the results to be easily presented to decision makers as evidence for a policy initiative has led to the growing importance of experiments outside of economics. Observed human behavior holds greater relevance for policy makers because it provides information on theoretical behavior that enables the decision makers to construct more effective policy measures. The definition of experimental economics must encompass the various uses of the results.

Experimental economics is *the creation of an environment simulating an economic phenomenon from which to observe human behavior that might otherwise be unobservable in nature*. For the theorist, the use of experimentation is focused on identifying flaws in existing theory, not creating theory. Experiments test the assumptions regarding human behavior and that serves as the backbone of theories; they test whether the predicted behavior can be observed in an environment that simulates the premises of the experiment. The application of experimental results within economics is described by the following:

"Theory organizes knowledge and helps to predict behavior in new situations... Conversely, data collection and analysis often turn up regularities that are not explained by existing theory. Such empirical regularities spur refinement of theory..."¹

The ability for empirical evidence to shed light on gray areas in existing theory allows economists to refine their models and give the models greater explanatory power. The underlying assumptions used to support a given theory gain credibility when experimental evidence provides results consistent with those predicted by the theory.

The use of experiments by theorists can be separated into three categories: investigating issues with one clear theory; investigating issues with two contrasting theories; and investigating issues with no clear theoretical (an ambiguous) prediction. When there is one clear theory, experiments can find systematic regularities not accounted for in the theory. The experiments reveal whether or not the underlying premises of the theory are justified. An experiment simulates an event where theory has made a prediction and can strengthen or weaken the relationship between the theory and the fundamentals on which the theory is based. When human behavior in the experiment agrees with what was predicted by the theory, the assumptions on which the theory was

based gain credibility. It is this ability to observe the relationship between the assumptions and the theory that make experimentation powerful.

When there are multiple theories providing explanations for an economic event, experimental economics assumes a different role. Competing theories predict different outcomes to the same economic event. Some utilize the same set of assumptions but many do not. The data collected in the replication of the event can help identify conditions where each theory holds. Experimental evidence can also help recognize additional cases or premises needed to select the proper theory. A further possibility is that the results of the experiment will provide contradictory evidence to the underlying premises of one of the theories. In this instance, experimental data do not disprove one theory over the other; the results instead provide new information as to the applicability of the theory. Experiments outline specific cases, not general cases, so the contradictory evidence can only be applied to the tested condition, not all possible situations. Experimental evidence can bring clarity to competing theories.

When no theory exists, experimental economics serves the purpose of providing additional data to discern trends in behavior. Experiments are not a method for establishing a theory, merely a way to observe actions in the established environment. Control of the environment and access to the participants enables the experimenter to observe variables of interest in the laboratory. These variables are often more challenging, if not impossible, to observe in the natural environment. The observed behavior and additional data can help theorists engineer new paths for studying an economic problem. The field of experimental economics provides an additional

mechanism for theorists to gain access to more and better information. This increased information may generate ideas for a series of premises on which to build a theory.

Each of these cases for the use of experiments within economics plays a vital role from the theorists' standpoint. However, the real world applicability of the results to policy makers also warrants consideration. The evidence collected through an experiment can provide persuasive evidence for an economist trying to influence a policy maker. Many economic theories are difficult to apply in their general form to possible real world situations. Experiments provide not only the scenario for an event but also insight into what behavior might ensue. The ability to isolate an aspect or variable of a model that might not otherwise be observable in the natural environment provides tangible evidence that is more compelling than a theoretical prediction. Policy makers can be influenced by detailed evidence from the laboratory. Therefore it holds that experimental evidence can be more compelling than theoretical predictions in determining policy.

Experimental methods offer economists a new mechanism to enlarge the data from which to perform empirical work. As Friedman and Sunder note, "traditionally, observations from naturally occurring economic phenomena were the only source of data to stimulate revision of theory."² Experimental economics provides an environment to study economic phenomena and to observe human behavior. The environment increases the observable data making the results from experimentation valuable in determining the extent to which theoretic predictions are based on the correct assumptions.

Theoretical economics predicts the actions during an economic event based on a set of assumptions or premises about behavior (human, market, etc.). As the definition

states, experimental economics observes human behavior during laboratory-created economic phenomena that replicate the set of assumptions cited by the theory. The results of the experiment establish the extent to which the theory is based on sound premises. The experiment allows economists to observe more detailed and obscure aspects of the theory and its underlying assumptions. When the results of the experiment reflect those predicted by theory, it implies that the theory was derived from sound premises of human behavior; the theory itself, however, is not directly proven. This evidence can be compelling within the discipline as economists refine theories, and outside the discipline as policy makers adjust decisions based on experimental evidence.

Condensing the different components of experimental economics into a single definition should facilitate the reader's understanding of why experimental economics has gained so much recognition over the past four decades and to assist in the coming section of the methodologies of experimentation. It is important to note here that not all economists find value in experiments (this topic will be addressed in more detail later). The definition only identifies experimental economics; it does not determine why or how well experiments are conducted. In order to come up with a litmus test for experiments of value, a concise method becomes essential.

1.2 Methodological Overview

Certain fields within economics lend themselves to experiments more than others. A dependable method is necessary to assist economists in their efforts to improve research by means of experimentation. The definition strives to identify experimental economics and its components; the methodology strives to develop the framework for

successful and valuable experiments. The following is an overview of the methodological elements necessary for performing experiments in economics.

Much like the work of purely theoretical economists, the results of experiments must withstand the scrutiny of naysayers. Other economists must be able to understand the work and procedures. Confirmation of the results occurs when other economists review the prior work and are able to reconstruct the experiment and make similar observations. Unlike the natural sciences, it is impossible to replicate the results exactly, but economists can compare results looking for similar outcomes. The data are often different in experimental replications, but the economic outcomes (dynamic, equilibrium, etc.) are similar. This adds credibility to an experiment. An experiment is said to be *of value* when the procedures and results withstand the criticism of other economists and when the conclusions drawn from the experiment add to the existing body of knowledge of the field. Economists trying to revise experiments or identify other possible variables of interest rely on previous experiments. It is prudent therefore that experiments be well documented and of value so that researchers preparing subsequent experiments in the area can depend on the results. The ability to review and understand past work is vital to the research process.

There are three fundamentals in the method for performing experiments in economics: the relevant areas in economics that lend themselves to experimentation; the methodological elements that form experiments and ultimately influence the results; and finally field specific considerations needed in the design of experiments. Ingrained in much of the discussion of the methods for performing experiments is the history that precedes the recent or current work. Representative works³ credited with influencing the

development of experimental economics are reviewed throughout this section. An experimental economist must understand each factor in the method in order to produce an experiment of value. It is the lack of a universal method that draws some of the criticism to the field of experimental economics. This section aims to remedy that problem by creating an outline of the areas of economics that lend themselves to experimentation and the various methodological steps necessary to design and run an experiment in economics.

1.2.1 Relevant Areas Open to Experimentation

Economists desiring to enhance their work with the explanatory power of experiments must identify the research question's relevant area of economics. Three areas within economics that lend themselves to experimentation are: market experiments; game experiments; and individual choice experiments. Market experiments focus on market components, market dynamics, and price theory. Game experiments are designed to examine game theoretic models of behavior. Individual decision-making experiments seek to improve utility theory. The particular area of economics is generally chosen based on the questions being asked, the variables the experimenter wants to study, or the policy intent of the researcher.

Market experiments evolved from the belief that, despite their complex nature, economic theories of market activity could be tested in a simulated market environment. An early example of this is Edward Chamberlin's experiment published in 1948. This experiment was designed to test the hypothesis that markets were not efficient when there was some contractual obligation preventing suppliers from resetting their price.

Participants were given a card with values from which they could derive their reservation prices for the buying or selling of some good. The laboratory for this experiment consisted of a large room in which participants could move around and freely trade their hypothetical good. Chamberlin assigned varying amounts to the values and costs of the good for different participants. Subsequently, the results formed a supply and demand curve for the good (and an equilibrium price could be determined). The inability for participants to renegotiate their contracts resulted in the market not being able to reach equilibrium. In his report, Chamberlin noted that the experimenter could control the shape of the supply and demand curves through the choice of the values given to participants. Chamberlin's experiment showed that a market could be simulated in an experimental study and that an important characteristic of the market could be reproduced and tested in a laboratory environment.

In his discussion of Chamberlin's experiment, Roth (1995) notes that the design of the experiment was to show that lags caused by contracts slowed the movement of prices towards equilibrium. Chamberlin's experiment was an early indication that markets were conducive to being tested in the laboratory environment. "Chamberlin's experiment illustrates the empirical power that comes from being able to create an environment in which the predictions of a theory can be precisely known."⁴

Siegel and Fouraker (1960) address the negotiation aspect of the market economy. In their experiment, pairs of competitors negotiated over a price and quantity for some good until an agreement was reached. Each was given a payoff table listing their levels of profits that varied with the agreed on price and quantity. While Chamberlin broke ground for the use of experiments in economics, Siegel and Fouraker increased

awareness about what information is provided to competitors during experiments. The authors went to great lengths to ensure anonymity among participants as well as gain a better understanding of the roles of information and how the magnitudes of payoffs affect results (see also Smith, 1962).

Game experiments combine the disciplines of psychology and game theory to test participants' responses. Experiments test a number of principles including whether or not participants appear to make decisions based on the assumption of utility or profit maximization. A prime example of how experimentation has risen with regards to game theory is the prisoner's dilemma.⁵

The prisoner's dilemma was initially a psychology problem where two criminals were captured and separated. The story goes that the district attorney's office does not have enough evidence to pin murder charges on the criminals, but all the evidence points to the two in custody. During the ensuing interrogation, each criminal has to decide between confessing and remaining quiet. Neither knows the decision of their partner before having to make their own decision. The ramifications can be drawn up into a four-quadrant game (see Figure 1). If neither of the criminals confesses, the district attorney is stuck with lesser charges that carry sentences of five years. If only one confesses, the district attorney is in a position to cut that criminal a deal where he only gets one year in prison and the district attorney will throw the book at the other criminal resulting in a term of fifty years. To increase the likelihood of a confession, the prosecutor promises early parole if they both confess. In that case, each criminal would serve a sentence of twenty-five years. The best solution for the two criminals is to stay quiet, as they would each be free in five years time. Game theory provides an alternative

explanation that the equilibrium solution is not the preferable result of both defendants remaining quiet but for both to confess.

		Criminal 1	
		Remain Quiet	Confess
Criminal 2	Remain Quiet	<div>5</div> <div>5</div>	<div>50</div> <div>1</div>
	Confess	<div>1</div> <div>50</div>	<div>25</div> <div>25</div>

Figure 1

The following is a discussion of the “best responses” for each criminal. The point of best response for both players is the Nash Equilibrium,⁶ the point of best response for each player thus determining the outcome. From the first criminal’s perspective, if the second criminal stays quiet, he has a choice between one year for confessing and five years for remaining quiet. The decision to confess is the optimal choice as one year is less than five. On the other hand, if the second criminal confesses, he is in danger of spending fifty years in prison if he stays quiet, so again his best choice is to confess and only serve twenty-five. The converse is true from the second criminal’s perspective, so he too will choose to confess. The equilibrium choice (Nash equilibrium, shaded in gray) is both criminals confessing as it is each criminal’s best response. Experimenters can then test to see what decisions pairs of individuals would make and determine if it follows the predicted equilibrium. As game experiments evolved, economists saw the parallel between game experiments and duopoly pricing and oligopolies (see also

Kalisch, et. al (1954) and Friedman (1969, 1971). This led to increased interest in experiments that examine the decision theory as it relates to firms.

Individual decision-making experiments focus on the assumptions regarding the risk level and the utility functions of consumers. L. L. Thurstone used experimentation to determine individuals' indifference curves in his 1931 paper. Thurstone asked participants to choose between hypothetical bundles consisting of two of the goods (hats, shoes, and coats) with varying quantities (e.g., four hats, two shoes). This question was posed with varying numerous quantities to each participant. From the data Thurstone could explicitly define the preference function for each participant. This experiment was groundbreaking in that it used experimentation to examine individual choice theory. Mosteller and Nogee (1951) sought to test expected utility theory. This paper focused on utility theory being derived for the individual with the expectation that the experimental environment lent itself to such observations without the confusion of other considerations muddling the decisions. This experiment highlighted the ability to define the individual's utility function. The design of the experiment was constructed through the acceptance or refusal of gambles with varying levels of risk. The gambles also were over real money (not hypothetical decisions as in the case of Thurstone).

Experimentation concerning individual choice theories generally focuses on optimization under uncertainty and decision theory, trying to isolate variables that will reflect the preferences of the participant. The other method for these experiments is to predetermine the preference function and see how participants react within the environment. A common application of this is changing the magnitude of the payoffs, as the possibility exists for monetary restrictions on experiments to not accurately simulate

real world payoffs (lotteries, for example). It is unlikely that an experimenter would have sufficient funds where a recipient had the chance to earn a high payout from a lottery (e.g., a thousand dollars) merely to make the experiment parallel to the real life situation. Each of these areas is predisposed to experimentation. A further example of an individual choice experiment can be found in the next chapter, where Maurice Allais' examination of his paradox is outlined. The methodological points laid out in the next section of the paper are common to all economic experiments.

1.2.2 Methodological Elements for Experimentation

There are a series of key methodological pieces universal to experiments regardless of the area of economics involved. This section explores the methodological concepts of experiments including purpose, control, the environment, the laboratory, motivation of participants, determining preferences, the implications for the foundations of the experiment, and the interpretation of the results. These are the pieces of the methodology pertinent to designing and running experiments that yield noteworthy results.

The purpose of an experiment is of great importance both to the researcher and to the economic community. The experiment must have a purpose consistent with the earlier definition of economic experiments. The purpose must also include running an experiment of value that seeks to add what observation of natural occurrences cannot. In general, experiments have two major purposes: testing the validity of the lynchpin assumptions on which a theory is based; and testing the limits of the applicability of a

theory (Smith 1989). The remaining principles in the method outline the necessary components to observe such behavior.

The second principle of experimentation is that of control. Control of the experimental environment separates experimentation from empirical work. All aspects of the experiments including the decisions of the participants and the information revealed by the study are directly affected by decisions made by the experimenter. It is this control that gives experiments much of their power. Control enables the experimenter to isolate the variables he or she wishes to study. It also requires that the experimenter make decisions as to how to represent the underlying assumptions being tested. Control will also enter into the discussion of where experimenters must exercise caution. The concept of control is best illustrated in the discussion of two other parameters of importance: environment and motivation.

The environment for an experiment is crucial to isolating the desired variables needed for testing the desired hypotheses. Generally, the environment matches some real world example (the prisoner's dilemma) and is constructed to place the participants within the environment so that their actions reflect their behavior as if it were a naturally occurring situation. An important question the experimenter must address is the question of whether or not experiments should strive to mimic reality or theory (Friedman and Sunder 1994). In the end, the experiment should be designed in a manner that best reveals useful information to answer the research questions. The environment forms the foundation of the experiment so that it replicates the assumptions of the model and then allows participants to maneuver freely. The environment should be designed simply to

mirror the premises, not force the actions of the participants. Some of the effects of decisions made regarding the environment are visible in the setup of the laboratory.

The laboratory for experimental economics can be as simple as an empty classroom or as elaborate as a computer facility. The necessary components of the laboratory depend on what environment the experimenter is trying to replicate in the experiment. For the market economy in the earlier Chamberlin example, participants needed only a large room in which to move about in order to trade freely with other participants. For a negotiation experiment, a table and chairs might prove useful to negotiate across. Computers are taking on an increasingly important role in experimentation. The world is becoming more and more computer literate, so there is very little sample selection bias introduced by using them. Computers also allow for a larger sample size as the cumbersome and time intensive barrier of conducting experiments by paper is removed. It is also easier to control other methodological parameters when using a computer. Anonymity becomes far easier to maintain as computers can make opponents or partners completely blind to who is on the other end. The nature of the laboratory varies with the requirements of the experiment.

The motivation for experiments is often driven through monetary payoffs. Undergraduate students are attractive candidates for experiments as they have low marginal costs for their time and will accept lower wages relative to older adults with stronger commitments. It is difficult to achieve a representative sample, and college students offer experimenters flexibility. Experiments driven mostly by hypothetical decisions tend to hold less weight and often provide faulty results because they offer participants the ability to think about the problem in the same way they would a math or

logic problem, not as real life decisions. Their responses are based on their solution to the problem, not their response to the situation and the consequences of any decision. The Prisoner's Dilemma will serve as an example of how parties might act under different situations.

In the event that the question is asked purely hypothetically, the choice between confessing and not confessing appears to have the obvious decision to remain silent. That would ensure the possibility of the best outcome because they have a chance at escaping with only one year of jail time. Furthermore, they are not truly faced with the consequence, so this decision is not real. When placed in the actual environment of not knowing what the other prisoner might decide and faced with the real consequence of jail time, the true Nash equilibrium result of confessing is more likely to appear. The reality of actual jail time for the participant serves as motivation and is critical for the results of the experiment to have value. The introduction of monetary payoffs creates a real gain (or loss) for the participant. In this case, participants might be given money to begin with and then lose some or all of it depending on the outcome. Motivation is also one way to influence the next piece of the method, the preference structure for the participant.

Theories are based on the assumptions as to the nature of the preference structure of human beings (risk aversion, profit maximization, etc.). The preference structure plays a crucial role in the behavior of a participant in an experiment, and therefore the treatment of the preference structures requires a significant amount of contemplation by the experimenter. In general, a theory predicts actions based on a number of assumptions regarding environment and preferences. An experimenter has the option of trying to control the preferences or devising an experiment that reveals them. This choice, as well

as how the preferences are controlled, directly impacts the outcome of the experiment. In conjunction with the decisions about preferences, the rules set forth governing the environment, the structure of the experiment, and the motivation of participants all affect the ability for the experiment to fulfill its purpose. Much of the participant's preferences are controlled in the creation of the environment.⁷ The theories specify a certain environment in which they apply and the experiment must suitably replicate it.

The above discussion of important methodological principles reveals the significance of the construction of an experiment. The decisions made regarding the environment, the motivation of participants, and the treatment of preferences all have ramifications to the results. The choices for each of these components influence the frame of mind that participants have when they participate in the experiment and/or they affect the manner in which participants can operate during the experiment. The decisions made for them about the structure of their environment directly determine if the results simulate the same questions that the theory addresses. Therefore it is also important to examine the interpretation of the results based on the criteria chosen by the experimenter.

The results of an experiment bear mentioning because the value and robustness of the results depend on the decisions made on each of the methodological points. An economist can devise an experiment that will conclude a specific result but that result will not necessarily hold weight. The earlier discussion concerning the characteristics of experiments of value arises here. If the experiment controls too many parameters or forces the result in a direction that mirrors the theory, the experiment holds little explanatory value. It essentially shows one set of circumstances where the theory holds. However, even this conclusion is tainted by questions regarding the validity of the results

because some of the assumptions do not allow participants the necessary flexibility (the experiment is over parameterized). The robustness of any work rests on the extent to which assumptions are defined realistically. In experimentation, this is especially true.

There are methodological implications for writing experiments that are derived from existing theory. There is the natural risk that the experimenter will mistakenly compose an experiment that proves the theory as opposed to testing the foundations of the theory. When the intended results are already known (the results of the experiment will be compared with those predicted by the theory), the common course of action is to design the experiment to reflect the desired results. It is important, however, that the experimenter mimics the fundamentals of the theory and then allows the actions of the participants to answer whether or not the theory is founded in the premises. Writing an experiment that directs the result towards the theoretic prediction does not yield an experiment of value.

There are several other points that merit noting. An important truth of economic experiments is that no one experiment can be used to unequivocally validate a theory. The restrictions that enable experiments to control the environment also limit the ability of experiments to yield broad generalizations. The more common scenario is that a series of experiments or outgrowths of the initial experiment lead to the refinement of the theory over time. Vernon Smith, a participant in the earlier Chamberlin experiment, developed an extension of Chamberlin's experiment (Smith 1962, 1964). The revised experiment created a "double auction" where all transactions were public knowledge. Unlike Chamberlin's experiment where long term contracts locked buyers and sellers in, buyers were able to auction prices up while sellers were able to auction prices down until

they met – at the equilibrium level. While the results of Chamberlin's experiment did not support existing price theory in that no equilibrium was reached, this improvement on the experiment showed market convergence. An important step in making decisions regarding the details of the experiment is to review related work that might point the experimenter in a direction.

There are drawbacks to experimentation as well. Participants, often undergraduate students, are less experienced at making decisions and less sophisticated than markets. An experiment is often oversimplified to isolate the variables and allow participants to understand the rules of the experiment quickly. This can lead to misleading generalizations of the results. Data on some variables are hard to collect in the natural environment, and this is not necessarily made easier in the laboratory. Technical difficulty and the sheer nature of the variables contribute to making these variables difficult or impossible to observe. The question of sample selection bias also can persist as the experimenter might be limited in whom he or she can draw on as a participant. It is often the problems of oversimplification, obscure variables, and sample selection bias that draw criticism to experimentation and its legitimacy within the larger discipline.

Experimenters must consider and understand the benefits and limitations of experimentation. The previous discussion of the method of experimentation revolves around the mechanics of conducting the experiments. Unlike the natural environment where parameters are uncontrollable, the laboratory affords the opportunity for the experimenter to isolate variables of interest. It is this ability to control parameters and the environment that makes experimentation a powerful tool. Also it is this power that

makes the careful deliberation about methodological decisions important. The ability to control the environment, structure, preferences, and information in a simulation yield a tremendous amount of power to the experimenter. Strong consideration and careful design are imperative to an experiment's success. Each of the three areas of economics that lend themselves to experimentation has further methodological considerations unique to that area.

1.2.3 Applying the Methodology to Fields

There are several discipline-specific methodological considerations that researchers need to address when designing experiments. The element of environment is especially important when developing market experiments. Bargaining and game theoretic experimenters are faced with the difficult challenge of controlling the experiment while properly considering the utility curves of participants. Individual choice experiments are characterized by their close examination of decision-making, something that is increasingly complicated and not easily captured in an experiment. The principle goal of this section is to bring awareness to these issues within the context of their areas.

A critical characteristic in the definition of experimental economics is that experiments test the theoretical assumptions about behavior; they do not test the theory per se. Experiments that rely heavily on the underlying theoretical conditions for the environment must be careful not to force participants' actions. Market experiments are an example of such an experiment that relies on the environment. The rules and directions outlined by the experimenter directly define what kind of market the

participant is operating under (the power of experiments). The mode of compensation also drives the player's decisions. The design of the experiment should be such that the environment resembles that of the representative market but still enables the experiment to examine the underlying principles of the theory.

One of the challenges in running experiments is how to handle the expected utility curve of participants. Experimenters have eased around this problem with the assumption that the expected utility was equal to the compensation from the experiment. This leads to the assumption that all participants have identical utility curves (Roth 1988). The problem with this simplification is that when experiments failed, they failed not on account of the theory but on account of this assumption. As Roth notes, "in order to provide a test of the theory... an experiment would have to either measure or control for the expected utility of the bargainers."⁸ In this example, Roth determines that the values of the payoffs are not important relative to the nature of the payout. Participants negotiated over the number of lottery tickets each would receive. The winner of the lottery would receive some payout γ_1 . The other would receive γ_2 . If no agreement were reached, both would receive γ_2 . Roth varied the magnitudes of the prizes as well as the extent that bargainers knew these values. He concluded that neither the magnitude nor the knowledge of the magnitude altered the results. The decisions made regarding the expected utility functions and whether or not the experiment will test them directly alters the course of the experiment in so far as it drives the incentives for the participants. As long as a satisfactory level of motivation is reached so that participants are acting as agents of the economy, it does not effect the interpretive value of the results.

Individual choice experiments focus on the choices people make based on assumptions of risk and rationality. Models based on this assumed rationality are curtailed by experiments that test the underlying fundamentals of the assumptions. As economic models get increasingly complex, the reliance on these often-incorrect assumptions impacts the effectiveness of the theory. Studying these errors is important, as Colin Camerer (1995) notes, because the frequency and magnitude of the errors in judgment affect economic outcomes and efficiency. A key methodological difference between psychology and experimental economics is deception. Psychology often induces erroneous decisions through trickery and deception. Economic experiments are valuable because the results express natural violations of the assumptions in a laboratory environment, they do not induce violations through tricking the participants. Allowing participants to operate naturally is required in experiments of value; it is far more valuable to show an irrational response or decision in a natural environment than to have designed an experiment to force the irrationality.

This section focused on three areas of the methodology that deserve considerable attention by experimenters. The decisions regarding the environment and the preference functions of participants directly weigh on the results. The components of the methodology discussed throughout this chapter are critical to creating experiments of value regardless of the area of economics from which the research question is derived. In each area, however, there are special aspects of the methodology that require a considerable amount of thought so that the experiment holds value.

Notes

¹ Friedman and Sunder (1994), p. 2

² Friedman and Sunder (1994), p. 3

³ Much of this discussion stems from Kagel and Roth (1995), Roth (1993), and Smith (1990)

⁴ Roth (1993) on <http://www.economics.harvard.edu/~aroth/history.html>

⁵ Originally examined by Dresher and Flood in 1950, see Flood (1952); see also Pindyck and Rubinfeld (2001), pp. 443-445; and Roth (1993)

⁶ Dutta, p. 8

⁷ Siakantaris, p. 268

⁸ Roth (1988), p. 978

CHAPTER 2

Allais Paradox: An Experimental View

The Allais Paradox is perhaps the most widely cited piece of evidence on decision making under uncertainty, not because it is a large piece of evidence, but rather because it is a contrary piece of evidence.

- John Conlisk

The best way to illustrate the methodological principles of experimental economics discussed in the first chapter is through an example. The Allais Paradox was one of the first formal experiments designed to test the underlying assumptions of decision theory. This chapter will explore the Allais Paradox and what questions it raised regarding decision theory. The goal of the chapter is to demonstrate the principles from the previous chapter on designing and interpreting experiments before commencing with a larger experiment.

2.1 Allais Paradox

In two papers given in 1953, Maurice Allais outlined his paradox challenging existing decision theory that is based on expected utility theory. Decision theory specifies that there must be consistency between choices regarding risk preferences. In a choice between two items, if one is preferred to the other it must always be preferred. The level of utility attached to each choice determines the preference structure for the player. Allais found that when given the choice between two sets of lotteries, peoples' responses were inconsistent with those predicted by decision theory. These decisions implied that participants based their choices on erroneous valuations of expected utility for each option.

Assumptions regarding the nature of the utility function are not required. While traditionally it is assumed that the utility function for participants is upward sloping and exhibits diminishing marginal returns, this only serves to provide one case where the paradox might work. In this case, different levels of utility might be preferred based on risk preference, and allowing participants to determine their own preference structure

outside the model does not change the results of the Allais Paradox. The Allais Paradox refers to an inconsistency in preferences that a series of decisions reflects. By simply denoting the difference of relative values of utility between choices, the paradoxical conflict in decisions made by participants becomes clear. One assumption regarding the value of a utile is necessary. The utility of \$0 is zero. Four lotteries¹ will serve as an example for examining the Allais Paradox in detail.

The first choice is between lotteries A and B:

Lottery A:

Payoff of \$100 with certainty (a probability of 1.00)

Lottery B:

Payoff of \$0 with a probability of 0.01

Payoff of \$100 with a probability of 0.89

Payoff of \$500 with a probability of 0.10

The second choice is between lotteries C and D:

Lottery C:

Payoff of \$0 with a probability of 0.89

Payoff of \$100 with a probability of 0.11

Lottery D:

Payoff of \$500 with a probability of 0.10

Payoff of \$0 with a probability of 0.90

According to utility theory, participants should attach a value of utility for each of the possible choices, A, B, C, and D. Participants then choose between the first two lotteries. This choice determines the relative value of the expected utility for lotteries A and B. If A is chosen over B, then the expected utility level for A is preferred to that of B. Likewise, if lottery B is chosen over lottery A, the expected utility for B is preferred to

that of A. Decision theory then says that subsequent choices are made based on the first decision – if one level of utility is preferred in one instance, that same level of utility must be preferred in all other instances.

Allais noticed that there was an inconsistency with peoples' choices. In a similar replication of Allais' experiment, Christoph Hauer² showed responses A and D were the overwhelming pair of choices made by participants. Choosing lotteries A and D violates the premise of decision theory that there is consistency between choices. The following illustrates that if lottery A is preferred to lottery B, then lottery C should be preferred to lottery D. If lottery A is preferred to lottery B, the expected utility for the decision is shown to be:

$$\begin{aligned} u(A) > u(B): \quad & 1.00u(\$100) > 0.10u(\$500) + 0.89u(\$100) + 0.01u(\$0) \\ & 0.11u(\$100) > 0.10u(\$500) \end{aligned} \quad (2.1)$$

And if lottery D is preferred to lottery C:

$$\begin{aligned} u(D) > u(C): \quad & 0.10u(\$500) + 0.90u(\$0) > 0.11u(\$100) + 0.11u(\$0) \\ & 0.10u(\$500) > 0.11u(\$100) \end{aligned} \quad (2.2)$$

The expected utility of choosing lottery C over lottery D is calculated to be

$$\begin{aligned} u(C) > u(D): \quad & 0.11u(\$100) + 0.89u(\$0) > 0.10u(\$500) + 0.90u(\$0) \\ & 0.11u(\$100) > 0.10u(\$500) \end{aligned} \quad (2.3)$$

This is equivalent to choosing lottery A over B [$u(A) - u(B)$ above]. Similarly, when lottery B is chosen over lottery A, the level of expected utility is

$$\begin{aligned} u(B) > u(A): \quad & 0.89u(\$100) + 0.10u(\$500) + 0.01u(\$0) > 1.00u(\$100) \\ & 0.10u(\$500) > 0.11u(\$100) \end{aligned} \quad (2.4)$$

The value of expected utility for each choice is now known. It is clear that choices A and C yield the same level of utility while choices B and D yield another. The paradox lies in that the second choice by participants, given the choice of A in the first set of lotteries,

goes against the theoretical prediction that C be chosen. As shown above, choosing lottery A yields a different expected utility than choosing lottery D. Given that lotteries A and C provide the same level of utility and lotteries B and D have equivalent levels of utility, if A is preferred to B, then C *should* be preferred to D. The expected utility of choosing lottery C over lottery D is calculated to be $0.11u(\$100) > 0.10u(\$500)$ (equation 2.3). This is equivalent to choosing lottery A over B (equation 2.1). Similarly, when lottery B is chosen over lottery A, the level of expected utility is $0.10u(\$500) > 0.11u(\$100)$ (equation 2.4). This result is equivalent to choosing lottery D over C [$u(D) > u(C)$ above]. If for the initial decision lottery A is chosen, then lottery C should be chosen during the second choice. Since lotteries A and C have equivalent levels of utility and lotteries B and D also have equivalent levels of utility, if one level (A) was chosen over another (B) in one instance, it (C) should be chosen over the other (D) in all instances in order for rank ordering of preferences to be consistent. A participant who chooses lotteries A and D or lotteries B and C violates decision theory because they have shown conflicting preferences towards the same level of utility. This is the violation that Allais observed which led him to question the premises of decision theory.

2.2 Testing Allais Paradox

An experiment replicating the Allais Paradox (outlined above) was run to illustrate the methodological points from the previous chapter. In order to test the Allais Paradox, participants were presented with a choice between lotteries A and B and lotteries C and D (Appendix 2.2 contains a copy of the experiment). Participants were asked to answer the questions without help, being sure to read each lottery carefully.

Along with their choice, they were also asked to provide a brief explanation as to why they chose each lottery.

Asking the participant to explain their decision serves to motivate the participant to find a logical response. Their decision then holds some credibility as a real world decision. The validity of the results is somewhat diminished by the lack of a monetary payoff in this small experiment. The incentive for participants to try existed because the students were asked to participate by their microeconomic theory professor, so they may have felt compelled to try. The consequence of the choices made by the experimenter will be discussed later in this section. The substance of the process makes this experiment an illustrative example of the properties of experimentation. A complete description of the experiment's procedures is in Appendix 2.1.

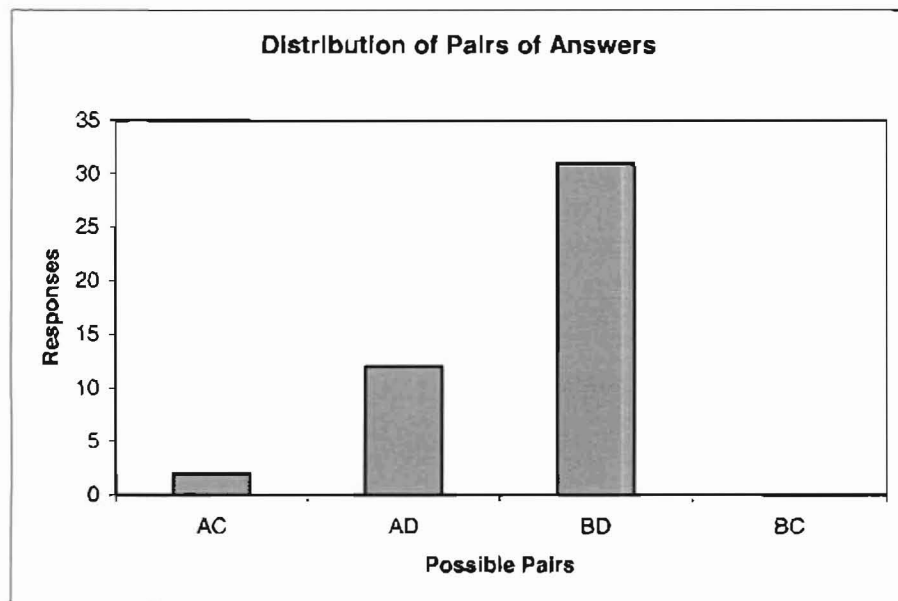
2.2.1 Data

The participants in the experiment were microeconomic theory students at Colby College. Colby is a small, liberal arts college with a population of approximately 1800 students and is located in Waterville, Maine. Students taking the microeconomic theory course are generally majors or minors in their third semester of economic education. There were a total of forty-five participants for this study, fifteen female, thirty male. The population of the school has slightly more females than males, so females were underrepresented in the study relative to the student body population. All respondents were asked to provide some explanation as to what led to each of their decisions. There was no time limit imposed on participants so they could carefully think through each possible choice. The experiments were numbered for convenience but taken

anonymously. The experiment was conducted during the lab section of the course, so no time sacrifice was made on the part of any of the participants.

2.2.2 Results

Graph 1 shows a bar graph of the four possible combinations of choices of lotteries (AC, AD, BC, and BD). As shown in the graph, 31 participants chose lotteries B and D, 12 participants chose lotteries A and D, and 2 chose lotteries A and C. No participants chose lotteries B and C.



Graph 1: Possible Combinations of Pairs of Lotteries

2.2.3 Analysis

As shown earlier, only two of the possible four pairs of choices are consistent with decision theory: AC and BD. Twelve of the participants chose the combination AD. These twelve observations represent twenty-seven percent of the total number of responses. While the majority of respondents chose a combination consistent with

decision theory, those that chose incorrectly aptly show what Allais saw – that decision theory based solely on utility maximization fails to cover many cases. Those who chose lotteries A and C or lotteries B and D offered explanations consistent with decision theory as to why they chose each lottery. Most revolved around risk seeking (B and D) or risk aversion (A and C) attitudes relating to the probability of each outcome. There were a high number of risk-seeking responses. One participant who chose B and D wrote, “You have about the same probability of winning money but you receive \$400 more [in the second case].”

Participants who choose lotteries A and D also provided explanations, but their logic fails to hold. One participant wrote for the decision between lotteries A and B that “The probabilities given for lottery B are too low – the probability of 0.89 is high enough so I would think I would get \$89 for B. But the 0.10 probability of the \$500 payoff is too low. The probability of 1.00 for lottery A seems like the best choice.” In essence, the person has stated that taking a one percent risk of nothing for the opportunity to get \$500 with a probability of ten percent is not worth the risk. However, in the second choice between lotteries C and D the same participant writes, “Although the probability of getting \$100 in lottery C is higher (0.11 compared to 0.10), the amount that you would get in lottery D is still significantly higher.” This logic contradicts the logic for choosing lottery A over B in the first pair as again the difference is only one percent. Allais proposed the concept of fanning out indifference curves to explain this phenomenon. As indifference curves shift outward with changing probabilities and payoffs, decisions are altered. Older decision theory required that indifference curves shift in a parallel fashion, thus the decisions should not change. The Allais Paradox holds true when a participant’s

indifference curves do not shift parallel but fan out as Allais proposes when the payoffs and probabilities change from lottery to lottery. The comments by participants in this study serve to verify that some possess utility functions of the form Allais described, even if it is due in part to faulty logic.

2.3 The Methodology of Experiments in Practice

The Allais Paradox experiment exemplifies many of the methodological steps outlined in the first chapter. The first point discussed in Section 2.1 regards the purpose of the experiment. The purpose of the experiment was to serve as a practical example of an experiment that would possess many of the critical components of the methodology. The experiment maintains the goal of holding the properties of experiments of value. The overriding goal was illustrative, not economic, but the experiment was devised in a manner as if the economic content was the primary purpose. Unlike the experiment presented in Chapter 3, the intent of the Allais experiment was to test the conditions that establish the groundwork for decision theory in a way that would help illustrate many of the methodological points.

One component from the methodology that was altered is motivation. The motivation for the experiment is driven completely by non-monetary means. Participants were not compensated for their responses, much less rewarded for the decisions that they made. It is possible that a lack of compensation has the ability to alter how a person acts in an experiment (the hypothetical decision does not always reflect a similar decision to the one made when the decision is real). However, having participants write down their explanation forces them to reflect on why they made their decision. Participants were

expected to be there and participate by their professor. This served as two forms of motivation. By not compensating the participants, the underlying rational may have changed. When faced with the possibility of real payoffs, more participants may have been risk averse (choosing lotteries A and C) compared to the large number of responses that were risk taking (chose lotteries B and D). Not compensating the participants effects the economic substance of the results of the experiment as it pertains to risk preferences, not the ability for the study to reflect Allais hypothesis or clarify the methodological points. Neither the illustrative purpose nor the lack of incentive-based motivation impedes the experiment from investigating the Allais Paradox or reflecting the methodological points discussed in the first chapter.

The environment of the experiment reflects the goals of the environment an experimentalist would establish in the laboratory. Students were given the experiment that laid out the different options for lotteries. They were then asked to choose which lottery they would prefer in each instance. The information provided to participants established the set of guidelines under which they could act (e.g., they could not consult with one another while making their choices). The established parameters ensure that the decisions made are based on the participant's own rationale. This is critical to testing the assumptions about decision theory. The ability to create an environment where the set of parameters mirror the assumptions is critical to conducting experiments of value.

The point concerning the control of the experiment exhibited by the experimenter is also shown in the Allais example. The control of the experiment is shown through the determination of the payoffs, the probabilities of each payoff, the order of the lotteries, and the previously discussed decisions about compensation and asking participants to

provide explanations for their choices. The magnitude of the payoffs impacts what the participant is thinking. For some people, the difference between payoffs of a few dollars is negligible while the difference between one and five million dollars might no longer be worth the risk (had the first choice been a million dollars with certainty, for example). The choice to set the magnitudes at zero, one hundred, and five hundred dollars respectively exhibits a middle area where people will alter their risk preferences because the difference is distinct. Others, including Allais and Haurert, chose higher magnitudes (millions of francs, thousands of Euros) that are not realistic decisions faced by a college student. Altering the payouts to a lower nominal value maintains a level of realism in that people are faced with making decisions involving a few hundred dollars more often than they might with several thousands or millions dollars.

The probabilities for each of the payoffs also demonstrate the control of the experimenter. Allais' decisions regarding the odds were designed to illustrate that there are differences in the level of expected utility even though the relative probabilities are close. The existence of close probabilities required that participants think through the scenario and carefully calculate their expected levels of utility for each option, a step necessary to achieving quality results. The order of the lotteries is also important. By placing the pair of lotteries containing the choice with a probability of one as the first set, the experimenter immediately determines the relative risk preference of the individual, as the probability of a certain event is less risky than an event with any risk. The decisions regarding the purpose of the experiment and compensation were made with the knowledge that the experiment was for illustrative purposes only. Part of the decision is

also forced by circumstances, such as a budget constraint, that prevented the experimenter from offering compensation.

In the analysis of the experiment, it was shown that the majority of respondents made choices consistent with decision theory. The economic content of these results is determined based on the points raised regarding the methodological legitimacy of the experiment. First, the experiment does not confirm the assumptions of either decision theory or the Allais Paradox regarding decision theory. The number of respondents that made choices consistent with Allais' conjectures is numerous enough to conclude that there are some questions regarding the completeness of the assumptions for decision theory. The fact that twenty-seven percent of participants failed to act in a manner consistent with decision theory should bring economists some pause. While the design of the experiment did not encompass monetary incentives, there is sufficient ability to draw definitive conclusions from the results regarding the underlying assumptions of decision theory.

The Allais experiment serves as an example of the various components of the methodology for experimental economics described in the first chapter. The pieces of the methodology inconsistent with those specified offer the reader insight into the violations that can affect the effectiveness of an experiment and its results. The Allais experiment provides information regarding the inconsistent nature of decision theory as well as insight into the methodology and how it relates to running experiments. The careful consideration of each methodological component is critical to running experiments of value.

APPENDIX TO CHAPTER 2

2.1 Procedures for Allais Experiment

2.2 Allais Experiment

2.1: Procedures for Allais Experiment

Procedure For Classroom Experiment: Allais Paradox

Brief introduction of the project:

I am doing a Senior Scholar project focusing on experimental economics. This small classroom experiment is being used to act as an example of the methodologies of experimental economics.

Introduction of experiment:

This experiment is a reproduction of a classic experiment. Your responses to this experiment are all anonymous. The experiment involves choosing between lotteries. Please be sure to read all options carefully and answer them thoughtfully, including a brief description of why you made your choices. Please fill this out on your own. If you have any questions, I can take them now.

Thank you. When you are finished, turn your sheet over on your desk. Wait quietly until everyone is finished. I will now pass out the sheets.

Has everyone completed the experiment?

Please pass the sheets to the person on the aisle. I will come down and collect them now. Thank you for participating.

2.2: Allais Experiment

Gender: Male ☐ Female ☐

Major(s): _____ Minor(s): _____

Below are four lotteries. Pick one lottery from each group. Pick either A or B. Then pick either C or D. Be sure to read each of the lotteries carefully. Please complete this exercise alone with out the consultation of your peers. Write the letter of each of your choices in the space provided. Please also provide a brief explanation of your choices.

Lottery Group 1:

Lottery A:

Payoff of \$100 with certainty (a probability of 1.00)

Lottery B:

Payoff of \$0 with a probability of 0.01

Payoff of \$100 with a probability of 0.89

Payoff of \$500 with a probability of 0.10

Your Choice: _____

Why? _____

Lottery Group 2:

Lottery C:

Payoff of \$0 with a probability of 0.89

Payoff of \$100 with a probability of 0.11

Lottery D:

Payoff of \$500 with a probability of 0.10

Payoff of \$0 with a probability of 0.90

Your Choice: _____

Why? _____

Notes

¹ Similar to Allais (a, b); a variation on Kagel (1995), p. 8; also see Hauert (a)

² Hauert (a)

CHAPTER 3

Experimental Economics Tackles the Gas Station Duopoly Problem

“Economic theories always deal with certain alleged behavioral tendencies in isolation, [and] the experimental laboratory is uniquely well suited for testing the validity of such theories.”

- Vernon L. Smith

Much of the first two chapters were spent defining experimental economics and outlining the manner in which economists can use it to aid in their research. The best way to illustrate the power of experimentation is with an original experiment. The previous chapter took an experiment devised by another economist that examined underlying assumptions of decision theory brought into question by the Allais Paradox. This experiment served as an example of one of the experimental methods outlined in the first chapter. The process of devising and running an experiment without the benefit of it previously being run offers the unique opportunity to examine in detail experimentation as it pertains to economics. This chapter will present a revision to the underlying assumptions of duopoly, the new model of duopoly that results from these revisions, and an experiment to test whether these changes are valid.

3.1 Duopoly and Experimentation

The exploration of duopoly lends itself to experimentation due to two of the previously defined principles of experimentation: control and transparency of participants' decisions. Empirical evidence on pricing decisions is difficult to collect, as the rationale used by competitors in how they determine their price is the optimal data, and this is not information that businesses willingly provide. The experimental environment can duplicate the market conditions faced by firms while seeking explanations as to why certain decisions were made. Furthermore, the experimenter can control the underlying foundations of the experimental market and then draw conclusions about the market tendencies from the players' actions.

Players in market games do not have the same motivations as actual business owners, but careful construction of the reward structure can create a similar desire to maximize profit. Simulating the incentives that the firms face when creating the payoff structure for players puts the players in a similar position as the owners. This enables the players' actions to be guided by a set of restrictions (assumptions from the theory). This makes the players' actions similar to a duopolist's, only now a player's actions can be observed and recorded. The purpose of the motivation is to force players into the same set of circumstances as market participants. The experimenter outlines the assumptions for the market and thus constrains the players to be in the position of a duopolist. The transparency of the participants' decisions offers the experimenter the ability to collect the necessary data to determine if the market actions of the participants reflect those expected by theory.

Oligopoly, the economic concept of which duopoly is a subtopic, lends itself to experimentation. James Friedman (1971) and Hoggatt, Friedman, and Gill (1976) review oligopoly experiments including duopoly markets. Claudia Keser (1993) presents experimental results on a duopoly market. While each author presents theories and models that differ from the one tested here, each of the experiments aim for the same market dynamics. Friedman discusses at length an oligopoly equilibrium structured around noncooperative oligopolies. Hoggatt, Friedman, and Gill design an experiment around a basic model of oligopoly and are interested in observed behavior. Their paper focused on price signaling and the extent to which price changes can be predicted by such signaling. These papers are examples of how experimentation is a natural instrument for extending the theories of oligopoly markets.

Keser's model, like the one presented in this paper, establishes the pricing decision as the only experimental variable. Restricting player (or firm) decisions to the determination of price allows for the examination of how modifying the assumptions of consumer behavior affect the pricing decision. The dynamic in duopolies has long been characterized by consumer behavior dictating firm behavior. Keser's paper is an example of using the price variable as the gauge to measure how accurately the experimental results are in line with theoretical predictions. The body of literature in experimental economics that focuses on market activity, specifically within oligopoly, reinforces the validity for the use of experimentation as a method for examining duopoly theory.

3.2 Review of Duopoly Theory

Discussions of and revisions to duopoly theory are prevalent throughout economic literature. Much of this is due to the inability of one set of simple assumptions to accurately reflect the real-world decisions made by competing firms. The result is that numerous economists present alternative models to fine tune duopoly theory. This section will focus on the roots of duopoly theory as well as several revisions. Much of the following discussion of the theories of Cournot and Bertrand comes from the textbook by Pindyck and Rubinfeld (2001). The revisions to duopoly theory of Kahn (1937) and Simon, Puig, and Aschoff (1973) are examined as each introduces important fundamentals of the model proposed in this paper.

Augustin Cournot developed the initial duopoly theory in 1838. He hypothesized that each firm must make a production decision based on market conditions and their expectation of their opponent's production level. There are several important

assumptions for the model. First, the market price is determined by the total output of the competing firms. The sum of the quantities produced by each firm determines the market quantity and thus the price. Second, each firm determines output based in part on their opponent's production decisions and assumes that their opponent's output in the current period will be the same as in the previous period. The third assumption is that the goods are homogenous and consumers are indifferent between homogenous goods. The final assumption is that the firms make their production decisions simultaneously.

It is the second assumption that provides the basis for the dynamics of the model. Output is determined based on the expectation of an opponent's decision, and each firm reacts to the expected decision of their opponent. Cournot develops a reaction function to assess how each firm will alter their output decision given various production levels of their opponent. The reaction function determines the profit maximizing level of production in the current period for each firm given their opponent's level of output from the previous period. The total revenue function is modified to incorporate the level of output for both firms (the sum of which determines market price). From this new total revenue function, the marginal revenue function is derived and set equal to marginal cost. This result, solved for the quantity of the first firm, forms the reaction function. Inspection of the reaction function shows that the two firms will choose the level of production where the two reactions functions intersect. This is defined as the Cournot equilibrium.

The dynamics of the model occur when the two firms are away from the equilibrium point. Because of the assumption that the opponent will remain fixed at the level of output from the previous period, each firm reacts to the previous period's level of

output. If Firm Two is initially below the equilibrium level of production while Firm One is above the equilibrium level, Firm One will react by decreasing output while Firm Two will react by increasing output. The end result is that over time Firm One will decrease output while Firm Two will increase output until the two firms reach the equilibrium level of output (Cournot). Figure 3.1 shows the dynamics if the two firms start out at such a point (denoted A). Firm One reacts by lowering its output while Firm Two reacts by increasing its output (indicated by the arrows in the diagram). The two firms end up at production point B during the second round. The third round would again show both firms altering output and thus moving towards the Cournot equilibrium as the rounds progress.

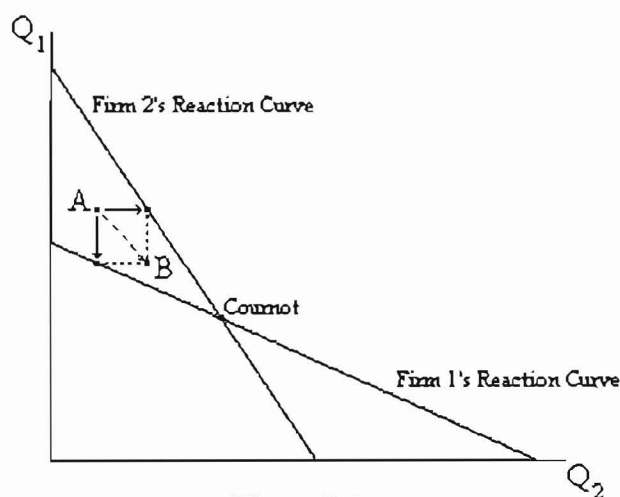


Figure 3.1

Cournot also provides a mechanism for finding the point where the two firms would be best off if they worked together, the collusive equilibrium. It is at this point where each firm is maximizing potential profits. This point is generally below the Cournot equilibrium (a lower level of output). The collusion curve is found by calculating the different levels of quantity that maximize profits. Figure 3.2 diagrams the equilibrium quantity solutions of firms: collusion, Cournot, and strict competition.

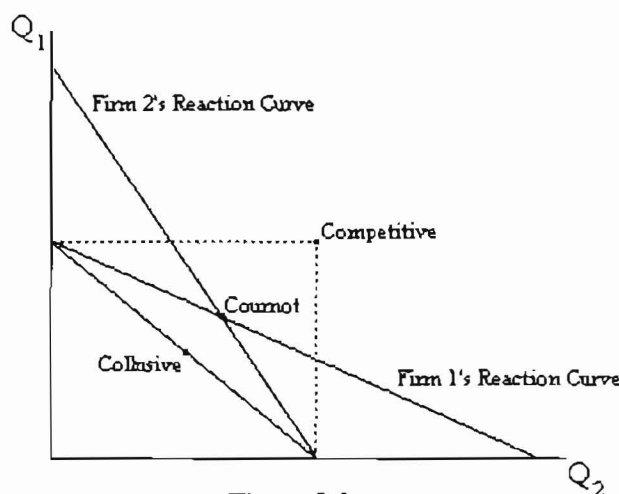


Figure 3.2

Cournot predicted that the two firms would produce where the two reaction curves were equal, but this point is not necessarily when the quantity is evenly distributed between the two firms. If the two firms each face different demand curves (the sum of which is the market demand curve), each firm has a different total revenue function and hence different marginal revenue functions and reaction functions. The equilibrium point does not necessarily occur when the market quantity is split evenly between the two firms.

In 1883, Joseph Bertrand argued that competition does not occur based on quantities, but on price. In his revision to Cournot, Bertrand relied on many of the same assumptions as Cournot but applied them to price competition. Bertrand assumes that the goods are homogenous. The assumption regarding stagnant quantities has been modified to stagnant prices – the price for the competitor for the current period is expected to be the same as price for the last period. Both firms make pricing decisions simultaneously. The final assumption is that the lower price determines the market price (and quantity) and that the firm with the lower price receives all of the business for that period. This

last assumption stems from the property of demand functions that any consumer can buy the product as long as they are willing to pay the market price.

The result from Bertrand's model is that the price chosen by each competitor is equal to the marginal cost of the product. The products are homogenous and consumers are indifferent between the two, thus the firm with the lower price will receive all of the business. At any price above marginal cost there is an incentive to undercut the current market price. As a result, firms will choose marginal cost as their price – they make no economic profit but both receive business.

The collusive equilibrium exists in Bertrand duopoly as well. The price at which both competitors share the maximum sustainable profit for the market is the collusive price. This price occurs at the point where marginal revenue equals marginal cost. The result of both firms choosing this price is that they split the market quantity and the profits. This is an unstable equilibrium as there is an incentive to undercut this price in order to receive all of the business, and as a result realize a higher level of profits. The assumption that the competitor will not change his or her price leads players to believe that undercutting will increase their profits. Subsequently, they each undercut and price begins to fall towards marginal cost. Cournot and Bertrand present the foundations for duopoly theory. One of the common criticisms of the theories is that they assume away too much and therefore lose applicability. In order to more aptly describe duopolists' actions, a discussion of other economists' criticisms and subsequent revisions of these theories is necessary for the development of a better model.

R. F. Kahn published an article entitled the "Problem of Duopoly" in 1937. In this article, he points out the erroneous supposition of Cournot and Bertrand that the

firms employ the tactic of determining quantity or price for the next period based on the expectation that their competition will leave their quantity or price level unchanged. The second part of the supposition states that the opposing firm makes the exact same assumption about the first firm's decisions. The illogical nature of the assumption that both firms believe that its opponent will not alter its price if the first firm alters its price is self-evident and thus the supposition is in need of revision. A better set of assumptions that clarifies the reactions by firms to changes in output or in price by a competitor is ultimately the direction of the development of duopoly theory.

The case of duopoly is especially difficult for this reason – any model put forth can claim some validity because the set of assumptions adopted by firms is as varied and complex as the economic theories that describe them. The decisions made by firms cannot easily be simplified into any simple set of assumptions, and therefore any theory aiming to map duopoly theory must take into account the varied nature of firm actions. Kahn postulates that “the assumptions which [the firm] makes [about an opponent's behavior] are *correct*, being based either on supreme intelligence or on the employment of the method of trial and error.”¹ That is, if Firm A reduces price (increases output), whatever response Firm B makes is the correct one. The importance of Kahn's article in the context of this paper is that he brings to light two facts: the existing assumptions regarding consumer and firm behavior presented by both Cournot and Bertrand are inherently unsound, and the nature of these reaction functions are flawed and must also be revised.

Kahn chooses to revise the reaction functions based on his assumption that firm behavior is always *correct*. Cournot and Bertrand assume that a change in quantity or

price by one firm will be “unexpected” and that no learning will occur by firms. Kahn determines that each firm has some automatic response to changes made by opponents based on their opponent’s reactions in prior periods. A firm *learns* about their opponent and thus determines the best automatic response to an opponent’s actions. The exact nature of this response is left unanswered by Kahn, as he notes that there is no way of determining the result of if Firm A increases output by Δx , then Firm B responds by increasing or decreasing output by Δy .² Specifically, there is no economic meaning to the magnitude of Δy without an understanding of how firms learn and thus create their “automatic” reaction function. The conclusion drawn by the author is that the relationship between firms will evolve into a price leader and price follower situation where Firm B will always react immediately to changes made by Firm A, and vice versa. While Kahn recognizes that such a model is not easily realized, game theory provides the ability to postulate how firms might make such decisions.

Simon, Puig, and Aschoff (1973) run a series of simulations that examine the decision process of firms, as well as the distribution of market quantity between the firms. These two ideas are encompassed in the model presented in Section 3.3. While the authors concerned themselves largely with the pattern of decisions made by firms, their underlying characterizations of how firms make pricing decisions is of interest. Bertrand believes that the expected price level of each competitor is equal to that of the previous period. Kahn anticipates some unidentified level of learning to occur. Simon, Puig, and Aschoff claim that each firm forms an expectation for its opponent’s price for the next period based on a function of prices from the previous period and a probability for how its opponents will react to price changes. Firms also consider the market

ramifications of their decision, as changing prices could alter market output. The final consideration the authors make is to discount future periods' revenues.

The second important modification the authors make is to the distribution of the market quantity between the firms. In their model, the distribution is based on a lagged term determined by the firm's previous period's quantities (a brand loyalty effect) as well as the current difference in price. If a firm is the lower priced firm in consecutive periods, the change in the percentage of market quantity received by that firm increases at an increasing rate (the lower priced firm over time will gain customer recognition as the cheaper alternative).

Both of these considerations alter the assumptions of Bertrand. The consideration of how an opponent might set its price is an important variation as it is far more realistic: no firm can reasonably expect that its competitor will do nothing as a response to a change in the competitor's price. Allowing the higher priced firm to receive business is also a realistic modification. The idea that firms weigh their expectations on what their opponent might do based on previous actions, is incorporated into the model presented in Section 3.3. The second consideration will be modified further, altering how the market quantity is distributed but maintaining that the lower priced firm does not receive the entire market quantity.

A final element introduced with the inclusion of game theory is that of collusion. While certain parameters in the model expressly do not allow for communication or collusion, the nature of infinitely repeated games makes collusion possible. A more detailed explanation of this occurs in the next section, which outlines the revised assumptions that form a new model for duopoly.

3.3 Towards a New Theory of Duopoly

There is a considerable amount of anecdotal evidence that one of the underlying assumptions of duopoly theory does not hold. Bertrand supposes that in a duopoly situation, the two firms would compete on price and the lower priced firm would receive all of the business. However, as you drive down almost any street in the country, gasoline stations with varying prices can be found, even those located directly across from, or next to, one another. This contradicts Bertrand's equilibrium prediction. Furthermore, there is almost always business at both firms, violating the underlying assumption that the lower price prevails in a market for a homogenous good.

Many explanations can be devised for why Bertrand's predictions do not reflect reality. The overall product, the gas station's services, is not a homogenous bundle of goods. For example, Mobile has a SpeedPass feature that enables customers to quickly pay for their gas by waving a wand already connected to a credit card in front of the pump. Bob's Gas and Oil does not have this feature. If Mobil is more expensive, it might be worth it to a consumer to pay the extra pennies for this convenience, even though the gas offered at both stations is exactly the same. Existing theory does not account for this disparity. Gasoline is a homogenous good, so there must be some way to account for the inconsistency in outcomes through modifying the assumptions.

There are two variations to the underlying assumptions of price theory. The first variation is that there is an opportunity cost to going across the street to the other station. Perhaps there is a median across the road or it is a busy highway. The consumer views this as an added opportunity cost to the gasoline on the other side of the street, effectively increasing the price of gas for the station across the street. The price at the pump might

even be cheaper at the station across the street, but if the opportunity cost is high enough, the real cost to the consumer might be higher at the station across the street (with the lower price at the pump). The second variation is that consumers obtain a higher level of utility by using one station over another. This might occur because one station has a good or service that the consumer wishes to have access to (car wash, credit card friendly, Mobil SpeedPass, etc.). Consumers choose which gas station to buy from based on the utility received from each bundle of goods (shape of the indifference curve) when compared to the price of gas at each station (the budget constraint). Each of these manipulations can be seen as an alteration in the budget constraint for a consumer or the definition of the indifference curve for a consumer.

The following example will illustrate a consumer's decision. If two gas stations are located across the street from one another, a consumer must make a choice between gas Station A on the same side of the road and gas Station B on the other side. The consumer attaches a convenience premium to gas Station B because it has the added convenience of a car wash. This modifies the shape of the indifference curve from indifferent between the two stations (straight line) to favoring the firm with the conveniences (B). Having to cross the road to get to Station B represents an opportunity cost to the consumer. This is seen in the form of an increase in the price of the gas for Station B.

Figure 3.3 shows the budget constraint line and indifference curve if a consumer is truly indifferent between stations A and B. Figure 3.4 shows the above example of a preference for Station B (indifference curve that is convex to the origin) with a change in slope of the budget constraint due to Station B's location (opportunity cost, effective P_B

increases). A difference in prices between stations would cause a similar shift in the budget constraint line. Note that the result is ambiguous, as the consumer will choose a station based on the magnitude of the shift in the budget constraint line as well as the strength of preferences (first derivative) of the utility function. In Figure 3.4, the consumer still chooses Firm B.

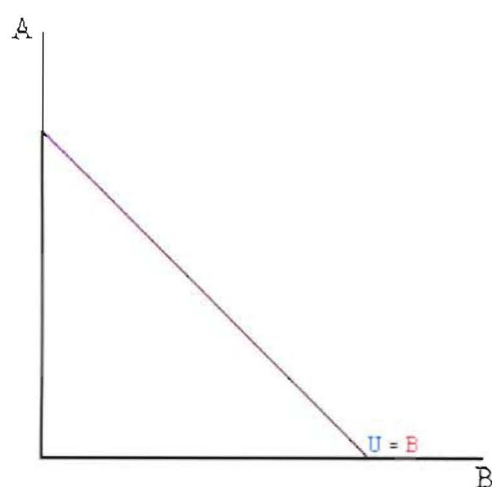


Figure 3.3

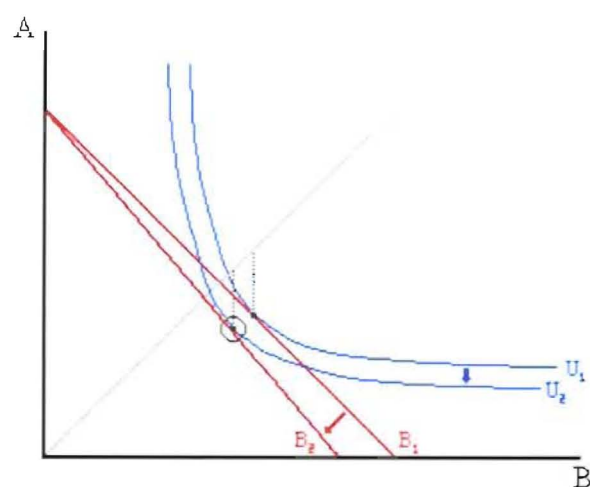


Figure 3.4

An assumption is that a consumer needs to fill up the tank in the car regardless of which station is chosen. The quantity of gas demanded is therefore unchanged regardless of the firm chosen. The consumer must evaluate the prices on both sides of the street given their indifference function and then determine the better station. Graphically, if the intersection of the indifference curve and budget constraint occurs above the A/B line, then Station A is chosen; if below the line, Station B is chosen. The A/B line is the line $A=B$. This is a necessary addition because the assumption is that the consumer cannot split his or her business between firms. As long as the opportunity cost for going across the street is outweighed by the convenience premium for having access to the services, this consumer will go across the street, even if it means paying more for the same gas.

This example is for one consumer and identifies why a consumer would pay a higher price for the same gas, an important component of the revised model.

Turning from the individual consumer to the market, the overall market is the sum of each consumer's preference function. The market will operate in a manner that rewards the firm with the lower price. As the difference in price between the two firms increases, the value of the convenience becomes outweighed by the greater difference in price. The result of this is that fewer consumers are willing to pay the higher price to go to the other station. If both prices are the same at the pump, the market allows for a difference in price to accommodate the opportunity cost and convenience premium that distinguish stations, allowing the station with the higher effective price to have some business, a different outcome from Bertrand. The next piece addresses the nature of this relationship.

The market is set (total quantity) by the firm with the lower price as any consumer can purchase gas at that price or higher. The elements of the linear demand function are the market price (P), the market quantity (Q), the maximum price at which consumers are willing to purchase gas (P_{MAX}), and the rate (slope) at which quantity demanded decreases with an increase in price (M). A linear demand function was chosen to simplify the expressions, but the theory is not constrained by this assumption. The demand function is defined as

$$P = P_{MAX} - M \cdot Q$$

or

$$Q = \frac{P_{MAX} - P}{M}$$

The price for the higher priced firm is defined as P_H and the price for the lower priced firm is defined as P_L , so the market quantity is redefined as

$$Q = \frac{P_{MAX} - P_L}{M} \quad 3.1$$

The market quantity is then divided between the two firms to favor the firm with the lower price. As the difference between the two prices ($P_H - P_L$) increases, the firm with the higher price loses business at an exponential rate. This is an added assumption to the model to account for the actions of consumers. A slight difference in prices does not force the higher priced firm out of the market. In terms of the utility function explanation, there are consumers in the market with strong enough preferences for one station (A) over the other (B) so that even if the price of A is greater than the price of B, they will still choose Station A. They are willing to pay a premium to have access to the services offered by Station A. As the price gap increases, the number of consumers priced out of the convenience premium increases at an exponential rate. The quantity of consumers priced out of the market is denoted D. Subsequently, the quantity for the firm with the lower price increases and the quantity for the higher priced firm decreases by this amount (D). If $P_H > P_L$, the quantity of each firm (H: higher, L: lower) is

$$Q_H = \frac{1}{2} Q_M - D \quad 3.2$$

and

$$Q_L = \frac{1}{2} Q_M + D \quad 3.3$$

D is defined to be an exponential difference function of the form

$$10 \cdot 2^{100 P_H - 100 P_L - 1} \quad 3.4$$

It is exponential in form because as the price gap grows, consumers are priced out of their willingness to pay for access to conveniences at an exponential rate. If the prices are the same the difference is zero (if $P_H = P_L$, the function is set equal to zero, not five). The difference in prices ($P_H - P_L$) is multiplied by 100 in order to normalize the difference in prices to an integer. This particular form was derived because it best simulated the realistic assumption that as the price gap increased, consumers would get priced out at an exponential rate. It also eliminated the higher priced firm when their price was more than five cents above their competitor's price. It is assumed that no consumer is willing to pay more than five cents for access to the conveniences at one station.

The quantity for each firm can now be defined as

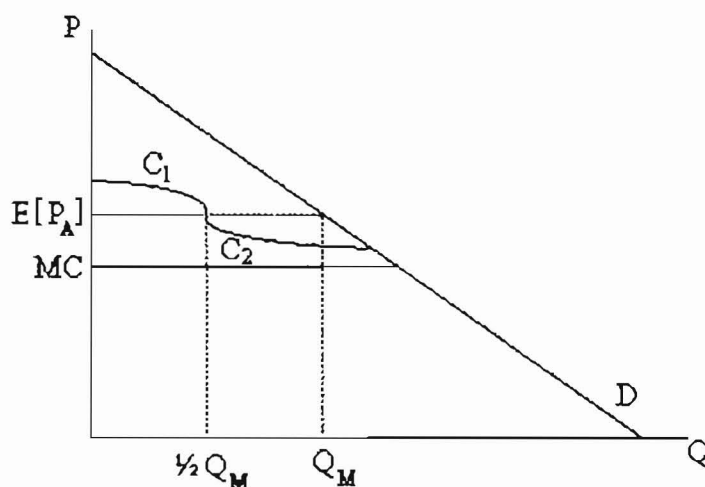
$$Q_H = \frac{1}{2} Q_M - 10 \cdot 2^{100 P_H - 100 P_L - 1} \quad 3.5$$

and

$$Q_L = \frac{1}{2} Q_M + 10 \cdot 2^{100 P_H - 100 P_L - 1} \quad 3.6$$

The higher quantity (Q_H) is bound by the maximum of the function ($\frac{1}{2} Q_M$) and zero; the lower quantity (Q_L) is bound by the market maximum (Q_M) and one-half of the market quantity ($\frac{1}{2} Q_M$). If the two prices are equal ($P_H = P_L$), $Q_H = Q_L$ (the maximum for Q_H and the minimum for Q_L). Each firm has a set of conveniences for half of the market over time (in the morning rush hour, Firm A sells coffee; during evening rush hour, Firm B sells soda). The exponential difference function allows for each firm to receive business as long as their prices are reasonably close to each other. Once the price difference becomes too great, consumers are priced out of their convenience premium and only the firm with the lower price receives business.

Graph 1 illustrates the effect of the convenience premium on the demand curve for the entire market. If Firm A chooses its price, then Firm B can map out the demand curve it faces based on that chosen price. If Firm B chooses a price such that it becomes the higher priced firm, it faces the part of the demand curve labeled C_1 . Conversely, if Firm B chooses a price that is below that of Firm A, it finds itself on C_2 . Graph 1 shows the market demand curve (D) with the market quantity (Q_M). As shown previously, if the two firms are priced the same (P_H equals P_L), the market quantity is divided evenly, each firm receiving one-half of the market quantity ($\frac{1}{2} Q_M$). Adding in the convenience function (C), the higher priced firm sets its price at $P_L + C$ and thus lose business according to the modified demand curve. Similarly, if the lower priced firm sets its price at $P_H - C$, it increases market output because it now has the market-clearing price (below P_A). Should Firm B choose a price below Firm A's price, the market quantity demanded increases above Q_M as dictated by the lower price (C_2 extends along the demand curve once the two intersect). C_1 and C_2 are associated with the exponential difference function (equation 3.4). Specifically, the shape of the C curve is a direct result of the redistribution of quantity due to the exponential difference function.

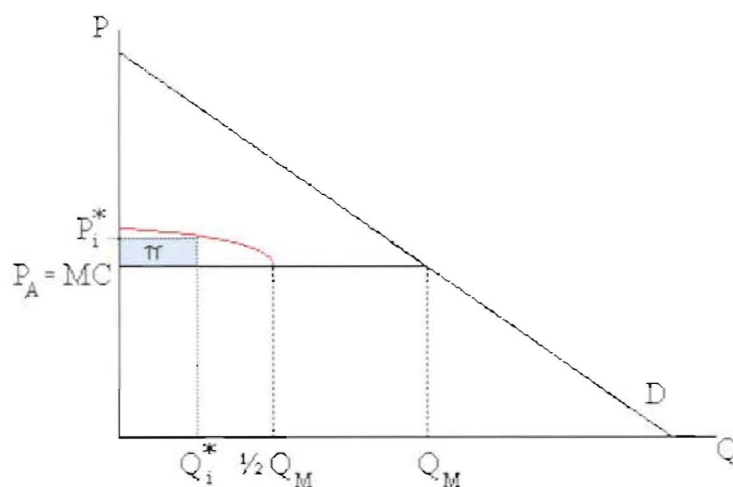


Graph 1

This accounts for the failure in the previous models that assumed away brand loyalty and other decisions based on conveniences. It makes the assumption more realistic – if the difference in the price of gas is greater than five cents per gallon, the higher priced firm will be hard pressed to receive any business. This break point of five cents per gallon is one of the assumptions of the model. The brand loyalty that was factored into the Simon, Puig, and Aschoff model is incorporated here. The preference functions for consumers include brand loyalty and other strong preferences such as clean facilities, and station specific features such as Mobil Speed Pass. For most items, brand loyalty is not so strong as to overcome a significantly higher price. There is no longer the need to incorporate the lagged effect of previous period's output into the model because the utility function is partially a function of brand loyalty.

The basic dynamics of the duopoly model are unchanged. In a one shot game, the best solution is the price that maximizes profit while guaranteeing business. In the Bertrand model, this occurs when price is equal to marginal cost. Given the assumption that the firm charging the lower price receives all the business, choosing a price above marginal cost allows for the possibility of being undercut. In this model, a similar dynamic is present. Like in Bertrand, prices are forced down due to the threat of being undercut. Prices do not fall all the way to marginal cost because of the ability to receive business even though the firm's price may not be the lower price. The one shot equilibrium can be found by selecting the price that maximizes profits if the other firm chooses a price equal to marginal cost (the lowest price making non-negative profits). This would be the lowest reasonable price for a firm to set (predatory pricing is not a viable option in a one shot game and thus is ignored here). Graph 2 shows Firm B's

demand curve when the price chosen by Firm A is equal to marginal cost (the *Bertrandesque* solution). Note that the C_2 curve no longer exists, as it is irrelevant to the decision process for Firm B. Firm B will maximize its profit given the expected price of Firm A to be marginal cost, and Firm B can make a profit by charging a price above P_A while it would make a negative profit charging a price below P_A . The C_2 curve would make Firm B worse off and therefore does not need to be incorporated into this decision.



Graph 2

If Firm A is the lower priced firm, $P_A = P_L$ and P_L is set equal to marginal cost (MC), and the marginal cost for each firm is the same ($MC_A = MC_B = MC$), then P_H is determined to be P_B , the profit-maximizing price (P_i^*). The general profit equation is

$$\text{Profit} = \text{Total Revenue} - \text{Total Cost}$$

as symbolized by

$$\pi_i = P_i \cdot Q_i - MC \cdot Q_i$$

$$\pi_i = (P_i - MC) \cdot Q_i$$

The profit-maximizing price cannot be equal to marginal cost as in Bertrand because the profit is zero and with a price above marginal cost, the firm can still sell gas and thus

make positive profit. In Graph 2, a price above marginal cost will yield Firm B a profit. This firm is therefore the higher priced firm, so the profit equation is now

$$\pi_i = (P_i^* - MC) \cdot (Q_H)$$

The profit-maximizing price is found by maximizing the above profit function. This price occurs where the first derivative is zero. Therefore

$$\begin{aligned} \pi_i &= P_i^* \cdot Q_i - MC \cdot Q_i \\ \frac{d\pi_i}{dP_i^*} &= dP_i^* \cdot Q_i + P_i^* \cdot \frac{dQ_i}{dP_i^*} - MC \cdot \frac{dQ_i}{dP_i^*} = 0 \end{aligned} \quad 3.7$$

Solving for P_i^* will yield the profit-maximizing price, or Bertrandesque solution.³ Q_i^* is the quantity that Firm B will sell for that period if it choose P_i^* as its price. It is important to note that this is not a pure Nash equilibrium.⁴ Because of the nature of the quantity difference function, there is an incentive to lower prices to P^* , and an incentive to raise prices at or below P^* . There is a finite range from MC to just above P_i^* where participants will not escape if they continue to compete. This is due to the nature of the market. The ability to have a higher priced firm that still receives business drives the incentive to raise price at or below P^* . The higher priced firm will still receive business and show a profit. At a price above P^* , there is an incentive to undercut rather than raise prices further (in a one shot game) because a much larger percentage of the market can be achieved enabling greater profits.

The long run dynamics of the model are defined by the underlying game theory for decisions that players must make when determining the price for the next period. The players decide whether to raise, lower, or keep their price the same (see nine-quadrant game matrix below).

		Player 1		
		Lower Price	Same Price	Raise Price
Player 2	Lower Price			
	Same Price	Values of Profit for Each Decision		
	Raise Price			

Players make this decision within the context of what their opponent might choose. The multi-period decision process becomes a nine-quadrant game where each competitor can raise, lower, or keep its price the same. When players are competing, each will choose their best response for what price to set from the nine-quadrant game.⁵ Much as in the Prisoner's Dilemma (presented in Chapter 1), each player determines his or her expected profits in the next round depending on what decision he or she might make and what decision the opponent might make. Each player then chooses his or her best response for each possible choice of his or her opponent. From the perspective of the second player (the opponent), the second player can see what choice the first player will make and pick his or her best response. This results in the Nash equilibrium solution, which helps to determine the *Bertrandesque* solution. Making this into a multi-period game also brings in the dynamics of an infinite horizon game and the model is subject to the dynamics inherent in such games.

The long-term dynamics of the model differ from the traditional conclusions of both Cournot and Bertrand. The infinite horizon model stresses that in a repeated game, there is a collusive equilibrium (the same value in all of the models) but it can be reached in this model of duopoly even without explicit collusion. In finitely repeated games, theory dictates that each player should "cheat" in the final round in order to increase his or her market share and earn a larger profit. Subsequently, to try and beat out an

opponent, each player cheats in the second-to-last round. In order to avoid this, each player then cheats in the third-to-last round and so on and so forth until the best decision for each player is to cheat in the first round of play – the *Bertrandesque* solution would result. In an infinitely repeated game, however, there is the possibility of a different dynamic altogether. Because neither player knows when the last round will occur, there is no incentive to cheat earlier and earlier because in every subsequent round, the opponent will cheat and both players will lose out on the profits made possible only through collusion. As long as the number of rounds remains infinite in the minds of the players, once they find the collusive price, there is no incentive to move away from the collusive price for fear of punishment.

The collusive equilibrium is found in the same manner as in Bertrand and Cournot (Figure 3.2 shows the collusive equilibrium relative to the competitive and Cournot solutions). The point where marginal revenue equals marginal cost determines the profit maximizing price and quantity for the market. The market is then divided in half and each competitor serves half the market. The marginal revenue (MR) curve is defined as

$$P = P_{MAX} - 2 \cdot M \cdot Q$$

Setting this equal to marginal cost (MC) defines the collusive market quantity (Q^C).

Therefore,

$$Q^C = \frac{P_{MAX} - MC}{2 \cdot M} \quad 3.8$$

This, by definition, yields the collusive price (P^C) at which both firms operate

$$P^C = P_{MAX} - 2 \cdot M \cdot Q^C \quad 3.9$$

The dynamics of the model allow for both strict competition (*Bertrandesque* solution) as well as collusive behavior. While Cournot and Bertrand discount the possibility of the

collusive equilibrium being attained, both theories acknowledge the possibility of the collusive equilibrium. The anecdotal evidence supports collusion as a possible outcome (if not at P^C then at some arbitrary price above the *Bertrandesque* solution). The experiment needs to show that these solutions are possible in order to substantiate the claim that consumers are willing to pay a premium for services or saved opportunity cost, that their decision is not based purely on the price at the pump, and subsequently that the distribution of the market is not solely dependent on the lowest priced firm.

3.4 Gas Station Duopoly Experiment

The new assumptions and model outlined in the previous section present an interesting opportunity to explore experimentation. In this case, the assumptions of an existing theory have been revised to account for a recognized inconsistency between observations and theory. The experiment provides a chance to explore the dynamics of the revised model and to draw conclusions about the suitability of the new assumptions.

The previous section highlighted the inconsistency between observed consumer and firm behavior and the theories of Bertrand and Cournot. Some of the anecdotal evidence as to why consumers would purchase the same gas from the higher priced station presented earlier focuses on the conveniences between gas stations such as a Mobil SpeedPass or avoiding the opportunity cost of crossing the road. A considerable number of other examples can be thought of, including access to clean restrooms, the availability of a convenience store, and the ability to use a credit card to name a few. Adopting a new assumption that consumers are willing to pay to have access to an increased number of goods brings a more realistic sense to consumer decision-making.

The ability for firms to make game theoretic decisions removes the obvious falsehood of the assumption that a competing firm will not change output or price levels regardless of another firm's actions. The addition of game theory presents a mechanism to incorporate firm pricing decisions. It also orchestrates the long term dynamic that parallels firm decision making more closely than the existing theories. The explanatory power that the new assumptions bring to duopoly theory is to close the existing gap between observed behavior and theory.

3.4.1 Experiment Design

The research question for this experiment is to examine the modifications to the initial set of assumptions for duopolies outlined in the previous section. The market dynamics of a gas station duopoly will be examined. If the results from the experiment reflect the modified model, then the revised premises, that form the foundation for the model not only more closely replicate reality but also add value to the theory.

The environment faced by participants is that each is a gas station owner with the responsibility of setting the price for regular gas each morning. The only information that the owner has is the cost of the gas to the station and that there are no fixed costs. The owner has no information regarding the market demand function. The differentiation between the two firms is done by consumers (and not specified in the experiment) and is incorporated into the demand and differencing functions presented earlier. Owners observe consumer behavior and their opponent's prices and react accordingly. Appendix 3.1 displays the instructions that each player sees.

The experiment was computerized for ease of calculations, uniformity amongst competitors, and ease of transferability around campus (it was a web application). It allowed the participants to read through and have easy access to instructions at all times as well as allowed players to move through the different rounds quickly (as opposed to lengthy hand calculations between rounds). It also enabled easy collection of the data and control of the environment. It prevented the participants from communicating with each other or pairing themselves up in such a way that it would alter the results of the study. To aid in this, the computer randomly paired participants as they logged in to the application.

Motivation was one of the important variables discussed in the methods section as well as earlier in this chapter. If the players are not compelled to act in the same manner as the economic participant he or she is simulating (a gas station owner), then the player will not operate in the same way and the results will hold no meaning. Reproducing the same motivations for the players as the economic participants face is imperative to an experiment's success. In this case, the player must act like a gas station owner and try to maximize profits. In order to persuade participants to act in this manner, part of their compensation was tied to their performance. Each player received two dollars for participating as a base payout. The remainder of a participant's payout was one and a half percent of the participant earned profits during the experiment. This motivated each player to do as well as possible, as each player's own interests were tied to his or her performance. The expected running time of the experiment was thirty minutes and the expected payout was over four dollars, a level above the hourly wage they could receive at the college.

The procedures for the experiment are included in Appendix 3.2. Each player had to read and accept an informed consent form (Appendix 3.3). This signified that the participants were playing of their own free will. Players were provided the instructions, as well as given the opportunity to have questions answered. Once all questions were answered, the players were instructed to begin the experiment. Given only the previous information about cost, each player had to determine his or her first price. For subsequent rounds, players were also informed of any profits earned that day and what their opponent chose for a price. Players then set prices for subsequent days and the game proceeded for an unknown number of rounds. One added capacity that each player has is to review the prices and profit levels for each previous round.

Before the end of the experiment, participants were asked to fill out a form that collected data (major; minor; age; gender; graduation year; state or country of residence) as well as asked them questions about why they chose their prices (how did you choose your first price?; how did you choose your second price?; how well do you think you did compared to your opponent?). This allowed for some insight into the decision-making logic of the hypothetical owners. While this bears no statistical significance, it adds to the circumstantial evidence regarding firm behavior.

The parameters for the experiment were assigned in order to accommodate the goals of approximate payout and so that participants could not easily figure out the market demand function. They were also chosen for their realistic connotations. Participants were all informed that their marginal cost for gasoline was \$1.50. The demand function had a P_{MAX} of \$1.90, a realistic current maximum for the price of gas in

New England. The slope, M , was set at -0.001 , for every penny the price of gasoline dropped, 10 more gallons of gasoline were demanded.

Given these parameters, the equilibrium points defined in the first section can be calculated. Recall that the *Bertrandesque* solution (equation 3.7) is determined by solving the first derivative of the profit function for P_i^* . Given the parameters, $P_i^* = 1.53$ (solved numerically⁶). Readers are reminded that this is not a pure Nash equilibrium, but that once prices approach this price, they remain within a few pennies of it as long as the players are competing and not colluding. The collusive equilibrium was defined to be the profit maximizing price and quantity for the market. This quantity (Q^C) and price (P^C) are calculated to be $Q^C = 200$ (from equation 3.8) and $P^C = \$1.70$ (from equation 3.9) respectively. This quantity is split between the two players if they are both operating at the collusive price.

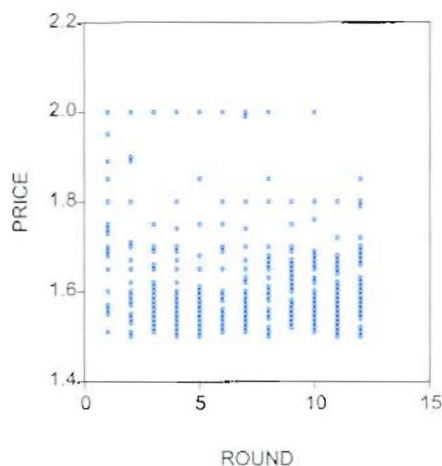
3.4.2 Data

A total of twenty-six pairs (fifty two participants) were collected from this experiment. The experiment was conducted at Colby College, a highly selective, small, liberal arts college in New England. Thirty-nine percent of participants were female. A wide variety of majors were represented in the study, though economics was the predominant major. Participation in the experiment was completely voluntary. Promotion for the experiment occurred through classroom announcements by professors, postings, sign up sheets, and public announcements.

3.4.3 Results

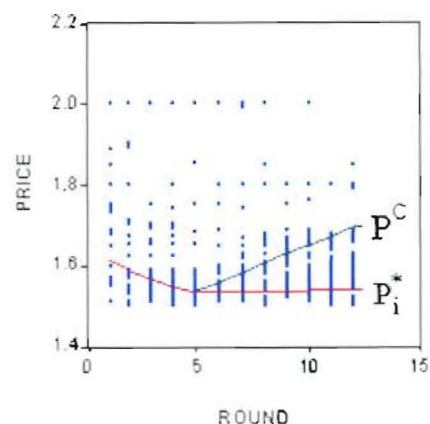
The results describe a similar dynamic to the one presented in the theory section. While competitors initially chose a wide range of prices over the course of the game, many participants engaged in competitive behavior consistent with the *Bertrandesque* prediction. There is also evidence that players were colluding, able to maintain a price above the *Bertrandesque* solution. The following analysis reflects that participants either competed (and thus fell to the *Bertrandesque* solution) or colluded (were able to maintain a price above the *Bertrandesque* solution) after some period of learning.

The first technique used to analyze the data was to graph the scatter plots for the prices chosen by participants in each round. This enabled a simple regression to be fitted showing the general trend of the data. It also enabled the tracing out of clusters of prices. Through inspection, it was possible to show that one group of participants chose prices around the *Bertrandesque* solution while another group moved towards a collusive solution. While the collusive solution was determined to be $P^C = 1.70$ earlier in this section, any price different from (and above) the *Bertrandesque* solution is a price competitors must cooperate (or collude) to achieve (A price of \$1.60, for example). Graph 3 shows the scatter plot for prices by round.



Graph 3

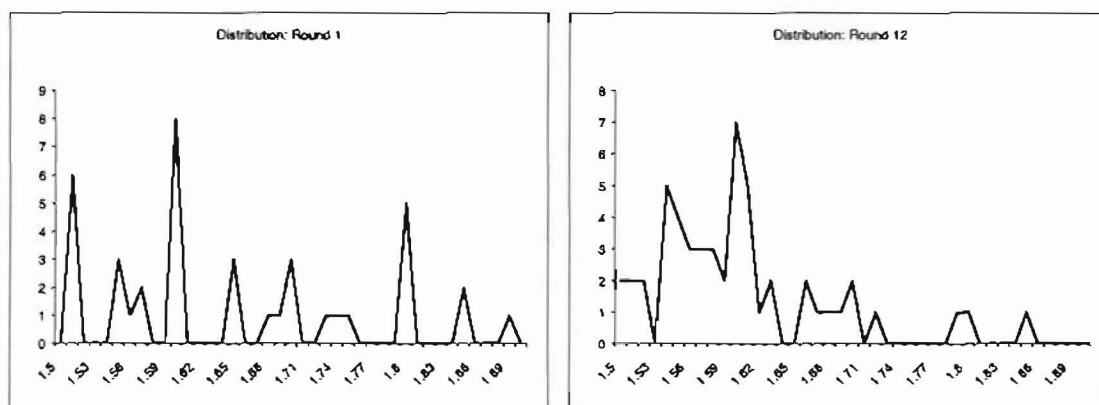
Graph 4 uses the same scatter plot to show the approximate separation of the data as the rounds progress. The bottom line represents the trend towards the *Bertrandesque* solution while the split upward represents the trend of prices moving toward the collusive region. Some participants competed the entire game, never leaving the *Bertrandesque* region; others realized that there was the possibility to cooperate and worked with their opponent to achieve a better outcome.



Graph 4

It is the split in Graph 4 that is the interesting result. It is a visual construction of the theoretical prediction of two solutions. In order to determine the extent to which the

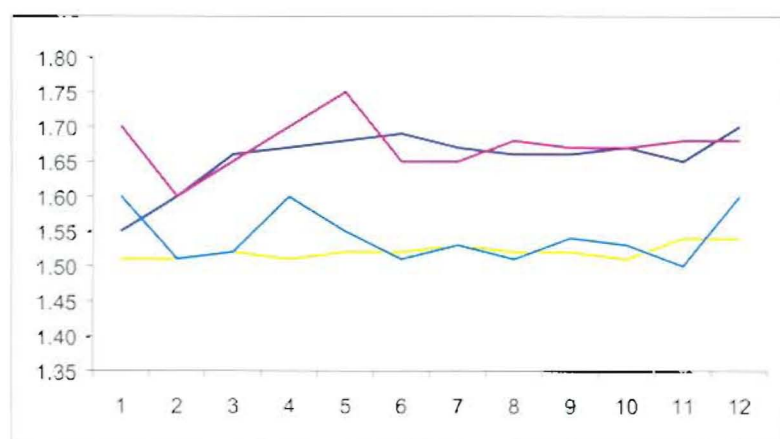
data separate, a second technique is used. The distribution of prices in each round is graphed to determine if there is any substantive split in the frequency that each price is chosen. A second important consideration is the extent that the pairs of data move together (regardless of solution). Showing this is necessary for any conclusion regarding the assumptions underlying duopoly theory (there is no meaning to one player operating in the competing group with the other in the colluding group). The two solution curves in the Graph 4 represent the peaks of the distribution curve. As the rounds progress, the peaks should split, one for the *Bertrandesque* solution (the lower prices) the other moving towards the collusive equilibrium (the higher prices). The separation need only show that there is some collusion supporting some price above the *Bertrandesque* solution, not necessarily at the collusive price (P^C). Appendix 3.5 displays the distribution curves for all twelve rounds. The first and twelfth rounds are shown below.



The first round (left graph) displays a wide range of prices chosen by competitors. A large group of these (20) are below \$1.60. By the twelfth round (right graph), there is a large cluster of prices below \$1.70 (all but four). There also appears to be some clustering of prices. It is clear that there is a break around \$1.59, below which is one

group, above which is another. One peak seems to develop around \$1.54, the other peak around \$1.62. This is the first evidence that there are two distinct solutions.

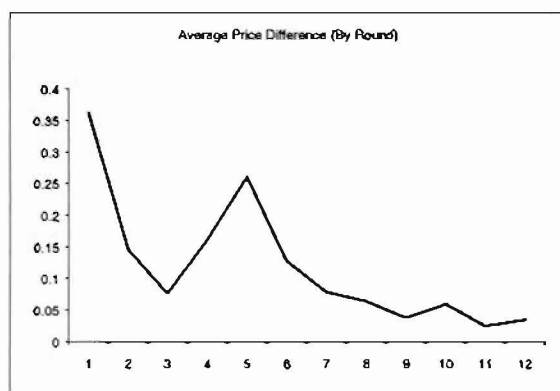
There are two ways to show that the pairs of prices travel together. The first is to follow each pair through the twelve rounds and show that they stay near each other. Graph 5 shows two such pairs (the first four observations). The top two lines represent the prices for the first pair; the bottom two lines represent the prices for the second pair. This offers the first piece of evidence that the players are staying together.



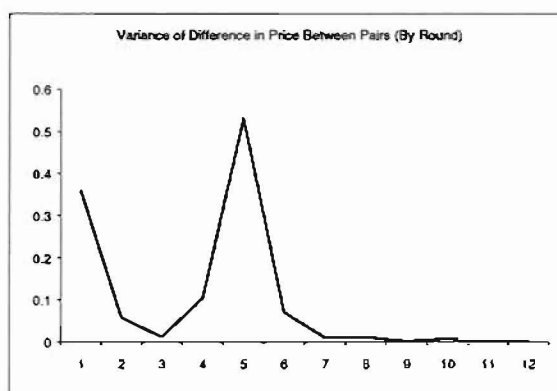
Graph 5

In order to show that this is common amongst all pairs, the average difference between pairs was calculated round by round. Graphs 6 and 7 show the average difference in price between pairs and the variance between the average differences in price between pairs as the rounds progress. Notice in the earlier periods the large difference between competitor's prices. This separation stage is referred to as the "learning period." Participants are learning about the demand curve that they face and their opponent's pricing behavior. Players also try to find ways to increase profits. It is during this time that the players resolve to continue to compete or to try to increase profits through

collusion. This occurs without the benefit of communication based solely on what the players learned about each other.



Graph 6



Graph 7

Graph 6 shows that the average difference in price approaches three cents. From this it can be concluded that the opponents cannot be in both the *Bertrandesque* and collusive regions simultaneously. The average difference in prices between competitors becomes smaller as the rounds progress so that as the solutions separate, it becomes unfeasible to be simultaneously in both solution regions. Graph 7 shows the variance in the average difference in prices approaching zero in round six. This provides further evidence that the prices are moving together. There is now sufficient evidence to conclude that each set of opponents (pair) move together. The question of whether or not there is a split of the pairs into groups – one group competing, the other group colluding, remains as the final piece to be addressed.

Using the frequency distribution of the average price for each pair, the hypothesis that the pairs split into two distinct groups is confirmed if a significant difference exists between the two peaks of the resulting binomial distribution. It has been shown that the prices within each pair approach each other in the last six periods, so it follows that the average price for each pair is representative of the pair's price relative to marginal cost.

It is expected that the binomial distribution will result with one peak representing the *Bertrandesque* solution the other the collusive solution (at some price above the *Bertrandesque* solution).

In order to show that the two peaks are different from one another, each of the average prices for each pair must be separated into a *Bertrandesque* group and a collusive group. These groups must then be tested to determine if any statistical difference exists. The first step in separating the data is to ensure that the observations for each round are kept as a set for each pair of participants. Graphs 6 and 7 show that the pairs of prices converge between the fifth and sixth rounds. From looking at the graphs, it appears as though round six is the “breaking point,” the round in which learning seems to be complete enough that prices for each pair converge and the decision to compete or collude has been made. For completeness, two models of the groups are created. The data are frozen in order to keep the set of observations together. The sets are then sorted by the sixth round (the break point round). The first eleven sets of observations are then grouped as the “lower” group and the final twelve observations grouped as the “higher” group. Each of these groups makes up Model I. In order for collusion to exist, the separation must be significant by the final round. Model II follows a similar process but sorts the data according to the prices in the final (twelfth) round. Each model is then examined to determine if a breaking point exists. It is the existence of a breaking point that confirms a statistical difference in the groups and subsequently in the solutions.

Tables 3.1 and 3.2 in Appendix 3.6 show the results of the two models. The t-statistic for each round is given. Using the critical values⁷ with 22 degrees of freedom, it is clear that by round 5 and round 8 (respective to each model) enough learning has taken

place that the prices for each pair of opponents have converged, and they have begun to either collude or compete. The t-statistic for round five in Model I is 1.790 (significant at the five percent, one-tailed level of significance). The interpretation is that in round five, a statistically significant difference exists between the mean prices in each of the groups. Similarly, the t-statistic for round eight in Model II is 2.089 (significant at the five percent level for a one-tailed test) reflecting the same thing. It is now possible to conclude that there is a statistically significant difference in the means (peaks of the binary distribution) at that point, implying that there are two distinct groups of players; one set competes, the other set colludes to maintain a price above the *Bertrandesque* solution.

A regression analysis was performed on the data as an additional test of whether or not there was a collusive equilibrium different from the *Bertrandesque* equilibrium. The regression (Model III) was run with the average price for each pair of opponents as the dependent variable. The explanatory variables are ROUND, COLLUDE, and BOTHECON. ROUND is a time variable. The expected sign on ROUND is negative or zero. As the rounds progress, competition should develop and prices should fall. Prices cannot fall below the Bertrand solution (marginal cost), so it is possible that they are constant (coefficient equal to zero). COLLUDE is a binary variable set equal to one if the average price for a pair is greater than \$1.59 in the current period and the two periods prior. \$1.59 is defined to be a significantly different price from the predicted *Bertrandesque* solution of \$1.54. The lagged component ensures that the pair has been above this price sufficiently long that they are colluding (not a random price difference that pulls the average above \$1.59 for one period). The variable is set equal to zero

otherwise. The expected sign on COLLUDE is positive, as colluding should shift the price up. BOTHECON is a binary variable equal to one if both players in the pair are economics majors. It is set equal to zero otherwise. The expected sign on BOTHECON is positive. It is positive because of the possibility that economics majors may have learned that in a duopoly there are ways to earn greater profits than by competing.

The results of the regression can be found in Appendix 3.8. The regression applies to a twelve-round game. The first round is eliminated because it is random and it is impossible for colluding to have occurred in the first round. The sign on ROUND is negative and significant. As each round progresses, the average price tends to fall just under a penny. The sign on COLLUDE is positive and significant. If the players are colluding, they can expect to have an average price fifteen cents higher than if they did not collude. The sign on BOTHECON is positive and significant. If both players are economics majors, they tend to have an average price that is five cents above pairs that are not both economics majors. The COLLUDE variable is most significant to the discussion of collusion. COLLUDE was found to be positive and significant and to have a magnitude of about fifteen cents. The interpretation is that those whom colluded were able to keep their prices fifteen cents higher than those that competed. The expected difference in the *Bertrandesque* solution price and the collusive price was sixteen cents ($P^C = \$1.70$ and $P_i^* = \$1.54$). The regression results add further credibility to the claim that there is the possibility for gasoline station owners to collude even without direct communication.

The final determination is whether or not the *Bertrandesque* solution is different from the Bertrand solution. It is important to show that the equilibrium is above

Bertrand's prediction; otherwise, the only result is that collusion is possible in an infinite horizon game. Tables 3.3 and 3.4 in Appendix 3.6 show the extent to which the lower group differs from the Bertrand solution of price equal to marginal cost (\$1.50). Both models show that by the tenth round, the *Bertrandesque* group is operating at a statistically different price from \$1.50. It now suffices to say that there are two solutions, a *Bertrandesque* and a collusive, and that the *Bertrandesque* solution is different from the solution proposed by Bertrand.

3.4.4 Conclusions

The results section determined that there was clear evidence of the *Bertrandesque* solution as well as the beginning of a split off towards the collusive equilibrium. Some participants found a way to maintain a price above the *Bertrandesque* solution, beginning to approach the collusive solution. The existence of a breaking point in each of the models justifies the existence of two solutions.

Some structural problems for the experiment also exist that influenced the results. It was not possible to make the game truly infinite. Players knew from the time constraint that the game had to end sometime and could begin to "guess" when they believed the game was coming to an end. Subsequently, players began to act as though it were a finitely repeated game. Many participants played concurrently in the same room. As other participants started finishing, it was possible to detect this and players started to question how many rounds were left in their own game. The results reflect this. In some of the later rounds there is some "cheating" from the collusive prices as people guess that

the game is almost over and drop their price. Irrespective of this, there is still evidence from the distributions that the groups split into upper and lower regions.

The clustering of the pairs of prices in each of the groups brings credibility to the underlying assumptions of the theory. The fact that the pairs remain close together, regardless of the group they are in, establishes that if the set of pairs as a whole develop a trend, that the pairs follow that trend together. The existence of the split in the groups verifies the claim that the dynamics hypothesized by the theory are possible. Players have the ability to collude or compete. It is therefore possible to conclude that the players in this game operated in a manner consistent with the assumptions of duopoly behavior. The more complex set of assumptions are more reasonable than previous theories. The end result is that the experimental results support the prescribed dynamics of duopolies so that the underlying assumptions are not only fit with the real-world better but also that they improve the foundations of duopoly theory.

Appendix 3.1

Instructions

You are a gas station manager and have been designated the responsibility of setting the price for unleaded gas for each business day. The station you work for is competing against another identical station located across the street. Once set, you cannot change the chosen price until the close of business. You can set the price at any level you choose. At the end of each day you will be given the opportunity to change your price for the following day.

The computer will randomly pair you with another individual. You do not have any contact with this individual during the game. The computer will tell you what price they choose and whether or not you made a profit.

There are several things to note. In the upper right hand corner are two boxes, I and H. By clicking on I, you can view the game instructions at any time. By clicking on H, you can view your and your opponent's past price selections. In the upper left hand corner is a box that will display your cumulative profits for the game.

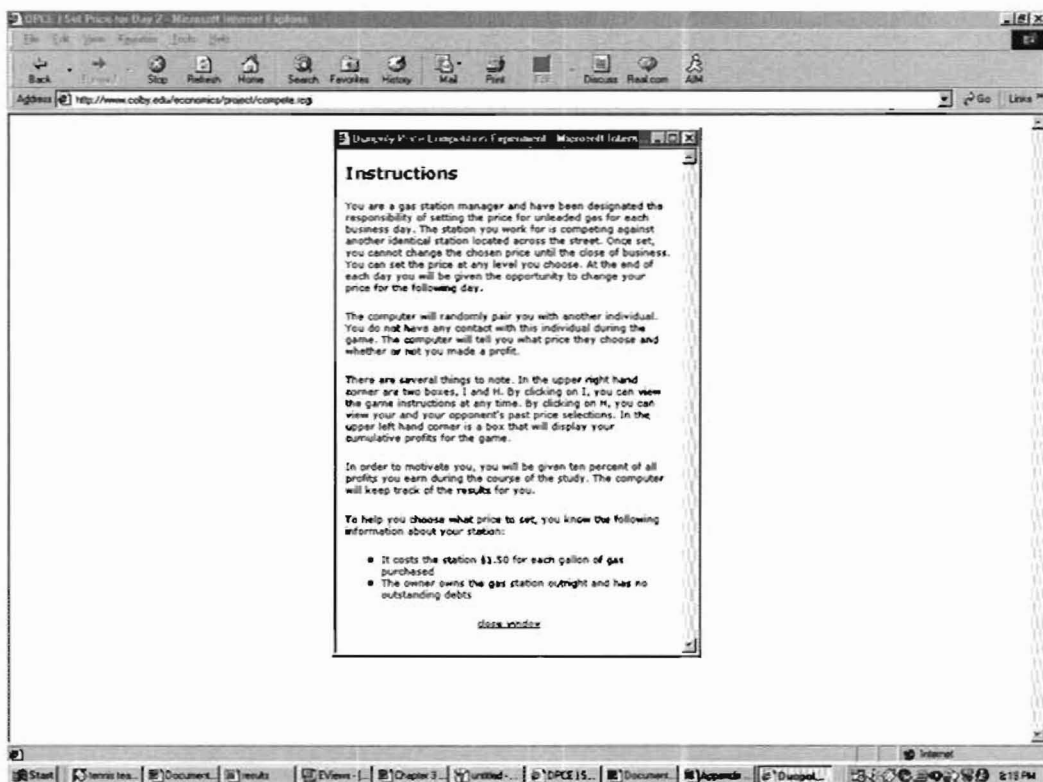
In order to motivate you, you will be given a percentage of all profits you earn during the course of the study. The computer will keep track of the results on the screen for you.

To help you choose what price to set, you know the following information about your station:

- It costs the station \$1.50 for each gallon of gas purchased
- The owner owns the gas station outright and has no outstanding debts

If you have any questions, please raise your hand now.

Continue with DPCE.



Appendix 3.2

Experiment Procedures

Students are asked to sit anywhere they want (24 maximum per session).

Once everyone is seated,

Thank you for agreeing to participate in today's study. The study will be completely computerized, but you may use scrap paper as you wish. From now until the end of the experiment, please refrain from holding conversations with your neighbors. To begin, please open up Internet Explorer and insert the following link:

www.colby.edu/economics/project

Once you have entered the link, please wait for further instructions.

Once everyone has the first screen up,

Please go ahead and insert your Colby username and password as indicated on the screen. Press enter when ready.

Pause as the participants enter their information.

Be sure to read all of the instructions carefully. They will be available to you during the game. If you have any questions, please raise your hand and I will answer them.

Pause for a full minute to allow them to read the instructions carefully.

Once everyone is ready,

If there are no more questions, please press "Continue with DPCE" which will take you to the informed consent form. After reading the form, press 'Accept' and begin the experiment. Once you have finished the experiment, be sure to print out your totals screen. Do not close your browser at any time. Again, if you have any questions, please raise your hand and we will answer them for you. When you have finished the experiment, please wait quietly for everyone to finish.

Once everyone has completed the experiment.

Thank you for participating in this study. Please be sure that you have completed the form and printed out the summary page. We will now call you out by name to come and be paid for your participation. Please wait quietly while we complete this process. Thank you again for your help.

Begin calling out names and paying the participants.

Appendix 3.3

Informed Consent Form

Title of Study: Price Competition Between Two Firms With Homogenous Products

Person In Charge:
Albert Goodman
Colby College

This study is designed to investigate how people, when acting as the owner of a firm, set prices over time when in direct competition with one other firm. If you agree to take part in this research, you will be asked to compete against one other person.

Your participation in this study will take approximately 60 minutes. The amount of money that you earn in this study will depend on the decisions that you and the other person make.

There is no deception anywhere in this study. What you are told is going on is exactly what is going on.

The experimenter is on hand in order that you may ask questions about the research procedures and so that these questions will be answered. Your participation in this research is confidential. Only the person in charge will have access to your identity and to information that can be associated with your identity. No record will be kept matching your name with your code number, so your information and performance in the experiment is anonymous even to the experimenter. In the event of publication of this research, no personally identifying information will be disclosed. To make sure your participation is confidential, only a code number will be used to identify you; furthermore, your name will not be used. Further, your participation is voluntary. You are free to stop participating in the research at any time or to decline to answer any specific questions without penalty. Finally, this study involves minimal risks; that is, no risks to your physical or mental health beyond those encountered in the normal course of every day life.

By clicking on 'Accept' below you are verifying the following:

I agree to participate in a scientific investigation of price competition in a two-firm market. I understand the above information and I have received answers to any questions I may have about the research procedure. I understand and agree to the conditions of this study as described. I understand that my participation in this research is voluntary and that I may withdraw from this study at any time by notifying the person in charge. Finally I certify that I am at least 18 years of age and that to the best of my knowledge I have no physical or mental illness that would increase the risk to me of participation in the study.

Accept

DPCE Informed Consent Form Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Forward Stop Refresh Home Search Favorites History Mail Print Edit Discuss Real.com AIM

Address http://www.colby.edu/economics/project/info.html

Informed Consent Form

Title of Study: Price Competition Between Two Firms With Homogeneous Products

Person In Charge:
Albert Goodman
Colby College

This study is designed to investigate how people, when acting as the owner of a firm, set prices over time when in direct competition with one other firm. If you agree to take part in this research, you will be asked to compete against one other person.

Your participation in this study will take approximately 60 minutes. The amount of money that you earn in this study will depend on the decisions that you and the other person make.

There is no deception anywhere in this study. What you are told is going on is exactly what is going on.

The experimenter is on hand in order that you may ask questions about the research procedures and so that these questions will be answered. Your participation in this research is confidential. Only the person in charge will have access to your identity and to information that can be associated with your identity. No record will be kept matching your name with your code number, so your information and performance in the experiment is anonymous even to the experimenter. In the event of publication of this research, no personally identifying information will be disclosed. To make sure your participation is confidential, only a code number will be used to identify you; furthermore, your name will not be used. Further, your participation is voluntary. You are free to stop participating in the research at any time or to decline to answer any specific questions without penalty. Finally, this study involves minimal risks; that is, no risks to your physical or mental health beyond those encountered in the normal course of every day life.

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Accept:

Start | Seminar... | Document... | results | View... | Chapter 3... | Untitled... | DPCE I... | Document... | Appendix...

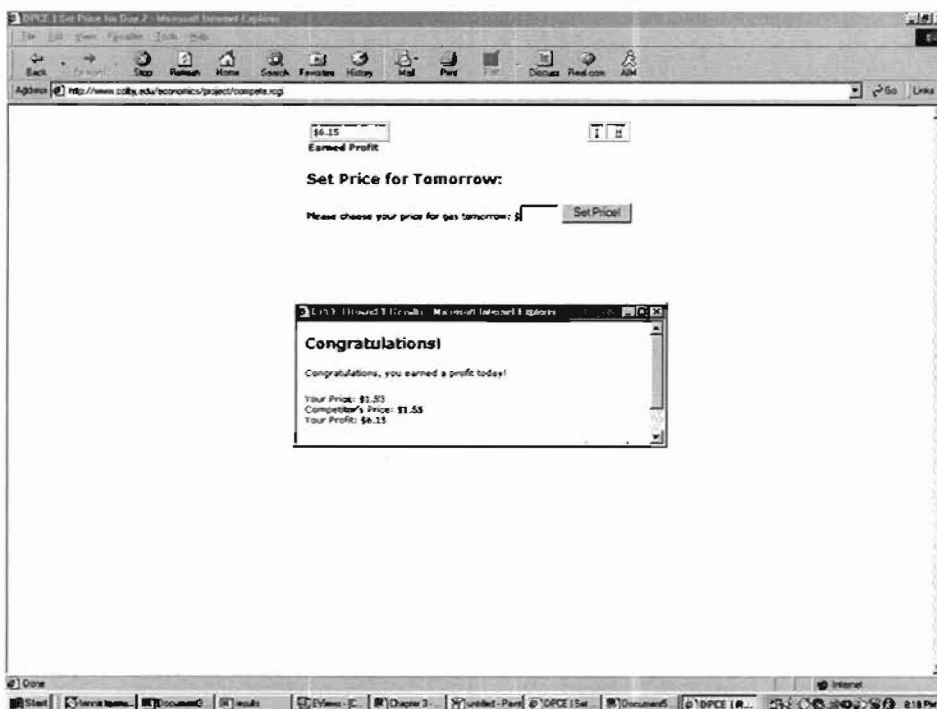
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Appendix 3.4

On Screen Displays for Experiment



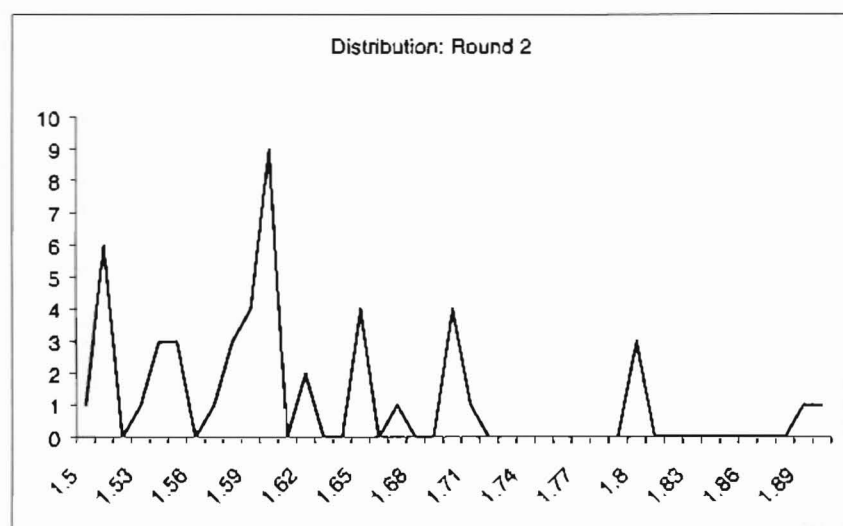
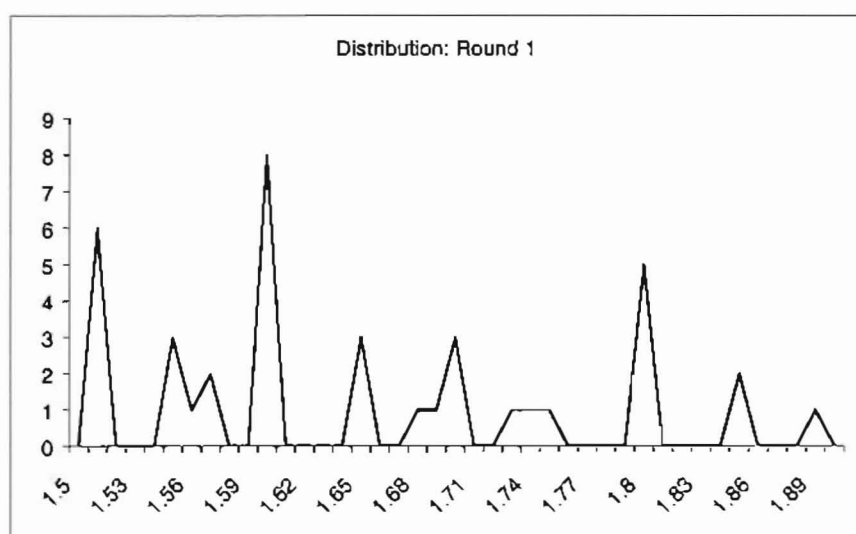
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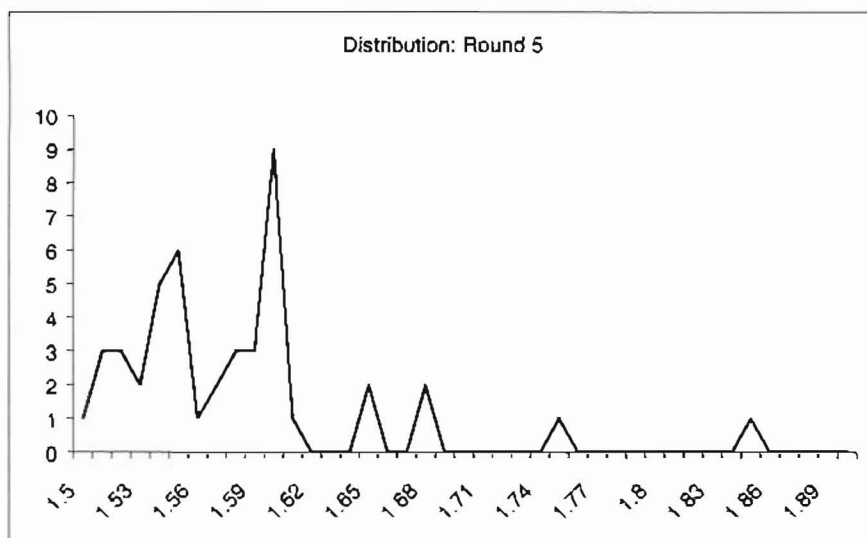
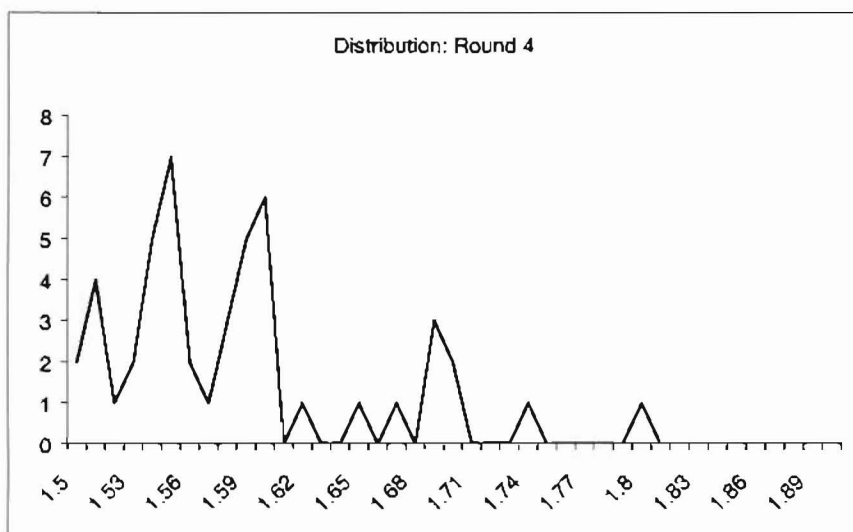
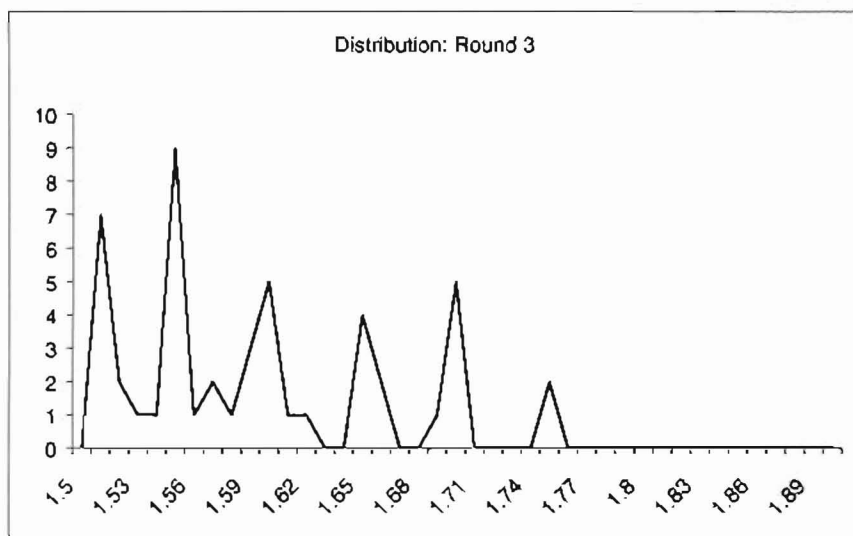


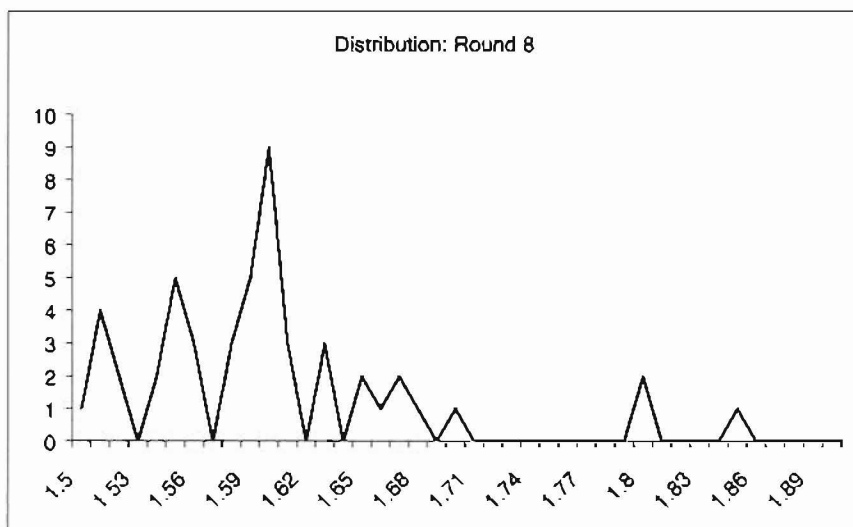
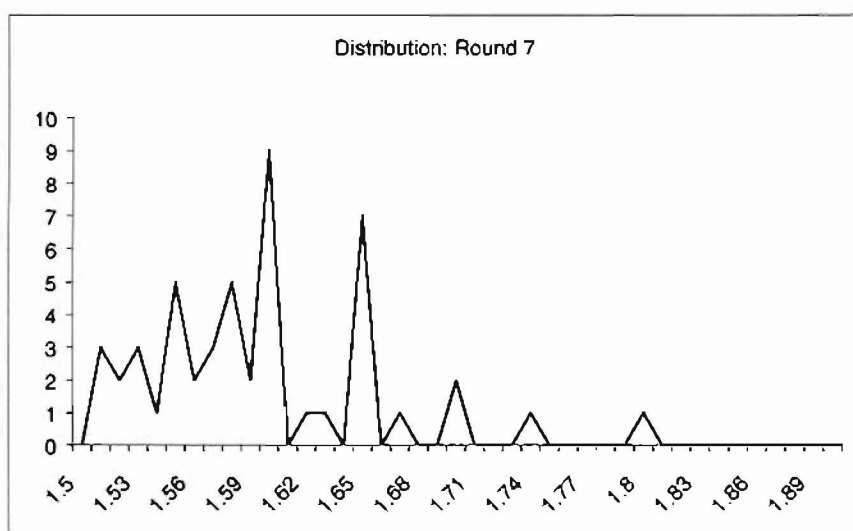
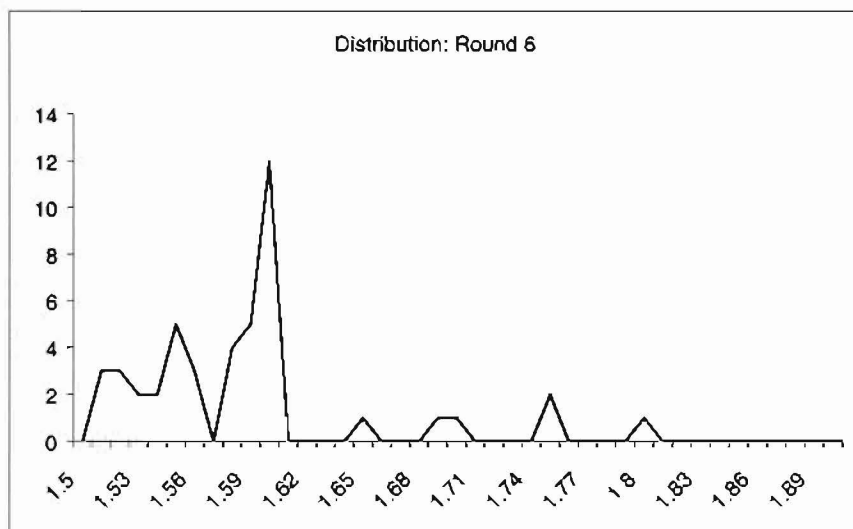
Display After Putting in a Price

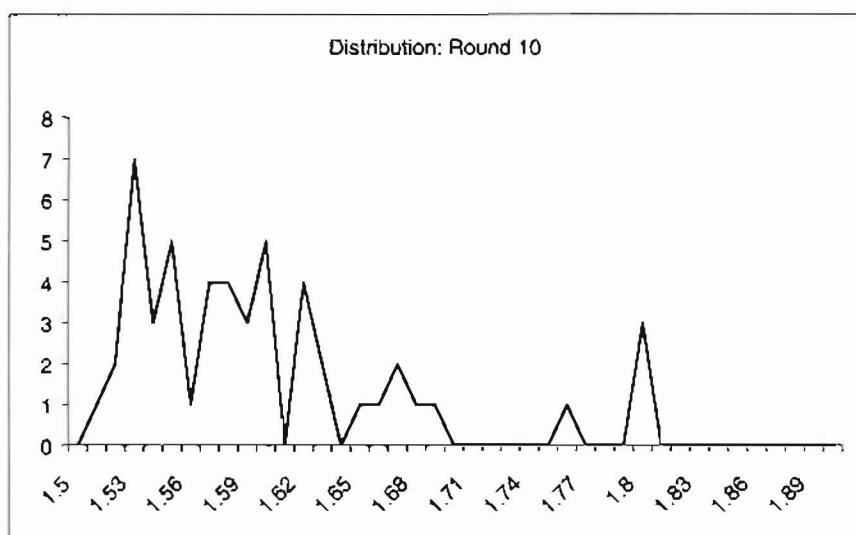
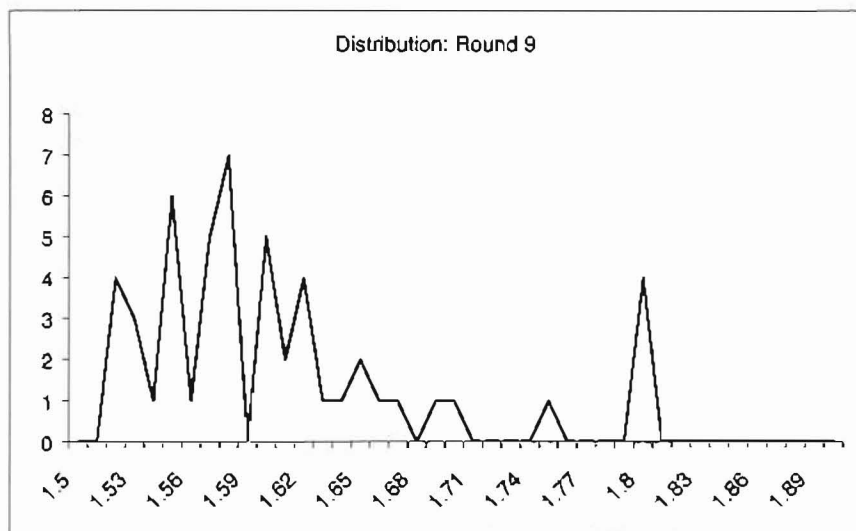
Appendix 3.5

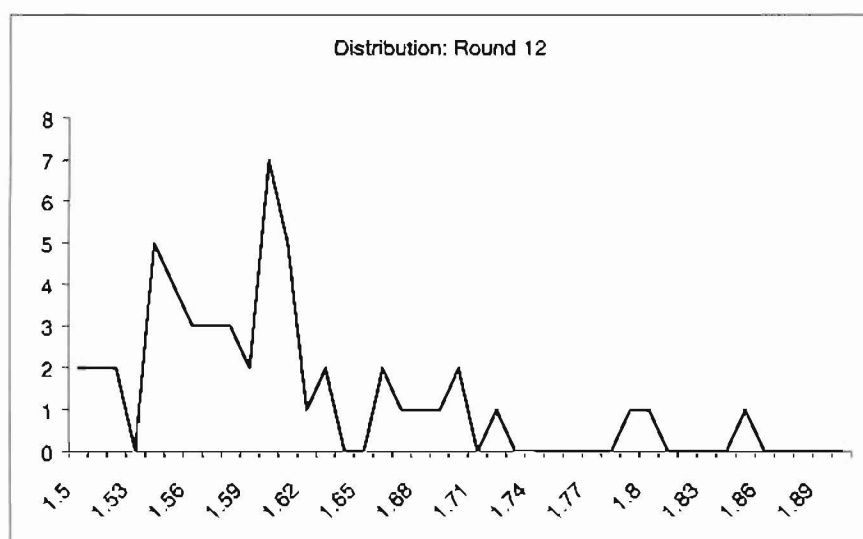
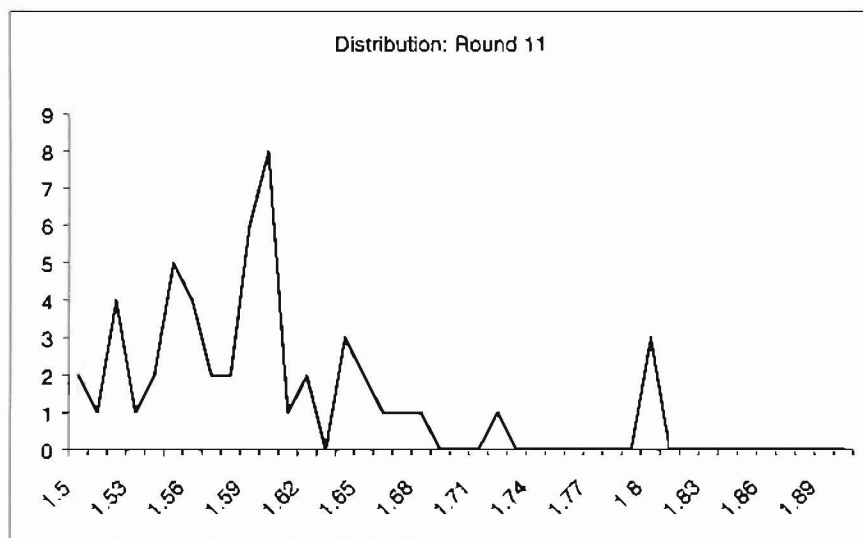
Distribution of Prices, By Round











Appendix 3.6

Figure 3.1

Model II: Data Sorted by Prices of Sixth Round

Round	Mean (Lower)	S.E.	Mean (Higher)	S.E.	t-Statistic
1	1.7409	0.3750	1.8738	0.3597	0.865
2	1.6595	0.2858	1.6804	0.1025	0.229
3	1.6155	0.2175	1.6438	0.0961	0.397
4	1.5918	0.1957	1.6854	0.1994	1.136
5	1.5536	0.1536	1.8363	0.5227	1.790*
6	1.5332	0.0525	1.7663	0.2800	2.829**
7	1.5655	0.0933	1.6413	0.0680	2.210*
8	1.5673	0.0733	1.6358	0.0693	2.300*
9	1.5723	0.0725	1.6317	0.0705	1.990*
10	1.5659	0.0411	1.6446	0.0912	2.703**
11	1.5627	0.0357	1.6333	0.0797	2.779**
12	1.5673	0.0415	1.6321	0.0890	2.267*

* Significant at the five percent, one-tailed level

** Significant at the one percent, one-tailed level

Figure 3.2

Model II: Data Sorted by Prices of Twelfth Round

Round	Mean (Lower)	S.E.	Mean (Higher)	S.E.	t-Statistic
1	1.7891	0.3669	1.8296	0.3785	0.260
2	1.6882	0.2819	1.6542	0.1103	-0.375
3	1.6459	0.2154	1.6158	0.0999	-0.423
4	1.6168	0.1961	1.6625	0.2076	0.543
5	1.7186	0.5391	1.6850	0.2676	-0.187
6	1.5823	0.1648	1.7213	0.2729	1.492
7	1.5759	0.0973	1.6317	0.0728	1.545
8	1.5700	0.0736	1.6333	0.0716	2.089*
9	1.5705	0.0713	1.6333	0.0700	2.131*
10	1.5577	0.0370	1.6521	0.0848	3.506**
11	1.5532	0.0277	1.6421	0.0725	3.944**
12	1.5468	0.0197	1.6508	0.0754	4.609**

* Significant at the five percent, one-tailed level

** Significant at the one percent, one-tailed level

Figure 3.3

Model I: Data Sorted by Prices of Sixth Round
 Test for Difference from Bertrand Solution (MC = \$1.50)

Round	Mean (Lower)	S.E.	t-Statistic
1	1.7409	0.3750	0.642
2	1.6595	0.2858	0.558
3	1.6155	0.2175	0.531
4	1.5918	0.1957	0.469
5	1.5536	0.1536	0.349
6	1.5332	0.0525	0.631
7	1.5655	0.0933	0.702
8	1.5673	0.0733	0.918
9	1.5723	0.0725	0.997
10	1.5659	0.0411	1.604*
11	1.5627	0.0357	1.759**
12	1.5673	0.0415	1.621*

* Significant at the ten percent, one-tailed level

** Significant at the five percent, one-tailed level

Figure 3.4

Model II: Data Sorted by Prices of Twelfth Round
 Test for Difference from Bertrand Solution (MC = \$1.50)

Round	Mean (Lower)	S.E.	t-Statistic
1	1.7891	0.3669	0.788
2	1.6882	0.2819	0.668
3	1.6459	0.2154	0.677
4	1.6168	0.1961	0.596
5	1.7186	0.5391	0.406
6	1.5823	0.1648	0.499
7	1.5759	0.0973	0.780
8	1.5700	0.0736	0.951
9	1.5705	0.0713	0.988
10	1.5577	0.0370	1.559*
11	1.5532	0.0277	1.921**
12	1.5468	0.0197	2.382**

* Significant at the ten percent, one-tailed level

** Significant at the five percent, one-tailed level

Appendix 3.7

Model III

Regression Results

Dependent Variable: Average Price for a Pair of Players

Sample (Adjusted): 254

Variable	Coefficient	Std. Error	t-Statistic	Probability
C	1.6174	0.0277	58.3538	0.0000
ROUND	-0.0089	0.0033	-2.7186	0.0070
COLLUDE	0.1469	0.0226	6.5082	0.0000
BOTHECON	0.0550	0.0208	2.6443	0.0087
Adjusted R-squared	0.1717			
F-statistic	18.4837			

Notes

¹ Kahn, p. 2

² Kahn, p. 3

³ This equation is not solvable for P_i^* algebraically; it must be determined numerically or graphically

⁴ A nine quadrant game outlines the process by which each player decides whether to raise, lower, or keep his or her price the same based on their best response (extension of Dutta, p. 11)

⁵ Recall that:

$$\frac{d\pi_i}{dP_i^*} = dP_i^* \cdot Q_i + P_i^* \cdot \frac{dQ_i}{dP_i^*} - MC \cdot \frac{dQ_i}{dP_i^*} = 0$$

Solving numerically with the given parameters yields $P_i^* = \$1.53$

⁶ Studenmund, p. 607

CHAPTER 4

Reflections on Experimental Economics

“It is an exhilarating time to do experimental economics.”

- Alvin E. Roth

One of the principle concerns of any research project is the experience gained from the completion of it. Having spent the better part of a year working on this project, the final chapter is dedicated to reflecting on the role of experimental economics within the discipline of economics, as well as some comments on the project. The first section discusses the role of experimentation, identifying some of the criticisms and weaknesses, but concluding that the addition of this technique to economics enhances the explanatory power and functionality of economic theories. The second section focuses on the process of a project of this magnitude.

4.1 Experimentation and Economics

The addition of experimentation as a tool for economists has been met with some contention. Many economists believe that the experimental environment fabricates results, essentially data mining the conclusions in support of the economists' claims. A considerable amount of this project was concerned with understanding experimentation as it pertains to economics. Therefore it is important to address and resolve this question. In doing so, it is imperative as an experimenter to review the experiment for possible shortcomings and possible avenues for further research. Determining the impact of the shortcomings will influence the power of the results. This discussion will help improve future duopoly experiments.

The questions concerning the validity of experimentation as a viable method for performing economic tests led Alvin Roth to write "Let's Keep the Con Out of Experimental Econ.: A Methodological Note" in 1994. Two important points Roth raises are that experimentalists must accurately and completely report their data. If they clean

their data to any large extent, the reasoning for this needs to be clear in the published work so that other economists can determine if the data cleaning affected the end results. The second point Roth calls “guarding against self deception.” As an experimenter looks to analyze the results, he or she must proceed carefully to reach a conclusion that is supported by the data. The careful treatment of data and interpretation of results with a blind eye to the desired results are important steps to bring credibility to the area.

One of the common criticisms of experimentation is that experiments are by nature set up to succeed. The design of experiments yields the author’s intended result. An experiment cannot “fail” unless the experimenter commits errors in devising the experiment. Critics explain that this is due to the control mechanism. Control allows the experimenter to establish the underpinnings of the economic principle under examination. Control enables the experimenter to define the output in such a way that the variables he or she wishes to extract are easily observed. Given the experimenter has control over the inputs and the form the outputs take, an experiment by definition reflects the author’s preconceived notions for what conclusions the results should support.

Empirical economists argue that economic models are developed through theoretical decisions and then evaluated and analyzed using outside evidence. The accuracy of the model rests in how well the data reflect the proposed model’s predictions. The empirical evidence comes from real world data and the economist has little ability to control the form it takes. The empirical economist is charged with the task of determining how well the data fit the model for the economic event, having little to do with the actual data collection.

While the observations regarding the uses of control are correct, the conclusion that experiments by definition fabricate results is not. The critique of control highlights the need for careful experimentation. It is worth noting that an empirical economist can data mine results just as easily as an experimental economist can fabricate results. Declaring that all experimental data are tainted would be just as unsubstantiated as determining that all empirical results are equally falsified. The capability that experimentation adds is that economists can now create economic events in a laboratory. It is then possible to collect data that might be unobservable under real world scenarios or obtain additional data to compliment existing evidence. It is the ability to collect different variables or specific variations on existing variables that makes experimentation so valuable. Like any science that is not purely theoretical, it is possible to fabricate results; it is only through careful consideration of experiment designs and parameters that this is avoided.

Regarding the criticism that experimentalists design their experiments to produce the desired outcome, there are a few key points that critics overlook. Experimentalists document their procedures, designs, and parameters very thoroughly. This enables other economists to examine the experiment as a whole and possibly to rerun the study. Subsequently, other economists are able to determine whether or not the results were established under false pretenses. Much of the work of the experimenter is to design an experiment such that the environment is accurately replicated and that the desired data are collectable but not predetermined. The second important element of experiments is that they do not explicitly set out to prove a theory. The environment established by the experimenter represents the environment of the economy. Players placed in that situation

act as a participant in the actual economy. Experiments test whether or not participants act according to the underlying assumptions of the model through comparison of the results with the model's predictions. Conclusive experiments observe participants acting in a manner consistent with the assumptions and predictions of the theory while using parameters that do not force the results.

Criticisms that revolve around the experimenter assuming too much about the market may also be inaccurate. The experimenter takes a theoretical model and then tests to see if the assumptions are correct. In the case of the experiment presented in this paper, the researcher thought that the underlying principles of a duopoly market were different from existing theory. The experiment hypothesized that the revised set of assumptions would result in a similar but different dynamic than previous models suggested. The experiment was designed to test whether or not the revised set of assumptions would lead the participants to act in a manner similar to the original theory. The revised set of assumptions more closely paralleled consumer behavior. If firm behavior reflected a similar dynamic, then the revised assumptions hold merit.

While this is a slight distinction, it is an important one. Some economists spend a great deal of energy arguing that experimental evidence should not be included as a way to verify economic theories. Experimental data are not designed to validate the theories *per se* but the assumptions that form the foundation for the theories. Theory dictates that a specific set of actions will occur under a set of circumstances. Experimental evidence shows that a set of actions *can* occur under this given set of circumstances. Experimenters acknowledge that it is a *possible* set of actions.

Understanding that experimentalists are merely trying to show that a set of actions can develop from a set of assumptions neutralizes much of this criticism. The elements of control that the experimentalist employs are aimed at establishing the same set of assumptions. As the experiment is set in motion, the results fall out and the experimenter is left to determine if these are similar to theoretic predictions. If they are, then the assumptions underlying the theory are characteristic of the market participants. It does not unconditionally validate the theory. This slight but important counters the criticisms that experimentalists are able to validate theories through fabricated results. Over time, the unwarranted criticisms of experimental economics will fade and experimentation will serve as an invaluable tool in an economists' arsenal.

Writing a chapter devoted to thinking about the project enables the review of work for systematic mistakes. Most of the mistakes are due to a lack of experience in running experiments. This is magnified by the use of a computer to run the program. The duopoly experiment was successful in many ways, as an economics experiment and as a learning instrument. In hindsight, the number of rounds chosen and the ability for participants to turn the infinite game into a finite game were design flaws in the experiment. The addition of the computerization of the experiment aided the experiment tremendously but also presented challenges.

The number of rounds chosen was twelve. From running computer simulations of the model, it seemed that the expected pattern should develop before the tenth round. Given the limited budget and the desire to maintain the maximum capacity for participants, the decision was made to restrict the rounds to twelve. It was believed that many competitors would reveal their strategy by then. It also was thought that it would

help curtail the time the game would take. In the end, the results begin to show a distinction between the two equilibria, but more rounds would have helped to determine if the collusive price would be reached.

A second design error occurred when working to make the game infinite in nature. College students are impatient and needed to know how long the experiment would take. This imposed a time limit making the game finite. The need to have many participants in the room at the same time was important for randomness of the pairings but worked against the infinite horizon game. As some players finished, others realized the game would soon end and any remaining infinite horizon mindset was lost. While there is no significant evidence that participants altered their behavior on account of the finite nature of the experiment, it was a problem that was not anticipated when determining the experimental procedures and is worth consideration from any future experiments involving multi-period game theoretic models.

The computer program made the experiment significantly easier to run while providing only a few technical problems. Not having to calculate all of the different profits for each participant for each round saved a considerable amount of time. It made the game run smoothly, kept the running time short, enabled the adjustment of parameters in the test phase, and assisted in other important methodological concerns of the experiment, such as lack of communication and randomness of pairing. Some difficulties included the unique nature of the program, as well as the complex coding that made it difficult to debug. Several rounds of pilot tests were done to ensure matching and that the program would not crash once the trials began. While the program certainly worked very well during the experiment, the process of debugging and testing the program added

a twist that was not anticipated when the decision to computerize the experiment was first made.

A final note on experimentation lies in the available resources. It is precisely because experimentation is a relatively new addition to the field of economics that those wishing to engage in experimentation need as complete information as possible. The following are a few indispensable resources for any economist thinking to add experimentation into their research: Davis and Holt (1993); Friedman and Sunder (1994); Plott (1982); Kagel and Roth (1995); Roth (1987, 1988, 1993); Siakantaris (2000); Smith (1989). Additionally, Vernon Smith has compiled a series of papers in economics, of which the seventh volume focuses on experimental economics (Smith, 1990). These resources helped to initiate the process of learning about experimental economics as well as developing a strategy for designing and running experiments.

4.2 Reflections on the Project

Any project to which a considerable amount of time is devoted deserves reflection. This project was embarked on for a number of reasons. No course in experimental economics currently is taught at Colby. Had there been a course, it might not have offered the opportunity to develop an experiment at this level of detail. In terms of the larger scheme, no such prospect really would present itself outside of a longer-term commitment to the world of academia (graduate studies). The researcher's level of interest in experimentation grew significantly during the course of junior year, and the ability to pursue an area of interest in this level of detail presented itself in the Senior Scholar program.

A long-term, self-directed project is the definitive form of self-education. It offers the ability to take the project in a direction that will maximize the experience. This was certainly true in the case of this project. The initial motivations for the project emerged from work with Dr. Matthew Mulford of the London School of Economics.¹ Much of this work was centered on negotiation theory but called upon economic theories as well. In an effort to not simply replicate the past work, thoughts for this project turned to economic theories encountered over the past three years. The idea of examining price differences in gas stations presented an appealing alternative to negotiation theory. After some thought, it represented an interesting application of duopoly markets. After further consideration, evidence about the market for gasoline showed that there were inconsistencies between the assumptions of duopoly theory and the observed actions of both consumers and firms. Seeing as these actions formed the underlying assumptions for the theory, it made an excellent experiment topic.

The process of developing and thinking through the experimental process offered the chance to deepen the knowledge of microeconomic and game theories. Exploring experimental economics allowed for the surveying of literature in several subfields of economics. The way game theory and experimental economics cut across many areas of economics makes one step back and realize that each are a process for considering economic events. Game theory helps to remodel economic theories using a different underlying thought process for decision-making. Though very different, experiments and econometrics are mechanisms for studying and evaluating economic models. Experimentation is a mechanism for learning about economic events rather than explaining them.

There has been a considerable amount of discussion regarding the benefits to an experimental component to economics throughout this paper. Physicists and chemists have long used experiments to test theories. Economics has long tried to accomplish as notable goals as physicists using only theories and outside evidence. The increased capabilities that experimentation brings to economics can now help to develop additional resources for testing assumptions or to supplement existing data. The end result is richer and better equipped theories.

The Senior Scholars project has presented a unique opportunity to explore experimental economics in great detail. Experimentation has been invaluable to the sciences for centuries and will now be a groundbreaking tool for economics. The process of learning about economic behavior in a laboratory environment creates the possibility for more refined, more potent economic theories. In short, the project has helped show that experimentation is a worthwhile addition to economics. Experiments in economics, as in any science, require clear, precise thinking and planning in order to develop work of value to the discipline, but it is evident that experiments provide the ability to draw new and more convincing inferences than ever possible with existing data.

Notes

- ¹ Project summarized in Mulford (2003)

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