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Raymond C. Battalio

John H. Kagel

HOUSEHOLD DEMAND RESPONSIVENESS TO PEAK USE PRICING: IMPLICATIONS DRAWN FROM EXPERIMENTAL STUDIES OF CONSUMER DEMAND BEHAVIOR OF BOTH HUMANS AND ANIMALS*

Raymond C. Battalio and John H. Kagel
Department of Economics
Texas A&M University
College Station, Texas

Abstract

The authors approach the problem of demand responsiveness to peak use pricing from the perspective of experimental economists working in the area of consumer demand behavior. Results from experiments involving both human and laboratory animal consumers are presented suggesting that wide classes of household economic activities will be quite responsive to changes in peak use pricing but that the demand for space heating and cooling will be highly inelastic without major changes in capital stocks. The reasons for these differences are discussed along with suggestions of low cost technologies for achieving greater price responsiveness in space heating and cooling demands.

1. INTRODUCTION

During the past few years public utility commissions of the United States have begun to seriously consider adopting time-of-day rate schedules for residential electricity consumers. Although the basic theoretical arguments underlying these proposals have long been familiar to economists, attempts to implement actual rate schedules based on these concepts have been hindered by the limited empirical data available upon which to base estimates of own-price elasticity of electricity demand during a 2-4 hour period and the cross-price elasticity between the different price periods within a given day. This empirical data is required for determining an economically efficient set of relative prices, determining the revenue yield of a given rate schedule and deriving the equity implications associated with any particular rate schedule.

Although determining the relevant elasticity estimates for residential electricity demand will require considerable direct empirical research, the results of previous studies examining related behaviors may prove helpful in making the pragmatic decisions required when allocating the scarce research resources during such studies. In this paper we report the results of several small scale experimental studies which we feel will be helpful in the above context. The data presented focuses on the general area of individual intertemporal reallocation of economic activity within 24 hour time periods. Individual consumer data is presented for economic activities including eating and drinking in addition to data for residential electricity consumption. This data provides some of the first direct information in the economics literature on the degree of plasticity of the intertemporal allocation of economic activities in response to changes in economic contingencies. In addition, we present data on the short-run (3-8 week period) responsiveness of total residential electricity use to

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changes in price and non-price factors. To the extent that some uses of electricity may be less substitutable than other uses within a day, e.g., space cooling or cooking during the 4-8 p.m. period compared to washing dishes or drying clothes during the 4-8 p.m. period, this data provides additional information on the likely response to a time-of-day price structure.

Given the intended goals of this paper--to present data indicating the degree of responsiveness of individual consumer behavior during daily time periods which can be used in selecting empirical research strategies (e.g., selecting experimental parameter values or sample designs)--it is not necessary to comment at length on either the "relevance" of the individual subjects used in these studies or the laboratory settings and experimental designs. Rather, we will report only those aspects of the studies relevant for our questions. Detailed discussions of the studies reported on here are available in the papers referenced.

2. CONCEPTUAL FRAMEWORK

The short-run daily temporal pattern of residential electricity consumption reflects the equilibrium adjustment of numerous, interdependent daily behavioral activities within a given environment, capital stock, prices and income. The short-run elasticity of demand for electricity during a given sub-period of the day will depend upon the degree to which total energy using behaviors are altered during the given sub-period. Assuming that an increase in the price of electricity results in a reduction in total use during a given sub-period of the day, it is useful conceptually to consider two alternative behavioral adjustments which could account for the reduction. First, specific behaviors that are electricity intensive such as drying clothes or cooking dinner could be transferred to an alternative time period and be replaced by other behaviors that are associated with less electricity use. This change in behavior would not result in very much change in total daily use of electricity. Alternatively, behavioral patterns could be altered such that the activity was still done during the high price period but the activity was changed to use less electricity, e.g., run the dryer a shorter time, schedule meal preparation to require less electricity or change the thermostat setting during this time period. These changes correspond to an overall decrease in daily electricity use.

Although observed behaviors may well reflect a combination of the above two alternatives, identifying the conditions under which either behavior dominates would greatly aid in guaging the likely impact of alternative rate structures. For example, if for a given use of electricity it can be determined that little intertemporal reallocation takes place (the second case), then previous information on the short-run own-price elasticity provides a beginning measure of the sub-period own-price response. Similarly, determining those sources of energy use that are primarily shifted to an alternative sub-period provides an initial way to determine the overall impact of the price increase during any given sub-period. That is, if we can estimate the interdependencies of particular energy using behaviors within a 24 hour period, then a composite estimate can be constructed from this micro-behavior.

3. INTERTEMPORAL REALLOCATION EXPERIMENTS

3.1 ACTIVITIES OTHER THAN ELECTRICITY

Within the economics literature little data is available describing behavioral patterns within 24 hour periods or examining the interdependencies of individual behavior within this time frame. We begin by presenting empirical data which demonstrates that an individual's daily behavioral patterns do respond to changes in economic conditions and, furthermore, these changes occur quite quickly. First we present data which examines a behavior that is spread out within a day (an animal's feeding pattern) and becomes "peaked" when economic conditions change. Second, we report data for a behavior that is initially "peaked" (an alcoholic's drinking pattern) and becomes spread out when economic conditions change. In addition to demonstrating the extreme plasticity of certain kinds of behaviors with respect to their intertemporal patterns, the experiments suggest complementary research paradigms which may be of use in studying the behavioral processes underlying responses to peak use pricing differentials.

During the past few years considerable theoretical and empirical research has been directed towards an examination of the interdependencies between an animal's behavioral patterns and the ecological niche it occupies and the habitat in which it finds itself. One aspect of this research has been to investigate the pattern of feeding shown by an animal. The data below is taken from two experiments in which the feeding pattern of male, albino, short-haired Guinea pigs was studied (4). The Guinea pig eating laboratory chow retains some characteristics of the natural feeding pattern in that it eats about 25 meals per day. The study reported on examined the effects of varying the cost of a meal on the feeding pattern, i.e., meal frequency, meal size and rate of eating.

The paradigm used first offers the animal food ad lib in the experimental situation to establish a free feeding baseline. Then, access to the feeder tunnel containing the food trough was made contingent on pressing a T-shaped lever. Once access was obtained by pressing the lever a predetermined number of times, the animal could control the duration of the meal by not leaving the food trough for more than 10 consecutive minutes. The number of lever presses required to gain access to the feeder tunnel was varied from very low rates (5-10 presses per period) to very high rates (over 2000 per access) with each lever pressing requirement remaining in effect for four days.

The results obtained show that the daily number of meals was a decreasing function in the log of the number of presses with a decline in the average number of meals taken from 25 per day at free feeding to 1 meal per day at the highest pressing rates. The reduction in meal frequency was associated with an increase in the food consumed per meal from 1.5 g. to 15 g.. The larger meal size was due to increases in both meal duration and the rate of eating. Relative to ad lib control animals, all the experimental animals maintained relatively normal growth rates throughout the first half of the experimental sequence although their food intake was declining, suggesting that feed efficiency has also changed. At ratios greater than this reductions in growth rates, relative to the ad lib control animals, were observed.

The changes in feeding behavior reported for the Guinea pig was strikingly similar to the responses of rats under similar experimental conditions. The results obtained are consistent with the general hypothesis that, in part, the ecological niche an animal occupies determines its feeding patterns (13, 14). Viewed in the more general framework of an overall daily equilibrium pattern of behavior, these data suggest that, within limits, changes in the economic parameters of an environment can result in relatively large changes in intertemporal behavior and that the animal responds quickly to these changes.

In contrast to the above "peaking" behavior introduced into eating patterns by changes in the price vector, we now present data where the original behavior occurred in a "peaked profile and the experimental changes in prices resulted in an intertemporal reallocation that spread behavior out during the day. The behavior examined is the temporal distribution of alcohol consumption for chronic alcoholics. The large social costs associated with individuals who drink too much too often have stimulated considerable research efforts directed towards an examination of the variables that control alcoholic drinking and the development of techniques to alter this pattern of behavior. The data reported is taken from one of the studies in this area in which the economic costs of drinking are altered. Though many alternative definitions have been used to describe alcoholic drinking behavior, one component of most of these definitions is that alcoholics are incapable of stopping once they have begun drinking. Indeed, alcoholics themselves often believe that they cannot stop once they have begun.

In this experiment 4 subjects, male chronic alcoholic volunteers, lived in a hospital behavior research ward (2). Volunteers were medically and psychiatrically screened. Drinks were available daily between 9 a.m. and 9 p.m., each consisting of 1 oz. of 95-proof ethanol in 2 oz. of orange juice. Drinks were purchased from the staff with tokens. At the start of each day, subjects were given a mixed number of tokens which could only be used to purchase drinks. During the control phases of the experiment the price of drinks was always 1 token per drink while during the experimental phases the price depended upon the temporal pattern of consumption. If more than 2 drinks were consumed within an hour, each additional drink cost 2 or 3 tokens each, or 2-3 times as much as the initial two drinks in the hour.* The separate experimental periods lasted between 3 and 8 days each with the total experiment lasting between 12 and 29 days.

In each case, the higher cost conditions were effective in reducing the frequency of high density, concentrated drinking. For the three subjects initially showing the greatest concentration of drinking during the control phase, the percentage of absolute interdrink intervals of 30 minutes or more between drinks was significantly increased ($P < .04$). The increased cost of "peaked" drinking patterns, in terms of less total drinks available within a given budget constraint, resulted in a significant intertemporal reallocation of drinking patterns. Given the nature of the behavior involved and the subjects' own beliefs about the degree of intertemporal substitutability these results suggest that questions about the responsiveness to peak use pricing are indeed empirical issues.

The above two experiments demonstrate that daily behavioral patterns which might, a priori, seem quite unresponsive to economic contingencies do adjust significantly when economic variables in the environment are changed. The relatively large responses obtained in the above studies are representative of a larger collection of experimental research indicating a wide range of intertemporal substitutability of behaviors in response to changes in economic contingencies (5, 6).

The experiments also suggest complementary research paradigms to use in examining responsiveness to peak use pricing differentials. First, the examination of peak use pricing responses are ideally suited to within subject designs where each subject serves as its own control and the effectiveness of an experimental intervention is evaluated through its systematic introduction and withdrawal. Such designs generally reduce the variance of response measures by removing the between subject variance, in which case one can reach a given level of statistical significance with smaller sample sizes. Second, to the extent that the intertemporal responsiveness of electricity demand to peak use pricing differentials is a particular instance of a more general behavioral process, certain elements of the process may be isolated and studied more efficiently under controlled laboratory settings in conjunction with, or prior to, large scale field studies. Such experiments can go far towards narrowing parameters for analysis and sharpening hypotheses to be investigated in field studies.

3.2 PEAK USE PRICING RESPONSIVENESS OF ELECTRICITY DEMAND

Little direct research has been reported in the literature examining the intertemporal patterns of electricity use in response to peak use pricing

*Experimental conditions for three subjects consisted of a 2 token progressive cost schedule only, while experimental conditions for the fourth subject consisted of periods with a 2 token progressive cost schedule and one period within a 3 token schedule.

differentials. However, available data is helpful in placing bounds on the range of responsiveness and in providing direct evidence on the effect of non-price variables on use in demand metering studies. We begin by describing a small scale study of peaking behavior per se. This is followed with data on changes in total use patterns which are particularly relevant where space heating and cooling demands are the dominant factors behind peaking.

Electrical energy consumption was studied over a three-month period (January thru March in Seattle, Washington) for three volunteer families using a chart recorder to record use for each 15 minute interval in the day (7). Subjects were volunteer families of middle class income each with two children and a wives' primary occupation as housewife. None of the residences were electrically heated, but each had an electric stove, a dryer, a dishwasher and an electric water heater. The main variables examined were (1) information about the implications of peaking on the local environment and information about the wattage ratings of household appliances; (2) a feedback signal actuated by peaking in the residence; and (3) feedback accompanied with a monetary incentive and further instructions both to motivate subjects and provide more information about their use patterns.

Peaking was defined as the energy consumed in a 15-minute interval that was in excess of the criterion level. The criterion level used in the study was the average of the 10 largest 15 minute use levels for each family during a two week pre-experimental (baseline) period.

The experimental sequence was divided into six two-week phases beginning with the installation of the recording device (with the window over the chart record covered) and the recording of the pre-experimental (baseline period) data. During the second two-week phase subjects were given information on the relationship between peaking and the controversial Ross Dam project and a list of 100-W lightbulb equivalents for the power ratings of household appliances. During the following two weeks a small light bulb was installed near the kitchen sink that was activated whenever total current levels exceeded 90% of the peak levels recorded in the two previous weeks. An explanation of how the light could be used in reducing peak consumption was also given. The feedback light was then disconnected for two weeks. Subjects were then informed that feedback reduced peaking, but not by very much, and were asked to make special efforts during the next two weeks to reduce peaking. In addition they were given the incentive to earn twice the amount of their two-week electricity bill if peaking could be reduced 100% compared to baseline. Proportionately smaller payments were offered for smaller reductions in peaking. The feedback light was reconnected and the cover over the recorder chart was removed and subjects were instructed how to compute peaking reductions from the chart recorder.

Information during the second two-week phase had no effect on the recorded peak use behavior. Feedback resulted in reduced peaking for each family, with a minimum reduction of 30 percent in the energy consumed above the peak criterion defined above. The removal of feedback was associated with a return to previous use patterns. The combined monetary incentive, feedback, and increased information resulted in a minimum reduction of 55 percent. The removal of the monetary incentive, disconnecting of the signal, the instructions that the subjects were free to engage in a comfortable pattern of consumption that would be representative of their future behavior resulted in behavior similar to that observed during the original two-week baseline period.

The generality of these results are, of course, limited by the sample size and the nature of the subjects participating. However, through the use of an own subject control design, the data on the effects of both feedback, in the form of a signal light, and the incentive conditions strongly suggest that peaking patterns can be significantly modified for households with comparable electricity use patterns. Interviews with the subjects at the end of the experiment indicated that the primary factors behind the reduction in peak use were changes in the times at which dishes were washed, showers were taken and clothes were dried. The fact that all three families reported the most difficulty in controlling behaviors activating the hot water heater indicates the value of current proposals to provide additional, inexpensive, capital equipment to control the cycle of electric water heaters where they are important elements of peaking. In addition, the marked reductions in peak use associated with the feedback light alone suggests the importance of non-price variables as factors in modifying peaking behavior.* The data suggests relatively large returns to investigating alternative feedback devices, and much work to be done on understanding the interaction effects between feedback mechanisms and price variables.

In the peaking study reported above, electricity was not used for controlling room temperatures and, although some changes were made in lighting, the alteration of peaking behaviors was primarily effected by an intertemporal redistribution of certain daily activities such as dishwashing, showering, etc. The experience in Europe and parts of the United States, where peaking has been primarily the result of nonspace heating and cooling factors, have all shown a fairly high responsiveness to peak use pricing differentials. Just as in the study reported above, much of this responsiveness is attributable to the relative ease with which the relevant behaviors can be redistributed intertemporally, in conjunction with the relatively inexpensive costs of maintaining large hot water storage capacities. However, in those parts of the U.S. where peaking is primarily a result of space cooling or heating demands in response to changes in weather variables (given the costs of today's technologies for maintaining a constant living temperature with significantly different energy flows) the primary response to peak use pricing differentials must come in the form of reductions in use levels rather than intertemporal reallocations. In other words, since space heating and cooling demands are not transferable intertemporally and storage costs are quite expensive, the question of peak use pricing response is in large measure dependent upon how thermostat settings will be changed during the higher price period for a given magnitude of price change and a given vector of feedback information. Although answers to this question require considerable further empirical research, some relevant data is available from short-run studies of demand responsiveness when space heating or cooling is the dominant energy use. We will survey these results below beginning with a study we conducted this past summer (1).

A sample of 129 residential electricity customers were studied during the summer months (June through August) in a southern region where typically 60-70 percent of the electricity use is for space cooling. Eighty percent of the participants owned their own residences, their median age was 42 years, median net income was between \$12,000 - \$15,000, and 90 percent of the participants were married. The study examined the effects of (1) different magnitudes of price changes, (2) weekly feedback on electricity use, and (3) information on electricity costs and conservation information.

The electric kilowatt-hour meters were read on the same day each week for 13 weeks. Each subject's experimental data was compared to their own average use during a two week pre-experimental (baseline) period. The week-to-week changes in use due to exogeneous factors, e.g., weather changes, were

*The large absolute response to the feedback lights alone could be attributed to the subjects' strong energy conservation motives as a result of subject pre-selection biases (subjects were solicited through a notice in a local conservation club newsletter). Nevertheless the impact relative to baseline and information conditions occurred under a presumably constant conservation ethic which one would expect price differentials to foster in the average consumer.

netted out, resulting in a measure of the differences in the changes in use between experimental groups. (Adjustments were also made for periods the residences were empty for 24 or more contiguous hours.)

Households were randomly assigned to one of five treatment conditions. One group was assigned to a control group condition. An information group received (1) two commercially prepared energy booklets containing conservation and kilowatt-hour use data and (2) a detailed example of instructions containing the local utility rate schedule and showing how to compute their own electric bill including fuel adjustment charges and taxes. A feedback group received the above information plus instructions on how to read their meter, and a preprinted form on which to record each week's electricity use that also contained their average use for the past summer. Also included were two types of direct feedback, (1) a copy of their meter reading each week and (2) a mailed form stating the current week's use and a percentage comparison to the past summer's use. There were two payment groups, each of which received the information and feedback on electricity use given the above two groups plus rebates for reduced electricity use relative to previous use patterns. The rebate schedules, which have roughly the same effect on the budget constraint as a Slutsky compensated price change (see (1) for details), average 240% of the marginal cost of electricity for one group and 50% of marginal cost for the other. The payment groups were informed of their earnings each week and received the payment check after the first four payment weeks.

Upper bound estimates of own-price elasticity for the rebate groups were between -0.15 and -0.08 indicating a highly inelastic short-run responsiveness to price changes (price elasticity estimates were adjusted to be comparable to the usual own-price elasticity estimates). Feedback without monetary incentives resulted in a mean decrease in use similar to the low price rebate group although the critical value was relatively large. Information alone did not result in any decrease in use. These results replicate earlier studies both with respect to the highly inelastic own-price response where space heating and cooling are the dominant source of energy use (15) and the total ineffectiveness of energy conservation information on reducing energy use (3).

The highly inelastic price responsiveness reported strongly suggests that in those parts of the country where residential space heating and cooling demands are the major contributors to peaking, that peak use pricing differentials will have a substantially smaller impact on smoothing loads than elsewhere. In addition to the fact that space heating and cooling are non-postponable in the same way that bathing and washing dishes are, residential temperatures affect all members of a household and all household activities unlike specific use behaviors which affect only a single member of the household directly e.g., in the peaking study reported here the primary adjustments in behavior were made by the wife. Consequently the introduction of low-cost capital devices, such as automatic thermostat controls, would probably aid in reaching and executing group decision to modify temperatures during peak periods. Automatic controls would also enable a decision to be made to reduce energy use during peaks well in advance of the peak. Research in psychology suggests that the introductions of such self-control devices would facilitate the actual execution of such decisions (8, 9, 10, 11). This literature also suggests some dividends from investigating alternative self-control and commitment strategies with a view to determining their cost effectiveness.

4. CONCLUSIONS

We have presented data from a number of sources which we think are relevant to the question of demand responsiveness to peak use pricing. In cases where, through simple rearrangement of time schedules and/or the availability of inexpensive home storage capacities, electricity demand is deferable over small subperiods--primarily hot water use demands--the data suggests that peak use differentials will significantly affect electricity use patterns. Further, information feedback devices have an important role to play, in conjunction with price differentials, in smoothing demand. In cases where demand for the commodity is not transferable and home storage capacities are expensive--primarily space heating and cooling demands--data from short-run elasticity studies suggest that there will be substantially less smoothing of demand on response to time-of-day pricing differentials. The data also suggest that under these circumstances attention be paid to devising optimal self-control and/or commitment devices.

The studies reported on above also presented complementary research paradigms to use in examining both the general processes underlying the response to peak use pricing differentials and in examining energy use behaviors per se. Small scale studies based on own subject control designs can be used to identify important variables and to better understand the behavioral processes in question. The pragmatic use of such small scale laboratory studies prior to, or in conjunction with, conducting relatively expensive large scale field studies is well known (12).

Biographies

Raymond C. Battalio, Associate Professor of Economics at Texas A&M University, received a B.S. degree from the University of California at Berkeley (1966) and a Ph.D. in economics from Purdue University (1970). His research is directed towards the empirical foundations of individual economic behavior and includes experimental studies using humans and laboratory animals as consumers.

John H. Kagel, was born August 28, 1942 in New York City. He received a B.A. degree in Economics from Tufts University in 1964, a Master's degree in public and international affairs from the University of Pittsburgh in 1966 and a Ph.D. in economics from Purdue University in 1970. He was an Assistant Professor of Economics at Texas A&M University from 1969 to 1975 and currently is an Associate Professor of Economics at that same university.

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