LESSONS TO BE LEARNED FROM THE LOS ANGELES RATE EXPERIMENT IN ELECTRICITY

PREPARED FOR THE LOS ANGELES DEPARTMENT OF WATER AND POWER

JAN PAUL ACTON, WILLARD G. MANNING, JR., BRIDGER M. MITCHELL

R-2113-DWP
JULY 1978
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PREFACE

This report summarizes in a nontechnical fashion the Los Angeles Electricity Rate Study, the design and analysis of which rests with The Rand Corporation. The principal focus of the study—which began in 1975 and will continue for five years—is on determining the effects of peak-load pricing of electricity on residential customers. This report discusses the policy issues underlying the study, the reason for selecting an experiment to answer some of these policy issues, the statistical methods employed in designing the study, and the expected usefulness of the results.

The study should be of interest to energy policymakers, including state and federal regulatory bodies responsible for approving electricity rate structures; officials within electric utilities who may be considering the implementation of a residential electricity experiment within their own system; and students of social experimentation who are interested in the methodology for design in implementing such a study.

Preparations for the Los Angeles Electricity Rate Study were begun in the spring of 1975, when the Los Angeles Department of Water and Power (DWP) at its own initiative sought permission to conduct an experiment with approximately 2000 households. Overall analytic responsibility for the study, including design of the experiment and analysis of the results, was given to The Rand Corporation. Rand staff members have also supervised the training of interviewers and have monitored the quality of data collection. DWP has primary responsibility for operating the experiment, including interviewing and enrolling sample households. DWP has also installed and read customers' meters, billed customers at experimental rates, and transferred data to computer files.

The study, which is partially funded by the Department of Energy, will require about five years to complete, as noted. The planning phase of the study began in the late summer of 1975. The first experimental tariffs went into effect in June 1976 and will remain in force for 30 months, during which time preliminary results will be reported.
The final analysis of the experimental data will be made when the experimental phase is concluded.

This is one of a number of Rand reports on different aspects of the electricity rate study. Related research on electricity pricing and demand is found in the following:


- **Peak-Load Pricing in Selected European Electric Utilities, R-2031-DWP, Jan Paul Acton and Bridger M. Mitchell, July 1977.**

- **Electricity Pricing and Load Management: Foreign Experience and California Opportunities, R-2106-CERCDC, Bridger M. Mitchell, Willard G. Manning, Jr., and Jan Paul Acton, March 1977.**

- **Design of the Los Angeles Peak-Load Pricing Experiment for Electricity, R-1955-DWP, Willard G. Manning, Jr., Bridger M. Mitchell, and Jan Paul Acton, November 1976.**

- **Conducting Survey Fieldwork Using Client Staff and Resources: Description of the Esseline Survey Procedures for the Los Angeles Electricity Rate Study, R-2223-DWP, Sandra H. Berry, forthcoming.**

- **The Los Angeles Senior Citizen Lifeline Electricity Rate, R-2278-DWP/NSF, Timothy Sullivan, forthcoming.**


- **Projected Nationwide Energy and Capacity Savings from Peak-Load Pricing of Electricity in the Industrial Sector, R-2179-DOE, Jan Paul Acton, Bridger M. Mitchell, and Willard G. Manning, Jr., June 1978.**
SUMMARY

The costs of supplying electricity vary by time of day, day of the week, and season of the year. The actual costs of any given electric utility system depend on the nature of its generating resources, the costs of fuels used to generate electricity, and the temporal and geographic pattern of demands for electricity by its customers. In some utility systems, peak-load conditions are associated with high fuel costs per kilowatt-hour supplied. In other utility systems, capacity constraints and the need to add new generation and distribution equipment make the total cost of meeting peak demands much higher than costs of off-peak demands. Still other utility systems display cost variations that reflect a combination of operating and capacity costs.

Current electricity rates in the United States do not generally reflect these time-of-day and peak-load cost differences, although peak-load pricing is a familiar concept in electricity pricing in a number of foreign electric utilities and has been in effect for several decades in U.S. long distance telephone rates.

If electricity customers have any price responsiveness at all, then introducing peak-load pricing will permit an electric utility to reduce both operating and capacity costs in the long run. Even if customers display very little price responsiveness, peak-load pricing promotes the generally accepted principle of rate-making that rates should be cost-based and that groups of customers whose pattern of consumption causes above-average cost to the utility system should see those cost differences reflected in their bills.

The major policy question for U.S. electric utilities, and for the public bodies that regulate their rates, is whether the benefits from introducing peak-load pricing outweigh the added metering and administrative costs of a more complicated rate structure. Most analysts feel that peak-load pricing for the largest commercial and industrial users will lead to unambiguous efficiency gains for the utility. There is considerable uncertainty about the potential gains from introducing
peak-load pricing for smaller customers, especially residential users. To judge the benefits from peak-load pricing for smaller customers, we must determine the effects of alternative electricity rates on the amount and time patterns of electricity use.

The Los Angeles Electricity Rate Study is designed to collect original information about the effects of time-of-day and seasonal rates on residential electricity use. To make the results applicable to future conditions within Los Angeles as well as to permit extrapolation to some other utility system, we chose a method of analysis based on statistical demand curves. This decision to estimate the statistical relationship between the price and quantity of electricity used—rather than to use the more traditional simple analysis of variance which answers the question, Is there an effect?—requires additional care and design of the study. We employed recent advances in experimental design to achieve the greatest expected statistical precision within a limited research budget. The Allocation Model is used to determine the proportion of households to assign to each of the experimental electricity rates. The Finite Selection Model assigns individual households to particular plans to assure balance and representativeness in each of the plans according to the quota set by the Allocation Model.

The Los Angeles Electricity Rate Study considers approximately 1800 households assigned to 1 of 40 different experimental rates for a 30-month period. Approximately 800 households are assigned to 1 of 4 seasonal or 2 flat-rate structures that range from 2¢ to 8¢ per kilowatt-hour. Approximately 1000 households are assigned to 1 of 34 different time-of-day rates. These rates apply over a peak period as short as 3 hours and as long as 12 hours. The peak charge ranges from 5¢ to 13¢ per kilowatt-hour and the off-peak charge is either 1¢ or 2¢ per kilowatt-hour.

To estimate consumer responsiveness over a range of electricity rates that may apply in future circumstances, some of these experimental rates result in an increased electricity bill to participating households. Lump sum participation payments are offered to such households prior to their joining the experiment to make them financially as well off as they would have been had they not joined the experiment. These issues
of participation payments, potential Hawthorne effects, the length of
time over which the experiment runs, and associated administrative
issues in conducting a social experiment present important challenges
to researchers in assuming the validity of results as well as observing
ethical standards with respect to participating customers.

As a result of the design of this study, the Los Angeles Elec-
tricity Rate Study can be expected to yield considerable information
about the pattern of response to peak-load pricing structures in the
household sector. The demand curves will be estimated with an expected
statistical precision that is within 13 kilowatt-hours per month of the
true value in peak and off-peak periods for the average consumer. This
amounts to a variance that is generally less than 10 percent of the
standard error of the equation. Furthermore, the variance with respect
to particularly interesting policy questions will typically be less
than 5 percent of the standard error of the equation. The results of
this analysis will be used not only to determine the effects of peak-
load pricing on residential energy use but also to analyze the potential
savings to the electric utilities in operating and capital costs from
introducing peak-load pricing for residential customers.
ACKNOWLEDGMENTS

This report has benefited from the continued interest and critical comment of several people at the Los Angeles Department of Water and Power and at Rand. Michael T. Moore, Dennis Whitney, and Harrison Call, Jr., reviewed the objectives of the study and helped assure that its initial design addressed policy questions likely to be of lasting interest to the utility industry and the city in particular. Frank Camm and Tom Glennan, Jr., made many useful suggestions on an earlier draft. The editorial assistance of Pat Bedrosian and Will Harriss also improved the earlier version. We are grateful for their assistance but assume responsibility for any errors.
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I. INTRODUCTION

A number of utility systems have already begun experimentation with one or more time-of-day rates for their residential customers. In spring 1975 the Los Angeles Department of Water and Power (DWP) at its own initiative sought the approval of its Board of Water and Power Commissioners and the Los Angeles City Council to conduct a rate experiment with approximately 2000 households using researchers at The Rand Corporation for design and analysis of the experiment. In summer 1976 the three major private utilities in California began to design peak-load rate studies and demonstrations for their residential customers in response to the orders of the California Public Utilities Commission in a generic rate case. In summer 1975 and again in summer 1976 the Federal Energy Administration (now the Department of Energy) provided partial funding for a number of demonstration projects designed to gain information about aspects of peak-load tariff design, customer reaction, and equipment that might be suitable for administering the rates or helping customers adapt to its terms.¹

With this considerable level of activity, as well as the great diversity in character of the experiment, it is useful at the outset to ask, What is the purpose of such a study and what can one expect to learn from rate experiments and demonstrations? We will address these questions in the context of the Los Angeles rate experiment, one of the most ambitious of the studies just reviewed both in scope and in statistical design. After a brief introduction we shall give an overview of its objectives, scope, and methods of procedure. We shall then consider, in separate sections, the analytical approach selected, the statistical design and choice of experimental rates, and some additional

¹As part of this program, DOE has provided partial support to the DWP rate experiment as well as the three other California rate studies mentioned above. In addition, the Energy Research and Development Administration (now DOE) has supported several demonstrations of bidirectional metering equipment which could, among other things, be used to implement a peak-load pricing scheme for electricity.
issues in experimentation. Finally, we shall conclude with some observations about the expected transferability and generality of the results.

THE POLICY ISSUE AND THE ROLE OF ELECTRICITY RATES

The electric utility industry is a major sector of the energy economy of the United States. In recent years it has accounted for approximately 26 percent of total U.S. energy consumption and over 20 percent of U.S. fossil fuel consumption. Virtually all projections of energy supply and consumption show the quantity of electricity consumed in the United States growing in absolute amount and as a proportion of all energy through the end of the century. Consequently, public policies with respect to electricity will assume an increasingly central role in energy planning.

Electricity costs depend importantly on the daily and seasonal patterns of demand. Utilities use a variety of generating resources that have different efficiencies in generating electricity. Because of the daily and seasonal variation in electricity demand, less efficient plants must sometimes be called into operation, making the cost of supplying a kilowatt-hour (kwh) vary in accordance with the peak-load conditions of the utility. The particular level of cost varies from one utility to another and depends on the generating resources available. The costs range from a fraction of a cent per kwh to several cents per kwh generated, depending on the type of fuel being employed and the nature of the generator (baseload, intermediate, or peaking plan). Furthermore, in the long run, additional aggregate generating capacity must be installed to meet the variability in demands over the daily and annual cycle. The consequence is that long-run marginal costs display an even greater variability in the combined operating and capital expenditure.

With the exception of direct rationing of electricity, changes in electric rate structures may be the most potent instrument available to policymakers for affecting both total quantity of electricity consumed and the time of day at which that electricity is used. Changes in the overall quantity consumed or in the nature of the utility's
load curve can, in turn, have a substantial impact on both the consumption of fossil fuels and the capital expansion requirements of the electricity industry.

Time-of-day and seasonal rates also support the generally accepted principle that electricity rates should be cost-based. Since the operating and capital costs vary with peak-load conditions in a utility, a rate structure incorporating this variation will more accurately track costs. Furthermore, it will serve the objective that customers pay in proportion to the cost they impose on the system. Groups of customers whose patterns of consumption cause above-average cost to the utility system will see those cost differences reflected in their bills.

Since it is not cost-free to introduce peak-load pricing, the policy issue is to compare the added efficiency and equity of more accurate pricing with the increased administrative and metering costs of more complicated rates. Most analysts feel that peak-load pricing can be beneficially introduced for the very largest customers. Even minute changes in their patterns of consumption will lead to efficiency gains that easily offset the costs of even very elaborate pricing schemes. For medium-sized and smaller customers, added information is needed on the cost of implementation, the degree of customer responsiveness to peak-load rates, and the reduced capital and operating costs to the utility from such a change in customer behavior.

Several recent cases before public utility commissions provide evidence of increased interest in altering electricity rate structures in the United States. These include generic rate cases in California, New York, Michigan, Connecticut, New Jersey, Massachusetts, and Florida as well as specific cases in Wisconsin, California, Massachusetts, and New York. The theme of these cases and their findings has almost always included the following points: Marginal costs should be taken into account in the design of electricity rates; time-of-day tariffs should be applied to the largest industrial and commercial customers as rapidly as feasible; consideration should be given to extending time-of-day rates to intermediate-sized commercial and industrial customers in the near future, and suitable metering capability should be installed immediately; and additional study is needed to determine if time-of-day
or seasonal tariffs will ever be beneficially offered to residential customers.

OBJECTIVES

The principal objective of the study is to examine the effects and desirability of alternative electricity rate structures for residential customers. Almost without exception, current U.S. electric utility rates are based on a declining block rate structure in which customers pay less per kilowatt-hour consumed as they use more. Much has changed since these conventional rate structures were developed, and four of these changes in particular prompt a reexamination of the theory and practice of rate setting. First, the high cost and shortages of fossil fuels require a reexamination of the rate structure. Many utilities have seen the costs of their fuel inputs double or triple in recent years and this has made their mix of generation facilities economically obsolete. Second, the assumption of declining long-run incremental costs in electricity that fostered the use of declining block tariffs appears to be no longer justified. In particular, most large public utilities no longer appear to enjoy economies of scale in generation and transmission, at least beyond a point well below the capacity of the system. Third, increased capital costs, delays in construction and licensing of new plants, and environmental costs may all affect the prices that should be charged for electricity. Finally, in a period of increased energy awareness and concern for prudent use of these resources, any rate structure that appears to reward greater consumption with quantity discounts is suspect. Although such a rate may have been justified under earlier circumstances, the present national awareness of energy shortages and changes in the underlying economics of energy supply mean that electricity rates should be reviewed to assure that they are consistent with other national energy policy objectives.

Most economists think that some form of peak-load pricing is the most attractive alternative to existing rate structures. It is an old

\(^2\) See, for examples, Christensen and Greene (1976) and Nerlove (1963).
concept in economic theory, but one that has been almost totally
neglected in U.S. tariff design. The major questions in the design
and analysis of peak-load tariffs concern the calculation of marginal
costs on which peak-load rates would be based and the quantitative
prediction of the changes in the amount and time pattern of electricity
consumption that will result from alternative tariffs. Although con-
siderable work remains to be done to have good estimates of marginal
costs for different U.S. utilities, there is a substantial body of
European writing and experience to draw upon. We will concentrate
our discussion on measuring the demand response to peak-load tariffs.

From a policy perspective, the decision to adopt or reject a peak-
load tariff for a particular utility presents a problem in benefit-
cost analysis. To assess the potential benefit of various rate struc-
tures, it is necessary to analyze data on the sensitivity of individual
demand to changes in the rate structure and the amount of substitution
that takes place between one time period and another or from one form
of fuel consumption to another. Any shift in electricity usage away
from peak periods will permit savings in fuel costs (because the most
fuel-costly units are employed to meet peak demand) and may permit
capital savings as well (shifts away from peak periods lessen the need
for new plant capacity and permit more efficient baseload plants to be
constructed to meet additional capacity requirements). Any savings in
capital and operating expenses that result from changes in consumption
patterns must then be compared with the costs of more complex metering
of electricity use; further, potential savings must be weighed against
the problems of implementation and administrative feasibility of these
alternative rate structures and against changes in consumer welfare.
Depending on the magnitudes of these costs and benefits, significant
overall social gains may be achieved by adopting one of the alternative
rate structures. Conversely, if there is little behavioral response
to an alternative rate structure, then a simple rate structure is

3See, for instance, Steiner (1957), Hirschleifer (1958), William-
son (1966), Bailey (1973), Panzar (1976), and the selection of articles
in Nelson (1964).

4See Nelson (1964), Turvey (1968), Mitchell and Acton (1977), and
Mitchell, Manning, and Acton (1978).
likely to be socially least costly. Only a demonstration of the
effects of alternative rates will illuminate the matter and form a
basis for policy.

Given the need to address such a fundamental question of benefit-
cost comparison, some basic quantitative measures must be provided.
Thus, the principal objectives of the Los Angeles project are:

- To identify alternative electricity rate structures that may
  be superior to the rate structures currently in use by U.S.
  utilities.
- To demonstrate and measure the changes in energy consumption
  of a representative sample of customers in response to these
  alternative rates—adjusting for the effects of other vari-
  ables affecting energy demand.
- To analyze the distribution of the impacts among different
  types of customers, including changes in consumption of and
  expenditures for electricity by age, income, family size,
  housing type, appliance ownership, and other important house-
  hold characteristics.
- To determine the administrative, technical, and economic
  feasibility of these alternative structures.
- To estimate total energy use as well as the efficiency of
  energy use resulting from the alternative rate structures.
- To estimate savings in operating costs (especially fossil
  fuels) and changes in capital costs that could be expected
  from systemwide adoption of alternative rate structures and
to project these savings to different utilities with specified
generating systems and customer profiles.

A major objective of this project is to ensure that the experi-
mental tariffs and the plan of analysis are sufficiently general that
the results will be applicable not only to the current cost structure
of the Los Angeles Department of Water and Power but also to a wide
variety of plausible conditions of electricity supply, including future
cost increases and peak-load conditions found in other utilities. The
importance of such flexibility can be seen, for one, in the major and unexpected change in world oil prices in 1973-74 as well as in the current uncertainty regarding the cost and availability of nuclear power in the United States.

WHY HAVE AN EXPERIMENT?

Two methods of obtaining new data are potentially available. A utility may simply adopt a new rate schedule for an entire class of customers in its service area. In this case a single experimental tariff can be tested and its effects measured by analysis of the before-and-after variety, adjusting, where possible, for concurrent changes in circumstances. The alternative is to introduce a number of different rate schedules for a selected sample of customers while maintaining the current rate schedule for most other customers. We chose the experimental approach to obtain new residential data for a number of reasons. 5

The first, and principal, reason for applying peak-load rates to only a fraction of residential customers is that there is considerable uncertainty about customer response. Because there is so little U.S. evidence upon which to base a judgment, applying a full-scale time-of-day (or other peak-load) tariff to all customers of a utility could be a costly error if the savings in capital and operating expenses did not offset the metering and other expenses. 6 Second, if a single peak-load tariff were offered to residential customers as an optional alternative to their present rate structure, we would encounter a selection bias in the observed response. Generally speaking, only those customers who would expect to be better off under the peak-load rate structure would select it. Consequently, we would have no evidence upon which to base an estimate of the quantitative response by other customers.

5 In a related aspect of the study, we expect to observe the pattern of electricity use among the largest industrial and commercial customers after a single time-of-day tariff is put into effect.

6 The capital expense for installing the simplest time-of-day meter to DWP's 940,000 residential customers is estimated to be between $100 million and $200 million.
should the tariff be extended on a mandatory basis. Third, the experimental approach allows us to observe the effects of several different tariffs instead of the effect of a single alternative. This not only permits cost-benefit analysis over a range of options, but also provides information that may permit fine-tuning at a future time of any tariff adopted as a result of the initial test.

OVERVIEW OF THE LOS ANGELES EXPERIMENT

In the next three sections, we discuss the methodological and statistical considerations that led to the specific set of tariffs in the L.A. experiment and the assignment of particular households to individual tariffs. The experiment consists of approximately 1800 households assigned to 1 of 40 different experimental rates for a 30-month period. An additional 400 households were selected for interview and observation as a control group. Because of somewhat different (although related) analytic issues, the experiment was divided into three groups: one for seasonal rates, one for time-of-day rates, and a control group on the current DWP declining block rate structure.

Approximately 800 households within the City of Los Angeles were assigned to one of the seasonal and flat rates, which ranged from 2¢ per kwh to 8¢ per kwh. The peak season charge applied to either a four-month summer period (June through September) or an eight-month winter period, and all rates were in effect at all hours, seven days per week. Approximately 1000 households were assigned to one of the time-of-day rates. These applied to peak periods as short as 3 hours and as long as 12 hours. The peak-period charge ranged from 5¢ to 13¢ per kwh and the off-peak charge was either 1¢ or 2¢ per kwh. In our design of the experiment, we selected 17 different combinations of peak/off-peak charges for maximum expected statistical significance. Since

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7 On the other hand, if we were certain that the tariff would only be offered as an optional rate, it would not be a disadvantage to permit such self-selection.

8 This point is developed further in the next section, where we discuss the use of a statistical design based on demand curve analysis in preference to the more traditional analysis of variance approach.
we were also interested in the effect of a weekend exemption from peak charges, half of the subjects under each rate were assigned to a tariff with a peak charge that applied five days per week, the other half to a peak charge applied seven days per week. This made the effective number of time-of-day tariffs 34.

The first experimental electricity rates took effect in June 1976 and the last of the principal enrollments had effective dates of December 1976. These households will be observed for a 30-month period on either time-of-day or seasonal or flat electricity rates. To increase our understanding of the specific details of individual household adaptation to time-of-day rates, we conduct surveys with participating households at three points during the study. Prior to enrollment of any household (and before the household is informed that an experimental rate may be offered) a baseline survey was administered. That survey, which took approximately half an hour to administer, gathered detailed information on the socioeconomic characteristics of the household, including its income, education, and family composition; the household size and type of housing; principal energy-using appliances owned, by fuel type and age of the appliance; and the work habits of participating household members (including whether an adult is normally in the house during weekday hours). In addition to this baseline survey, approximately halfway through the experiment all households will be interviewed to observe any changes in these variables, especially changes in appliance ownership, work habits, or in family composition. We will also ask some questions on family members' attitudes toward the experimental electricity rate. At the end of the experiment, all household members will be interviewed to determine their satisfaction with the experimental rate and to learn of any changes in important variables that took place since the mid-project survey. The dependent variable in the study is the amount of electricity used during different hours or seasons of the year. For all households on time-of-day rates as well as 20 percent of the households on seasonal or flat rates, consumption is measured with continuous recording tape cassette meters. In the remaining households, consumption is recorded using conventional electricity meters that show the total amount of electricity used in a given month.
II. ANALYTICAL APPROACH

Since a primary goal of the experiment was to provide general information about the nature of consumer responses to alternative tariff structures, greatest emphasis was placed on determining the underlying parameters that influence the quantity and time patterns of electricity consumption. Statistical design procedures developed in a number of recent social experiments in income maintenance and health insurance were used for the study. To gain the most useful information from the experiment, we must first identify the policy questions of greatest interest and then select an analytical approach that will yield the most precise information (with minimum statistical variance) about the policy questions. In our case, this essentially required choosing between an approach based on analysis of variance (ANOVA) and one based on demand curves. Since we found the demand curve approach more suitable, we then had to identify the basic structure of the demand relationships to be estimated.

POLICY QUESTIONS

Primary emphasis in the experiment was given to answering the following policy questions:

- Under time-of-day tariffs what is the magnitude of the change in quantity of electricity used in each time period (the load curve) and how does this response depend on (a) the length of the peak-price period and (b) the levels of the peak and off-peak prices?
- Under seasonal tariffs, is there a statistically significant difference in seasonal loads as compared with conventional tariffs?
- Under all types of tariffs, what is the level of load as a function of the level of the rates in the tariff?

1This section and the next on statistical design are deliberately nontechnical. A more rigorous treatment is provided in Manning, Mitchell, and Acton (1976).
Answers to the first policy question are necessary in order to perform a benefit-cost comparison for alternative tariffs. We need to measure the changes in customer well-being (as expressed in consumers' willingness to pay for differing quantities of electricity at various prices) and changes in the utility's economic circumstances (as measured by its costs and revenues) and to compare these changes with the added administrative and metering costs of a new tariff. These measures are more technically expressed as changes in "customers' surplus" and "producers' surplus," which form the basis for assessing economic welfare. Calculation of these changes when prices of several related services are changed required knowledge of the change in usage in both the peak and off-peak periods. It also requires a knowledge of increases or decreases in the consumption of alternative fuels such as natural gas. The first design objective was, therefore, to obtain reliable measures of changes in usage by period under a time-of-day tariff.

A closely related objective in designing the experiment is to measure the sensitivity of consumer response to the length of time that the peak price is in effect under a time-of-day rate. Given both uncertainties about the degree of shifting that customers can undertake in their patterns of consumption and uncertainties about the length of time that marginal costs are at their peak for a particular utility, it is necessary to examine the effects of varying the length of the peak period.

Seasonal tariffs, in which the peak period lasts for several months, can be implemented with existing residential meters and with only minor changes in billing and meter-reading procedures. The major policy objective with respect to seasonal tariffs, therefore, is not to establish the precise magnitude of change, but to determine whether there would be any significant effect of raising the price per kilowatt-hour for several months at a time and lowering it during the rest of the year, compared with maintaining a uniform year-around price. If consumers respond to seasonal variations in prices by lowering use when prices

\textsuperscript{2}See Harberger (1971), Turvey (1968), and Besen and Mitchell (1975).
are higher, this form of peak-load pricing will necessarily result in a net welfare gain, since there are no important costs of converting to such a rate structure.\(^3\)

The third policy objective centered on the need for reliable forecasts of the levels of loads during all periods under both conventional and peak-load rate structures. Both investment planning for capacity expansion and the design of a particular peak-load rate structure that will recover historical costs require accurate predictions of load by time period.

**ANALYSIS OF VARIANCE VERSUS A DEMAND CURVE APPROACH**

Choosing between an approach based on analysis of variance (ANOVA) and one based on demand curves is essentially a matter of deciding where one wishes to have the most precision and confidence in interpretation. If one is most interested in detecting the existence of an effect, then an ANOVA model is most suitable. If one is interested in determining the quantitative relationship between different levels of peak and off-peak prices and the quantity of electricity consumed in each time period, then a demand curve approach is more suitable.

In attempting to determine the existence of a response, the simple ANOVA approach directs us to select a single alternative peak-load tariff with a very high peak price and a very low off-peak price. The observed response to this single alternative tariff is then compared to the pattern of consumption in a control group. For any given amount of resources devoted to the experiment, the single experimental and control group can have a larger number of subjects than is possible in a study with several experimental plans. Since the variance (or standard error) of measured response to any experimental rate varies inversely with sample size, the result of this ANOVA assignment is to measure with greater precision the simple existence of an effect than is possible in a multiplan experiment.

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\(^3\) Of course, for distributional reasons it may be desirable to have seasonal tariffs that reflect variations in marginal costs even if no efficiency gains result. Since seasonal tariffs represent a likely gain over existing electricity rates in many circumstances, the additional gain of time-of-day pricing should be measured against the yardstick of seasonal tariffs in those circumstances. See Wenders (1976).
We can illustrate the strength (and some of the limitations) of this approach with an example. Suppose the current rate charges about 3¢ per kWh at all hours and that our alternative peak-load rate had been set at 7¢ per kWh from noon to 6 p.m. and at 2¢ per kWh at all other hours. Suppose that control households were observed to consume, on average, about 200 kWh per month during the hours noon to 6 p.m., and experimental households consumed an average of 160 kWh during those hours. If the difference is statistically significant (this will depend on sample size), then we could conclude that this particular time-of-day rate reduces peak consumption by about 20 percent for this sample.

We are sharply limited, however, in our ability to answer other questions about the effect of peak-load tariffs that might be of major policy interest. First, we cannot extrapolate these findings to other tariffs with very much confidence, because we do not know the shape of the response surface or which price effect drives the response. For example, instead of 7¢ and 2¢, the analyst or policymaker may wish to know the effects of a rate that charged 5¢ on peak and 3¢ during off-peak hours. Unless he makes the strong assumption that behavioral response is strictly proportional to peak period price, the effect of an alternative tariff cannot be estimated. Second, this ANOVA single tariff comparison does not permit us to identify separately the effects of peak and off-peak charges. Is the observed drop during peak hours due to the elevated level of peak price, or is it due to the reduced level of off-peak charges? Such information is crucial if we are to be able to judge the effects of still another tariff.

To a limited degree, these objectives can be partially overcome by permitting more experimental tariffs to be used in the ANOVA design. Additional tariffs can be employed to identify the effects of off-peak rates for different levels of on-peak price. An additional set of options can be introduced to determine the effect of length or location of the peak time period. But it is much more difficult, in both statistical precision and in ease of comprehension and information processing, to employ a fundamentally different procedure based on demand curves. Since the principal analytic problem is generally to determine
the effect of different variables, or underlying factors, that contribute to different behavioral responses, it is better consciously to design the study to elicit those parameters at the outset. Once measured, those parameters can be used to calculate the effects of a variety of different tariffs. We drew additional support for our demand curve approach from the practical experience of the Electricity Council of London. After they had conducted their ANOVA experiment, the British peak-load experimenters reached the conclusion that

With the aid of hindsight, the experiment might have been better directed to a more primitive problem. What are the price elasticities and cross elasticities of electricity demand by time-of-day, day-of-week and season-of-year? Such primitive, component information could be patched together to form views of the effectiveness of composite price structures without having settled those beforehand by somewhat arbitrary judgement.4

MODEL FOR DEMAND ANALYSIS

Once it was decided to employ demand curves, the nature of the demand equations that would be estimated had to be identified. Although statistical design can take place without an exact knowledge of the specification of the equations, the more information one has about specification, the better one is able to select a set of experimental tariffs to maximize expected statistical significance. In this section, we shall sketch briefly, and in nontechnical terms, the nature of the model underlying our analysis. The actual design was done in a manner that is not very sensitive to changes in exact specification over a range of alternatives. We experimented with several specifications to determine whether the resulting allocations were sensitive to specification of the form of the demand curve. The allocations finally chosen were very robust over a set of likely final specifications of the functional form of the demand response.

Synthetic Demand Curves

In the traditional ANOVA approach, the effects of an experimental

*See Boggis (1975).
tariff are compared with the effects of a control group. In many applications of demand curve analysis, a similar comparison is implicitly made, as researchers compare parameters estimated from a demand curve under one particular experimental tariff (for example, a peak charge from noon until 6 p.m. with different values of peak and off-peak prices) with parameters of a demand curve estimated for the control group. We can increase the effective sample size (and therefore increase the precision of the estimates) by pooling the entire sample across all types of tariffs under observation (for example, those with a peak charge from 9 a.m. to 3 p.m. can also be included in the analysis). This pooling is made possible by considering the entire pattern of demand under observation, not just one aspect, such as on-peak consumption or total kilowatt-hours consumed.

If the day is divided into three-hour blocks of time (9 a.m. to noon, noon to 3 p.m., 3 p.m. to 6 p.m., and 6 p.m. to 9 p.m.) in addition to the night hours (9 p.m. to 9 a.m.), we can consider all time periods simultaneously. Ignoring for the moment factors other than price that may affect consumption, the amount of electricity consumed in any one period is determined by the price in that time period and the prices in all other periods. In economic terms, consumption in any one period can be predicted as a function of different values of own and cross-prices.

The practical import of this specification is to increase substantially the effective number of households for purposes of estimating patterns of demand in any single time period. Once we have estimated the effect of each period's price on quantity demanded in each time period (for example, the effect on consumption between 9 a.m. and noon of prices in each of the four three-hour periods and the period 9 p.m. to 9 a.m.), we can estimate the effect of a large range of peak and off-peak combinations, including combinations not explicitly observed in the experiment. We have designated this approach synthetic demand curves because we can synthesize the effects of any particular tariff by using the parameter estimates for separate time periods as building blocks.
Price-Length Interactions

As noted above, we were interested not only in the effects of peak and off-peak prices, but also in the length of time over which the peak charge applies. This is not only of intrinsic interest for policy analysis, but also is crucial to our synthetic demand curve approach. Consider the expected customer response to a peak charge from noon to 3 p.m. We expect that the amount of electricity consumed during those hours may depend not only on the level of price in the preceding and following three-hour period, but also on whether all three (or two of the three) periods are at the peak rate. This requires that we be prepared to analyze the separate effect of length of peak charge as well as level of peak and off-peak prices.

General Principles of Design

To further support our overall objective in addressing the primary policy questions articulated above, three additional principles of design are important to assure that the data set is robust: achieving a spread of experimental design points, allowing for nonlinear responses, and treating correctly other factors that may influence the pattern or level of energy consumption.

It is important to achieve a reasonably large spread in the values of experimental treatments. From a statistical viewpoint, we obtain more precise (lower variance) estimates of the effect of price by spreading the prices in the experimental tariffs. Suppose we were especially interested in knowing the effect of on-peak charges in the range 4¢ to 6¢ per kwh. We could assign individual subjects to the values 4¢ and 6¢ for experimental study. Since actual consumption will result in a scatter of points at each level of price, the observed pattern will be something like the dots in Fig. 1A. Because of variability in individual responses or the luck of the particular statistical sample drawn,

5 It is impossible to know in advance what the net effect of these factors will be. On the one hand, peak prices in adjacent periods make it less likely that an individual will be able to shift energy use a few hours to take advantage of off-peak prices. On the other hand, a long peak-charge period makes it more worthwhile to purchase certain types of equipment (such as timers for large-capacity water heaters) that could shift a major portion of energy use to an off-peak period.
the demand curve actually estimated in a particular experiment may vary substantially from the true relationship between price and quantity (shown as the solid line). We have indicated two possible demand curves that might be estimated by the broken lines labeled 1 and 2. If, on the other hand, we selected more extreme values, say 3c and 10c for the peak charge (Fig. 1B), we would have considerably lower expected variance in the price parameter—in the range of interest (4c to 6c) as well as outside of that range of interest. Of course, one does not generally wish to select values of peak/off-peak prices that are too extreme, for to do so could increase substantially the cost per observation, increase participant refusal, or be too far removed from realistic policy alternatives to be of interest for judging other aspects of customer reaction. In the next section we will systematically consider how much variability is optimal from a design perspective.

We also wish to allow for the possibility that customers do not respond in a linear manner to changes in price levels. Generally speaking, to detect curvature in the demand relationship, we must observe at least three different levels of price. Figure 2 illustrates a possible demand response with curvature (line 1) that would not be detected if we observed only individuals billed for 3c and 10c (line 2). To assure detecting nonlinear relationships between price and quantity, we
generally require three or more price levels for a given type of experimental rate (e.g., peak price applies from noon to 6 p.m.).

The third design consideration is to assure that other factors that may be expected to affect demand are not systematically associated with some feature of the experiment. For example, if income or ownership of electric water heaters were found in certain experimental plans but were absent in others, then the experiment would contain a built-in bias that would be impossible to disentangle from the experimental rates. To avoid this we imposed a balance criterion on the assignment of individuals to experimental design points. That is, individuals are assigned to each of the experimental plans in a manner that ensures that the nonprice characteristics of the individuals are proportionately represented on all plans.
III. STATISTICAL DESIGN AND CHOICE OF EXPERIMENTAL RATES

A rate study of the type considered here is a costly undertaking and requires careful planning to yield the greatest possible information. Because project resources are limited and observations are costly, we had to select carefully the number and types of households for participation. The problem was exacerbated by the fact that, generally speaking, the very things discussed in the last section as being most desirable from the viewpoint of analysis—greater numbers of observations and spread in design points—tend to be the most costly to achieve. The problem then is to design the study in a manner to maximize statistical significance and relevance of the results, taking into account the cost of each observation and the overall budget constraint. ¹

Broadly speaking, our procedure was to separate the statistical design problem into two parts: selection of the optimal set of experimental tariffs and the number of households assigned to each tariff, and assignment of specific individuals to particular experimental plans in accordance with the quotas determined in the first step. The first step made use of an Allocation Model, adopted from the pioneering work of Conlisk and Watts (1969) in the design of the first income maintenance experiment in New Jersey. The second step makes use of the Finite Selection Model, developed by Morris (1975) for use in the Health Insurance Study now under way at six sites throughout the country.

THE ALLOCATION MODEL

The Allocation Model was used to select the test set of experimental tariffs (combinations of peak/off-peak rates and length of peak—called design points in the experimental literature) and to determine the optimal number of households for each design point subject to an overall

¹The importance of careful design is indicated by the magnitude of expense involved. The five-year British experiment cost more than $3 million. The overall cost of the L.A. experiment is expected to be on the order of $5 million over a five-year period. During that time, almost 7000 household interviews will be conducted and about $360,000 will be used to purchase and install new meters.
budget constraint. The basic procedure was to: (1) specify the
types of analytic equations to be estimated; (2) assign weights to
the different parameters of this set of equations to reflect the
relative importance for policy analysis of the parameters to be esti-
mated; (3) to identify the cost per observation on each of the dif-
ferent design points; and (4) then to select the set of observations
that would give the maximum weighted statistical significance within
the overall budget constraint available for the experiment. We dis-
cussed in the last section the type of analytic model upon which the
estimating equations were based. The remaining inputs needed for the
Allocation Model were a set of permissible design points, a set of
weights for the policy parameters of interest, and a measure of the
cost of each observation on each potential design point.

The selection of permissible design points is most interesting
for present discussion. The Allocation Model starts with a large
initial set of potential design points and then determines a smaller
optimal set. We deliberately chose a wide range of potential peak/
off-peak price combinations that are more extreme than may be ap-
propriate for DWP's situation at this moment. This was done for statis-
tical precision as well as to make the results applicable to future
DWP circumstances or to those of other utilities.

At the time the study was designed, we were guided by current
operating conditions in DWP as well as possible changes that may take
place in capital and fuel costs. At that time, the average variable
cost of producing electricity was sometimes as low as 1¢ per kwh. The
short-run marginal cost, however, ranged between approximately 2¢ and

2The Allocation Model can also be used to determine optimal design
points also identified by nontariff characteristics (such as income or
appliance ownership). We did not use the Allocation Model for this
task because (a) costs per observation do not depend significantly on
such factors and (b) we were interested in the effects of these factors
only to study tariff effects, a secondary matter. Consequently, we
use the Finite Selection Model to achieve balance in these nontariff
dimensions and to assure that they are not correlated with any plan
characteristic.

3The other two types of inputs—a set of policy weights and a mea-
ure of costs per observation—are discussed in detail in Manning,
Mitchell, and Acton (1976).
3.5¢ per kwh, depending on the hour of day and season of use. In DWP's configuration at that time, assigning capital costs sufficient to meet total revenue requirements adds between 1¢ and 2¢ per kwh to peak-period prices. Thus, a peak-load tariff currently might have an off-peak rate as low as 1¢ per kwh and a peak rate as high as 5.5¢ per kwh.

When we consider possible costs of supply five years from initiation of the study (when tariffs based on the results of this experiment might be in effect), peak costs may be even higher. If the price of natural gas is decontrolled, the short-run marginal cost at peak hours might well be in excess of 10¢ per kwh—not counting any charge for capital expenditures.

The experiment consists of two types of peak-period tariffs: seasonal rates and time-of-day rates. Although the designs of the two aspects were coordinated, the two types of tariffs can be considered separately for the present discussion. In addition, using the existing

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4 In addition to setting price equal to short-run marginal costs in each time period, peak-load pricing rules also assign to peak users part or all of additional revenue requirements to cover capital expenditures. See Panzar for a discussion of different circumstances for determining how much capital to assign to peak and off-peak users.

5 A committee representing business, labor, consumer advocates, DWP officials, and energy researchers (including one of the present authors, Acton) completed in April 1977 an 18-month study on water and power rate structures for Los Angeles. It recommended time-of-day electricity rates for large commercial and industrial customers of about 4¢ per kwh during peak hours (designated as noon to 8 p.m., Monday through Friday) and 2.3¢ per kwh during off-peak hours. It recommended extending these rates (with minor markup to reflect the added costs of voltage losses and additional distributing equipment) to the 5000 largest commercial and industrial customers as rapidly as suitable metering could be installed. The Committee recommended that all customers not covered by time-of-day rates pay for electricity on a flat-rate schedule (replacing the current declining block rate structure) and that further consideration of time-of-day pricing for residential customers await the results of this residential rate experiment. See the Mayor's Blue Ribbon Committee Report on DWP Rate Structure (1977).

6 Gas turbines provide the peaking capacity for many U.S. utilities. They have an operating cost of about 5¢ per kwh at current, controlled prices of natural gas. Most analysts feel that the price of natural gas would go up by at least a factor of two if it were decontrolled; see MacAvoy and Pindyck (1973).
declining block tariff (which charges about 4¢ per kwh for a majority of households observed) for control subjects, we included four flat rates and thirteen seasonal rates. Table 1 gives the terms of tariffs that were available for selection by the Allocation Model. All seasonal tariffs were broken into a summer period (June through September) and a winter period (the remaining 8 months). Note that tariffs that charge a higher amount in winter than in summer were allowed. Although DWP's current cost structure indicates a greater price in the summer, this reversal was included for generality as well as statistical significance. If we had excluded winter peak tariffs, a substantial increase in sample size would have been required to achieve the same expected degree of statistical significance in measuring the effect of changing winter as well as summer prices.

The results of the Allocation Model assignments for seasonal and flat tariffs are shown in Table 2. In addition to the 400 households on existing tariffs (labeled controls), two tariffs with flat rates of 2¢ or 5¢ per kwh at all times were selected. These households effectively served as controls for all experimental plans in the conventional ANOVA sense. The remaining rates served to estimate the demand curve by identifying the "end points" and the curvature of demand responses.

The potential set of time-of-day rates was greater because there were more parameters of interest to be estimated (level of peak/off-peak prices, location of peak period, and length of peak period). The day was divided into four three-hour periods plus one twelve-hour night period. We permitted off-peak rates of 1¢, 2¢, or 3¢ per kwh and peak prices of 4¢, 5¢, 7¢, 9¢, 11¢, and 13¢ per kwh. The length of peak rate could vary from three to twelve hours. Forty-seven tariffs were potentially available for selection; their values are shown in Table 3. Seventeen tariffs were selected by the Allocation Model, and plans selected are shown in Table 4. To measure the effect of off-peak pricing on the weekend, we selected one-half of the subjects on each plan to pay the peak price for the five week days and one-half to pay the peak price seven days per week. Therefore, the actual number of time-of-day plans under observation was 34.
Table 1

POTENTIAL SET OF SEASONAL AND FLAT TARIFFS
(In $/kwh)

<table>
<thead>
<tr>
<th>Experimental Declining Block</th>
<th>Seasonal Tariffs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls Flats</td>
<td>Summer</td>
</tr>
<tr>
<td>4^a</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

^aAverage charge from a declining block tariff.

Table 2

SEASONAL FLAT TARIFFS SELECTED BY THE ALLOCATION MODEL

<table>
<thead>
<tr>
<th>Tariff</th>
<th>Number per Plan (rounded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Winter</td>
</tr>
<tr>
<td>Controls</td>
<td>400</td>
</tr>
<tr>
<td>2 (flat)</td>
<td>350</td>
</tr>
<tr>
<td>5 (flat)</td>
<td>110</td>
</tr>
<tr>
<td>5</td>
<td>140</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>1220</td>
</tr>
</tbody>
</table>
Table 3

SET OF POTENTIAL TIME-OF-DAY TARIFFS

<table>
<thead>
<tr>
<th>Peak Period</th>
<th>Peak/Off-Peak Prices (c/kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 a.m.–noon</td>
<td>11/3, 5/3, 13/2, 9/2, 5/2</td>
</tr>
<tr>
<td>Noon–3 p.m.</td>
<td>11/3, 5/3, 13/2, 9/2, 5/2</td>
</tr>
<tr>
<td>3 p.m.–6 p.m.</td>
<td>11/3, 9/3, 5/3, 13/2, 9/2, 5/2</td>
</tr>
<tr>
<td>6 p.m.–9 p.m.</td>
<td>11/3, 9/3, 5/3, 13/2, 9/2, 5/2</td>
</tr>
<tr>
<td>9 a.m.–3 p.m.</td>
<td>5/3, 13/2, 9/2, 7/2, 5/2</td>
</tr>
<tr>
<td>3 p.m.–9 p.m.</td>
<td>5/3, 13/2, 9/2, 7/2, 5/2</td>
</tr>
<tr>
<td>Noon–9 p.m.</td>
<td>5/3, 4/3, 7/2, 9/1, 5/1</td>
</tr>
<tr>
<td>9 a.m.–9 p.m.</td>
<td>5/3, 4/3, 7/2, 9/1, 5/1</td>
</tr>
<tr>
<td>9 p.m.–9 a.m.</td>
<td>11/3, 5/3, 13/2, 9/2, 5/2</td>
</tr>
</tbody>
</table>

Table 4

TIME-OF-DAY TARIFFS SELECTED BY THE ALLOCATION MODEL

<table>
<thead>
<tr>
<th>Peak Period</th>
<th>Peak/Off-Peak Price (c/kwh)</th>
<th>Number per Plan (rounded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 a.m.–noon</td>
<td>5/2</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>9/2</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>13/2</td>
<td>20</td>
</tr>
<tr>
<td>Noon–3 p.m.</td>
<td>9/2</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>13/2</td>
<td>20</td>
</tr>
<tr>
<td>3 p.m.–6 p.m.</td>
<td>5/2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>9/2</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>13/2</td>
<td>80</td>
</tr>
<tr>
<td>6 p.m.–9 p.m.</td>
<td>5/2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>9/2</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>13/2</td>
<td>60</td>
</tr>
<tr>
<td>3 p.m.–9 p.m.</td>
<td>7/2</td>
<td>40</td>
</tr>
<tr>
<td>Noon–9 p.m.</td>
<td>5/1</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>9/1</td>
<td>20</td>
</tr>
<tr>
<td>9 a.m.–9 p.m.</td>
<td>5/1</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>9/1</td>
<td>80</td>
</tr>
<tr>
<td>9 p.m.–9 a.m.</td>
<td></td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>980</td>
</tr>
</tbody>
</table>
The results of the Allocation Model choices for time-of-day rates were broadly similar to the results for seasonal rates. Plans with extreme values of peak or off-peak prices were selected to reduce variance (although the high cost of the former meant that relatively few households were assigned to them), and tariffs with intermediate values were selected to detect curvature. Again, one plan was selected with a reversed set of rates—a peak rate between the hours of 9 p.m. and 9 a.m. Although this is the least costly time period for DWP to supply electricity, the inclusion of this overnight rate produces an increase in statistical precision on the effect of the response to the overnight price.

FINITE SELECTION MODEL

The Finite Selection Model is used to achieve two desirable features of sample selection that cannot be achieved practically with the Allocation Model: statistical balance and the identification of particular households to be enrolled in the study. The Finite Selection Model works in a manner similar to the Allocation Model. A large number of households are potential candidates for selection, and the Finite Selection Model chooses a fraction of them for assignment to tariffs selected by the Allocation Model. Balance is achieved by assuring that household characteristics that would be expected to influence the pattern of electricity use are proportionately represented in each plan. The Finite Selection Model selects households with different values of income, appliance ownership, housing characteristics, and ethnicity so that none of these factors is systematically associated with any feature of experimental plans. It also selects the particular households for assignment to plans in accordance with quotas set by the Allocation Model. This is in contrast to the Allocation Model, which determined proportions of the sample to be enrolled in each type of plan, but did not designate which of a finite set of the candidate households should be assigned to which plans.  

7The Allocation Model results are based on the characteristics of the entire sample universe; that is, a sample of infinite size, with average characteristics (such as income) exactly equal to the universal
Our actual field strategy was to select approximately 200 neighborhoods using the 1970 census. These neighborhoods were chosen from throughout the City of Los Angeles to represent the full spectrum of climate, appliance ownership, income, housing, and ethnicity. We then randomly selected 12,000 customers from these 200 neighborhoods using the DWP customer billing file and stratified customers by their level of electricity usage. Figure 3 shows the proportion of all DWP residential customers in each of these strata. In general, statistical precision will be increased by considerably oversampling in the high-consumption D stratum, because households in that category have more electric appliances. We deliberately sample disproportionately from the four strata in accord with policy questions of particular interest.

One major question of general policy interest is the effect of price on the quantity of electricity used—especially as policymakers consider a revision of the rate level or the adoption of lifeline rates. These effects are best studied in the seasonal and flat tariffs. Consequently, those plans sample proportionately at the low end of the spectrum of usage (A) and oversample in the moderate and high strata of use (C and D). In contrast, response to time-of-day rates is especially important to observe at high levels of use—either because these are the customers most likely to be offered time-of-day rates in the future or because we are particularly concerned about the effects of appliances owned by those customers on pattern of use. Consequently, the time-of-day tariffs undersample for customers at the low and medium levels (A and B) and greatly oversample customers using above 400 kwh per month.

RESULTS OF STATISTICAL DESIGN

The preceding sections have discussed the assignments of households to experimental tariffs so as to yield maximum statistical significance for the given budget size. The design does not indicate how much precision to expect, only the best way to maximize the weighted value of mean. In fact, because of the costs of selecting eligible households, actual assignment to plans is made from a finite set of candidates, whose particular characteristics may vary importantly from the universal mean.
Fig. 3—Proportion of households in DWP system and on specific experimental tariffs
statistical significance. In determining the best assignments, the Allocation Model calculates expected variance of all parameters of interest. These variances are stated as a proportion of the overall precision of the equation (that is, as a fraction of the standard error of the equation).

The expected overall precision of the equation is unknown; indeed, if we had that information much of the study would be unnecessary. A first approximation to calculating expected precision can be achieved by looking at the five-year rate experiment conducted by the Electricity Council of London. \(^8\) One inference from their data is that the variance under a time-of-day rate experiment might be as great as the mean level of consumption observed in that peak period. Our calculations indicate that the typical standard error on parameters of interest (e.g., the effect of a peak price between the hours of noon and 9 p.m.) will be around 9 percent of the mean level of consumption in the seasonal experiment and around 6 percent in the time-of-day experiment. This means, for example, that if 200 kwh were consumed per month during the peak-charge hours of noon to 9 p.m., we would expect the standard error to be about 13 kwh per month.

Although the overall effects of the design procedures cannot be briefly summarized, it appears that we can expect to obtain statistical results that are highly accurate indications of what the effect would be if these same plans were extended to much larger numbers of households under similar circumstances.

\(^8\)See Electricity Council of London (n.d.).
IV. OTHER ISSUES IN EXPERIMENTATION

The choice of analytic model, the permissible set of alternative tariffs for experimentation, and the results of the statistical design determine the basic character of the study. They do not, however, exhaust the set of issues that arise when designing an experiment or in interpreting the results. In this section we discuss briefly the time horizon for the experiment, education, participation payments and Hawthorne effects, and administrative issues.

TIME HORIZON

In any study based on temporary participation by individuals one asks, Is the period of study long enough? There are several aspects to the question. Is it long enough for individuals to learn the terms of their experimental rate? Is it long enough to permit cost recovery of any energy-saving investments that the household may wish to make? Are there important changes customers might make on the boundaries of the experiment (just before the experiment begins or after it ends) that may reduce the effective number of months of "normal" behavior? Is it long enough to observe normal appliance retirements and conversions?

The Los Angeles experiment is designed to last 30 months, after which households will return to paying for electricity under the prevailing rate structures. We believe that this is a sufficient period to examine most of the response that is observable at all in an experiment in Los Angeles. The nature and degree of major capital investments that customers might make in response to peak-load tariffs are quite limited in Los Angeles. Since natural gas is currently inexpensive and the climate is mild, few homes have major investments in electric heating. Storage heating devices are one of the principal means that European customers have for taking advantage of favorable off-peak electricity rates, and we might expect similar demand in the United States--especially in colder climates and in areas without plentiful natural gas supplies. There is no comparable device readily available to store cool air at night for use on hot summer afternoons. Consequently, capital investment alternatives for most households will be
limited to inexpensive timers to switch certain appliances off during peak-charge hours. The one significant opportunity we have to observe wholesale conversion of appliances occurs when a household moves. This is especially true of moves from apartments or houses with several appliances of one fuel to a unit with appliances of another fuel. For this reason, we have made every attempt to allow any household that moves to remain on its experimental rate at the new address as long as it is within the city limits.

The major evidence of response in Los Angeles will be behavioral changes that permit using less energy at peak periods and perhaps shifting some usage to off-peak periods. For these reasons, we are determining in advance what hours people work, when they currently run the air conditioner, and when other appliances such as washers and dryers are used. We will attempt to determine whether shifts occur in any of these uses in response to terms of the tariff.

We believe that most of these behavioral responses will occur in a relatively short period, so that during most of the 30 months we will see steady-state behavior. The experiment is designed to cover usage over two full summers' and winters' usage, as well as part of a third summer for many households.

CUSTOMER EDUCATION

The experiment also offers the opportunity to engage in a considerable degree of education in helping customers take advantage of the terms of their experimental rate. The appropriate degree of education to introduce in the experiment is not easily determined. On the one hand, we can certainly predict that if time-of-day rates were commonplace, there would be considerable general education and advice (as well as specialized equipment) available to assist households. To withhold all education in the experiment would lead to an underestimation of the effect if the tariff were available systemwide. On the other hand, any attempt to help individuals change the way they use electricity runs the considerable risk of introducing an unexpected experimental effect in addition to the effect of the terms of the tariff itself, thus biasing the results of the study. Households may
wish to please the person interviewing and "educating" them and may respond with a pattern of electricity use that is not representative of their response in a nonexperimental situation. (This so-called Hawthorne effect is discussed in the next subsection.)

One could deal with customer education as an explicit experimental treatment and assign different amounts to different groups of households. For the present, we have adopted a simple strategy of providing the same, low-level assistance to all participating households in the form of a brief handbook. It contains a number of suggestions for shifting energy use to off-peak periods to lower the overall electricity bill. We are reserving the alternative of adding an explicit degree of education to part of the study at a future point to test the effect of such education.

PARTICIPATION PAYMENTS AND HAWTHORNE EFFECTS

To experiment with a wide range of tariff alternatives, we selected many tariff combinations that may result in a higher electricity bill for the household. If we had excluded such tariffs, we would limit severely the relevance of options examined. To induce cooperation in the study (and to not introduce a bias that would result from differential acceptance), we offer a lump-sum participation incentive payment to any household where the electricity bill goes up--calculated on the assumption of no change in pattern of consumption. Since the household retains any cost saving, this is generous compensation. Most households can be expected to make at least modest adjustments in their pattern of energy use, so this "no change" incentive payment overcompensates them.

In theory, the household should treat the payment like a modest transitory increase in its nonearned income. Since the payment will remain the same regardless of any changes in electricity use, the household should act as if it faced the full terms of the experimental rate. However, we cannot be certain that some (or all) households will not regard the payment as an offset to their bills and simply consume electricity exactly as before.

Although we cannot rule out the possibility of such behavior, we can test for its existence. Half of the households getting incentive
payments will receive their full payments quarterly throughout the study. The other half of the sample receiving payments will get half the amount each quarter and the remainder as a lump sum at the end of the 30-month period. If these two groups behave differently after adjusting for other factors that are expected to affect demand for electricity, then we can conclude that the participation payments have affected behavioral responses and that price responsiveness may be mis-measured in the experiment.

A related issue is the so-called Hawthorne or experimental effect, in which behavioral responses are simply a result of participating in an experiment (or some unobserved aspect of the experiment) rather than of responding to the treatments applied to experimental and control subjects. An example was offered in the dilemma raised by the option to educate households. Although we cannot rule out a priori such experimental effects, we can attempt to limit them in all obvious ways and to test for their presence in the final results. In fact, several degrees of customer contact are under observation: no direct contact at all; no interview, new meter placed outside; interview, no other change; interview, contact for new electricity rate, old meter; interview, new rate, new meter; interview, new rate, old meter, participation payment; and interview, new rate, new meter, participation payment. We thus can test separately for each of these factors as influencing customer response.

The original Hawthorne effect was observed in a study conducted over 50 years ago, when an attempt was made to see whether improved lighting increased worker productivity. Existing light bulbs were exchanged for brighter bulbs and productivity rose. Even brighter bulbs were tried; productivity rose again. Then the experimenter substituted bulbs with lower light output for existing bulbs. Productivity rose! It turned out that the experiment itself was increasing productivity.

It is not clear that rate experiments are vulnerable to precisely the same danger, because it is not clear what a better outcome is in each case. If energy use systematically rose (or fell) with every plan, we would not falsely ascribe any of the results to tariff levels; our conclusion would be that tariffs produce no effect.

Nevertheless, there is a danger that experimentation will affect the results. Perhaps a closer analogy is the so-called Heisenberg effect. Heisenberg, a physicist, found that the very act of attempting to measure certain small phenomena changed the values of the phenomena because his measuring device was larger than that which he was measuring.
INTERVIEW AND ENROLLMENT STRATEGY

We employed a mixed strategy of interviewing and enrolling our sample that permitted both an expeditious initiation of the study and greater precision in assigning households to specific plans. On the one hand it is desirable to know in detail the characteristics of individual households so that they can be assigned to specific plans to maintain balance and representativeness across all experimental dimensions. This strategy, however, would require that we interview all households first, then make an assignment using the Finite Selection Model of individuals to specific plans. A lengthy period of time would be needed to conduct interview enrollments, necessitating two sets of appointments and visits to each enrolled household. On the other hand, we can assign households to plans based on the characteristics of their neighborhood and enroll the household at the end of the interview process if the household is eligible. We employed a mixed strategy of interviewing and enrolling approximately half of the households on first contact and interviewing only for the remainder of the sample. We then analyzed the responses of the households that were only interviewed and used the individual specific information to make the enrollment assignments to maintain balance across all plans. This was particularly important where we were dealing with relatively expensive plans that required large participation payments or where we were dealing with plans that had very few potentially eligible households (for instance, high levels of consumption in some of the climate or neighborhood zones).

SAMPLE MAINTENANCE

A significant number of enrolled households can be expected to move during the 30-month period. On the average, utilities serving the Southern California area start approximately 37 percent of their residential accounts at a new address each year. To maintain a significant number of observations as well as to adequately represent the significant number of moving households, we adopted rules that permitted any household that moved within the City of Los Angeles to remain on the experimental rate. This required continuous sample
maintenance and file updating of the analytic files in order to assure continuity of participation. We are unable to continue households moving out of the City on their experimental rates, and we necessarily lose their contributions to the study. During the initial enrollment period that extended through most of 1976, several households moved out of the City and became ineligible for the study. We decided to stop the initial enrollment process just short of the originally intended quota of 1800 experimental households to see how many households would be lost to the study. In April of 1977, approximately 90 households had moved or had otherwise become ineligible. Therefore, in May and June of 1977, we enrolled an additional 100 households to reach the originally intended quota of almost 1800 households, appropriately balanced over the plans that seemed most important to analyze. These additional households will be on the study for a 24-month rather than a 30-month period so that their termination date is the same as the other households in the study. In all other respects they are the same as those enrolled during 1976, and in the majority of cases, a baseline survey had already been conducted on these households during 1976 so that we have comparable income, appliance, and other information.

**ADMINISTRATIVE ISSUES**

A number of administrative issues arise in the conduct of an experiment of this type, but three important ones are choice of meters, selection of interviewers, and rules for participation in the study.

We selected continuous tape recording cassette meters, which record electricity used every 15 minutes. Although these meters cost around $300 each (rather than the $80 each for two-register meters plus a time switch to record peak and off-peak kwh), the increase in information offsets the cost differences. Use of continuous recorders permits us to employ the synthetic demand curve approach, because we can observe more than two periods in each day as well as weekend effects. In this manner, each household serves as a control for every other household. If we had used only two-register meters, we would then have been deprived of a significant number of degrees of freedom in estimating each demand curve.
In this study, DWP employees interviewed and enrolled participants. Generally speaking, only professional survey organizations, with trained interviewers, have been used in social experiments and other social research that expects to meet minimal standards of analytic rigor and representativeness. The major successful exception of which we are aware is in the British Electricity Council's five-year rate study, which used employees of the regional distributing boards. Rand researchers and the DWP cooperated in the training and supervision of about 45 DWP employees (four Rand survey researchers spent two weeks training the group of interviewers). The results were remarkably satisfactory. Interview completion rates were in excess of 90 percent (compared with normal survey experience of 80 to 85 percent) and some 93 percent of the households agreed to join the study (compared with about 85 percent in a number of other social experiments). Although this aspect of the study will be the subject of a separate report, our general feeling is that with highly motivated people and careful training and supervision, a successful field operation can be conducted.

Finally, rules for participation in the study must be developed and made known to participants. These should cover such issues as eligibility for enrollment, calculation and payment of the incentive payment, conditions for disenrolling a household (fraud, failure to cooperate with interviewers, failure to permit the meter to be read, delinquency in payment), and continued eligibility when someone moves into or out of the house, the household changes residence, or in the case of marriage, divorce, death, and so forth. These matters do not arise often, nor, taken as individual examples, are they very important, but failure to determine and adhere to such rules invites attrition of households, unexpected (and uncontrolled) experimental effects, and possible public backlash that can threaten the study.

2 In fact, the survey lore is replete with detailed stories about studies that have been attempted with nonprofessional interviewers and the disastrous results.
V. CONCLUSION

The Los Angeles rate study has been designed to provide analysts with a data base on individual household responses to peak-load tariffs. Given the dearth of information, it is important that the data base generated be sufficiently robust to answer a wide range of questions with some precision. To ensure that this level of quality is achieved, we did the following: used demand curves rather than ANOVA models; assumed that the functional form of the household response can be quite complex; selected price and policy options that bracket any reasonably likely prospects for electricity supply; and provided tests for the existence and magnitude of experimental biases. We have relied on a recently developed, powerful statistical design method, the Allocation Model, to select those tariffs that minimize the variance of the answers to the policy questions about peak-load pricing. A related algorithm, the Finite Selection Model, guarantees that the subsamples on each tariff are similar to those on other tariffs and permits certain precision gains in estimating the impact on consumption of different appliance stocks and income levels.

The design we have selected should yield estimates of consumer demand and responses to policy-relevant tariffs of considerable statistical significance. Experience with the Allocation Model indicates that particular parameters on price and other variables of interest will be estimated with a variance generally less than 10 percent of the standard error of the equation. Furthermore, the variance with respect to particularly interesting policy questions will typically be less than 5 percent of the standard error of the equation.

We may ask what the generality of the results is likely to be. Will the findings be transferable to other situations? We believe there is considerable reason for optimism. Within the DWP system, the study should be useful in system planning and tariff design for a number of years. The high degree of statistical significance as well as the considerable range of tariff values studied should produce results that will guide major revisions as well as the fine-tuning of any peak-load tariff that might be adopted.
The results of the study should be equally useful for analysis in other utility systems. This is especially true of utilities serving customers with a summer peaking load and a significant amount of air conditioning in place. Some elements of the study may even be useful to systems serving a fundamentally different type of residential demand, for example, a winter peaking system with significant electric space or water heating. This is true for two reasons. First, although electric space and water heating is not very common within DWP at the present time, we are deliberately including a disproportionate number of such customers in the study. Second, the present study will measure changes in habits in response to peak-load tariffs for some uses of energy that are fundamentally the same regardless of locale. For example, if we measure customer responsiveness in the timing or amount of electricity used for lighting, clothes washing and drying, and small electrical appliances, that type of behavioral adjustment may be expected to be reasonably independent of climate and utility characteristics.

We expect to conduct a preliminary analysis of the effects of these experimental electricity rates when data have been accumulated for approximately 12 months on all participating households. We wish to wait for a year to be assured that measured household behavior is not still going through its preliminary adjustment as customers learn the details of the terms of their experimental rates. Furthermore, we wish to be assured that unusual features of electricity use that may be associated with one season of the year are not unduly influencing the results. This analysis will be conducted primarily using multiple regression techniques to estimate the type of model discussed in Sec. II of this report. It will measure changes in total consumption of electricity and shifts from peak to off-peak periods, and will analyze the effects of a number of potentially important variables, including the level of price, the length of time for peak rates, the effects of weather, appliance ownership, and so forth. We will also analyze the speed of adjustment that households seem to make in changing from previous patterns of consumption to patterns of consumption under time-of-day electricity rates.
BIBLIOGRAPHY


