Time-of-Day
Electricity Rates
for the United States

Jan Paul Acton, Bridger M. Mitchell,
Rolla Edward Park, Mary E. Vaiana
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PREFACE

For the past ten years, Rand economists have been studying electricity pricing issues of interest to energy policymakers, utility officials, and regulators. Many of these studies have focused on individual parts of this large and complex subject. Under a grant from the John A. Hartford Foundation, Rand staff have considered the national significance of these findings and have developed recommendations for pricing reforms for residential and business customers.

This report is an executive summary of this larger body of research. It is addressed to elected officials at the state and federal levels, public utility commissioners, interested intervenors in rate cases, and chief executive officers of utilities. It contains the authors' major policy recommendations for electricity pricing. The detailed analyses on which these findings are based are contained in some 48 separate studies. The final section and the bibliography suggest additional readings—both Rand publications and other studies—for readers who wish to follow up on specific areas of demand, rate structure, or rate design.
ACKNOWLEDGMENTS

Our analysis has benefited from the support and assistance of several organizations and individuals. The major findings for residential customers are based on a five-year study supported by the Los Angeles Department of Water and Power, with the cooperation of the U.S. Department of Energy. In addition, more focused studies of residential customers, business customers, or costing and pricing methods were supported by the California Energy Commission, the Electric Power Research Institute, the Ford Foundation, the Maryland Power Plant Siting Program, and the National Science Foundation. A major grant from the John A. Hartford Foundation has allowed us to extend and integrate this analysis in a national focus.

Numerous individuals in these organizations, as well as utilities who supplied primary data, assisted in the understanding and review of draft material. We would especially like to thank the members of the Hartford Advisory Committee consisting of Carol Barger, S. David Freeman, Carl Gilzow, Leigh Hammond, Barbara Haskew, William Pendleton, Grant Thompson, John Tillinghast, Dennis Whitney, and Charles Zielinsky, as well as John Billings of the John A. Hartford Foundation. Paul Joskow of MIT provided several useful suggestions for improving this report. We appreciate the assistance of each of these individuals.
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I. INTRODUCTION

During the 1970s, U.S. electric utilities modified their pricing practices to cope with rapidly changing circumstances. A major development was the introduction of new forms of electricity rates that reflect time-of-day (TOD) variations in electricity costs. Several utilities experimented with TOD rates for a limited number of residential customers to determine their effectiveness. Others applied mandatory TOD rates for their largest commercial and industrial users.

Two major considerations stimulated the interest in TOD rates. First, after decades of steady or falling prices, all energy prices rose rapidly following the Arab oil embargo. Consequently, the rates and rate structures of electric utilities, which are publicly regulated, came under close scrutiny by customers and public utility commissions.

Second, the economics of electricity supply focused attention on the peak-load aspects of electricity costs. Since electricity demand varies over the day and over the year, the cost of fuel to meet peak-period loads may be two to four times the cost of meeting off-peak loads. It also takes more generating capacity to meet these swings in demand, increasing the difference between peak and off-peak costs.

Most utilities still do not reflect these daily and seasonal cost differentials in their retail rates. Because electricity is underpriced during peak periods, customers continue to overuse it at the very times when it is most expensive to supply. If a fraction of the peak load were eliminated or shifted to off-peak periods, immediate savings in fuel bills would be realized and existing plant and equipment could be stretched further—reducing additional construction costs in this most capital-intensive sector of the U.S. economy.

The turn to TOD pricing during the 1970s was a way to reflect these cost differences more equitably in customers' bills and to help reduce the source of rapidly escalating fuel and capital costs of utilities. TOD pricing offers customers lower rates when the cost of producing electricity is low but charges them more when cost is high.

Conditions have changed, however, since the beginning of this decade. Oil prices have fallen and the growth in electricity demand has slowed somewhat. It is therefore reasonable to ask whether TOD pricing remains a promising strategy, and whether it will have the desired effect. Briefly, the answers are that:
• TOD pricing is still relevant for pricing deliberations in the 1980s.
• TOD rates do shift the pattern of electricity use by U.S. customers. TOD prices, appropriately targeted on certain kinds of customers, yield annual net benefits of several hundred dollars per residential customer and up to several thousand dollars per customer for large businesses.

To understand how these conclusions came about, we need to look behind electricity costs to the economics of electricity supply, and then review the evidence of response to TOD rates by residential and business customers.

THE ECONOMICS OF ELECTRICITY SUPPLY

For decades, consumers benefited from a very favorable set of circumstances in electricity supply. Steady fuel prices, technological advances, and economies of scale in operation combined to lower the costs per kilowatt hour (kwh) of electricity delivered. In response, regulators held retail prices steady or even reduced them. Utilities actively promoted electricity use, and their profits increased. Throughout the 1960s, consumers gave little thought to electricity prices.

The "benign era" ended abruptly in the early 1970s. The dashed lines in Fig. 1 show the price of electricity each year for residential and large industrial users, and the solid lines show these prices adjusted for inflation. Prices for commercial customers are very close to those plotted for residential customers. Prices moved sharply higher in 1973, but they had begun their upward movement a few years earlier. The two chief causes for this dramatic change in price trends were that fuel prices increased abruptly, and the capital costs associated with electricity production reversed their downward trend and began to rise.

Fuel costs—for oil, coal, natural gas, and other fuels—jumped during the Arab oil embargo of 1973–74 and rose rapidly thereafter. Expenditures on fossil fuels by electric utilities doubled in 1973–74, increased another 2.5-fold between 1974 and 1980, and now exceed $40 billion per year. Before the embargo, fuel expenditures accounted for about 24 percent of the retail cost of electricity; in 1974 the figure rose to 37 percent and has remained at that level. Despite the currently waning influence of OPEC, oil prices are now almost ten times what they were a decade ago, and they are likely to remain high for the foreseeable future.
Fig. 1—Average price of electricity for residential and industrial customers

But other forces affecting cost were operating independently of OPEC. From the beginnings of commercial electricity production, technological improvements and economies of scale in generation and system design had steadily driven down the real capital costs of plants. Most analysts agree that these cost-lowering factors ceased to operate in the late 1960s. Technological improvements had been thoroughly exploited and economies of scale for individual generating units had been exhausted. Indeed, some of the more recently constructed plants are so large as to experience dis-economies of scale.

Along with the halt in cost-lowering technological advances, utilities began to incur increased costs for meeting higher standards of safety and pollution abatement. They also had to pay sharply higher interest rates during the 1970s, which cost them even more because of the longer time it now took to obtain permits and complete construction.
The confluence of these forces produced generally higher average costs per kilowatt (kw) of new capacity than historical experience suggested.

Beyond these features of average costs of electricity supply, there are important daily and seasonal variations in costs. Figure 2 shows a typical daily load curve in the summer that is representative of many utilities. The vertical axis shows the level of electricity generation needed at each moment to meet the sum of customers' demands at that moment. With rare exceptions, utilities meet total demand with a mixture of generating units that may include nuclear, coal, oil, natural gas, and hydroelectric facilities. They operate the mixture of plants that has the least overall cost for an expected pattern of demand. This usually means operating baseload plants, which have a relatively low operating cost, at all hours of the day; operating intermediate plants, which have higher operating costs, for a large fraction of the day; and using their peaking plants for a limited number of hours or only on days when unexpected shortfalls in capacity occur. As the typical

Fig. 2—Utility costs vary by time of day
sequencing of plants in Fig. 2 shows, electricity at the peak demand time may be two to four times as expensive to supply as electricity at off-peak hours.

The fluctuations in demand have another cost effect in addition to that on fuel costs. To cope with daily and seasonal fluctuations, utilities must invest in more total capacity than they would need to meet the same total demand for electricity at a steadier rate. For example, to meet the expected load curve illustrated in Fig. 2 a utility may have to construct 50 percent greater capacity than it would need to supply the same total quantity of electricity at a uniform rate of demand. And they must invest more in systems for transmitting and distributing the electricity, which must be sized to handle the maximum level of demand. These magnitudes are important since, overall, capital costs account for roughly half of the annual electricity bill that customers face.

The greater costs of fossil fuels associated with peak-load generation, along with the added capacity investment for peaking (instead of flatter) load curves has led to an important and widening gap in the costs of supply between peak and off-peak periods.

EVALUATING TIME-OF-DAY RATES

TOD pricing is a way to bring about a closer match between the price charged to customers, and variations in load and the associated costs of electricity production. Figure 3 shows a simple TOD rate. Instead of a flat rate at all hours, consumers pay lower rates during the off-peak hours and higher ones during the hours of peak demand. Consumers respond to these pricing patterns in several ways: They may eliminate some peak-period uses, they may shift some consumption to the cheaper hours, and they may increase their consumption use in the cheaper off-peak hours. The upshot may be an increase or a decrease in total consumption. A new pattern of use will form, as shown by the dotted load curve in Fig. 4.

In theory, TOD rates benefit both utilities and consumers. During the cheaper hours, when rates are lowered, customers can use more electricity and the utility can still cover its costs for the extra fuel. The result: Consumers get the benefits of additional uses of electricity. At the peak, higher prices encourage consumers to curtail unimportant
Fig. 3—An example of time-of-day rate

Fig. 4—TOD rates shift patterns of electricity use
forms of consumption. If consumers respond by shifting their consumption to off-peak hours, the utility can reduce production and save more in fuel and fixed capital costs than it would lose in revenue.\footnote{The greatest increase in efficiency would occur from peak and off-peak rates equal to the marginal costs of electricity in each period. However, TOD rates may differ from marginal costs, for example, to cover the utility’s total allowed costs. The key economic point is that when electricity rates are based on marginal costs in the peak and off-peak periods, rather than on average cost, electricity will be used more efficiently.}

When regulators consider introducing TOD rates, two important elements of their evaluation are the fairness of the TOD rate compared with existing rate structures, and the economic efficiency—the benefits versus costs—associated with introducing the new rate. Economic efficiency in this context means getting the most benefit for the resources expended; it helps make the “total social pie” as large as possible.

Fairness has many different meanings. One widely shared view of fairness is that consumers should pay the costs of the services that they consume. By this standard, cost-based TOD rates are fairer than conventional rates because costs of electricity supply vary by time of use, and TOD bills will more accurately reflect these cost variations; clearly, TOD rates will lower bills for some consumers but raise them for others, according to their patterns of peak usage. Other people regard fairness as meaning that there should be an attempt to overcome inequities in the income distribution—perhaps to assist the poor or the elderly—or to assure a minimum standard of consumption at a reasonable price.

Our analysis will abstain from the debate over fairness beyond agreeing with the general proposition that customers should pay for what they consume. More searching judgment lies within the province of regulatory bodies that must review costs and a host of other factors, including social and political considerations. We can contribute to informed judgment, however, by analyzing the efficiency gains associated with introducing TOD rates. To do this, we must weigh the benefits against any costs of introducing TOD rates. Figure 5 is a simple model of how we do so.

Utilities can readily calculate the cost side of this balance from their own administrative experience and from suppliers’ quotations for TOD meters. They also know how much electricity their customers use now, and within the uncertainties of fuel and construction costs, they know their own current and projected costs. The missing piece of information is the magnitude of load changes that will result from TOD rates, which will determine the changes in consumer cost and well-being and
the changes in utility cost and profits. The research we summarize in Secs. II and III makes it possible to evaluate the costs and benefits of TOD pricing by estimating how consumers of various kinds will respond to different rate structures.

An important consideration in evaluating the costs and benefits of TOD prices is the vastly different scale of electricity consumption by three customer classes: residential, commercial, and industrial. Table 1 shows that U.S. utilities have over 83 million residential customers, but fewer than 500,000 industrial customers. The commercial class itself includes a broad range of customers, from small stores and offices to giant hospitals, hotels, and office towers. On average, each commercial customer consumes about six times as much electricity as does each residential customer. Industrial consumption per customer is almost 200 times the residential figure.

**FINDINGS AND RECOMMENDATIONS**

To preview our findings and recommendations:

- Residential consumers at all levels of use respond to TOD rates, reducing peak-period consumption and shifting some load to
Table 1

ANNUAL ELECTRICITY CONSUMPTION BY CUSTOMER CLASS

<table>
<thead>
<tr>
<th>Customer Class</th>
<th>Number of Customers (thousands)</th>
<th>Percent of Total Customers</th>
<th>Electricity Consumption (billion kwh)</th>
<th>Percent of Total Consumption</th>
<th>Consumption per Customer (kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>83,459</td>
<td>88.9</td>
<td>736</td>
<td>35.4</td>
<td>8,820</td>
</tr>
<tr>
<td>Commercial</td>
<td>9,903</td>
<td>10.6</td>
<td>541</td>
<td>26.0</td>
<td>54,600</td>
</tr>
<tr>
<td>Industrial</td>
<td>487</td>
<td>0.5</td>
<td>800</td>
<td>38.5</td>
<td>1,640,000</td>
</tr>
<tr>
<td>Total</td>
<td>93,849</td>
<td>100.0</td>
<td>2,077</td>
<td>100.0</td>
<td>22,100</td>
</tr>
</tbody>
</table>


off-peak hours. However, the cost of per-household metering makes TOD rates cost-effective for only a small proportion of all consumers, primarily the largest users.

- On efficiency grounds, residential TOD rates should be introduced selectively and designed to attract households for whom they are cost-effective. TOD rates could be required for all residences whose monthly electricity use exceeds a fairly high level, or they could be optional and include a separate charge to recover the additional cost of TOD metering.

- Business response to TOD rates has been small in percentage terms to date, but it is statistically significant. Overall, the average customer reduced relative peak load by one percentage point, but about four percent of the industrial firms have responded a great deal. However, commercial customers as a group, and most industrial customers, have not responded at all.

- On efficiency grounds, TOD rates are justified for the business class as a whole. Even the small average response to date yields benefits that far exceed metering costs.

- As practical ratemaking policy, it is probably desirable to apply TOD rates to all large business customers served under similar circumstances: first, because the responsive firms cannot be separated from the unresponsive ones in advance; second,
because placing all firms on TOD rates will encourage them to make longer-run adaptation that may require capital investment, learning, specialized equipment, and so forth.

Sections II and III explain how we arrived at these conclusions and recommendations.
II. RESIDENTIAL RESPONSE TO TIME-OF-DAY RATES

Time-of-day electricity rates for residential consumers were first given systematic consideration in the United States in 1975, when several utilities and the U.S. Department of Energy began a series of field experiments. In this section we examine the responses of residential consumers to TOD rates, assess the benefits of TOD rates when implementation costs are accounted for, and investigate whether the responses of one utility’s customers can be generalized to another utility’s area.

There are more than 88 million residential customers in U.S. utilities. Nationwide, they use an average of 700 kwh per month, a figure that varies greatly depending upon appliance holdings, household size, climate, and whether the customer lives in an apartment or single-family house. Electric space heaters, air conditioners, water heaters, electric stoves, and swimming pool pumps are the major electricity-using appliances and equipment. Households having several of these items can average ten times the use of households without them. The cost-effectiveness of residential TOD rates depends upon customers’ level of use and price-responsive.

The following discussion is primarily based on a major experiment conducted by Rand in cooperation with the Los Angeles Department of Water and Power (LADWP); we also use results from residential tests conducted in North Carolina and Wisconsin to calibrate these findings and determine how generalizable the results are to other parts of the country.

THE LOS ANGELES RESIDENTIAL TIME-OF-DAY RATE EXPERIMENT

This 30-month experiment tested 17 TOD rates on approximately 1000 households, as well as six seasonal and flat rates on 800 other households. The experiment had four major objectives:

- To assess the benefits of TOD rates for Los Angeles by measuring how rates alter both total consumption and daily patterns of use.
• To compare these benefits with the added costs of installing meters.
• To forecast future electricity use at higher prices and to determine whether TOD rates would affect that use.
• To support policymaking by producing data that would be relevant to other settings.

The rates for the experiment were designed to yield two kinds of information: how consumers change their total consumption of electricity, and how they shift the pattern of their consumption. We measured total change by varying the actual overall price of electricity from 2 to 5–1/2 cents for different households. We measured shifts in consumption by providing a variety of TOD and seasonal rates. Some of these rates are shown in Fig. 6. Under various pricing schedules, peak rates were assigned to particular hours throughout the day—e.g., morning, early afternoon, later afternoon, and even overnight. These rate patterns were not intended to reflect the utility’s costs; rather, they were designed to help us forecast consumer responses for a utility whose basic load curve and costs of supply were very different from those in Los Angeles.

We also collected detailed information about the participating households, their specific appliances, and their weather that would permit us to characterize those customers who respond and to determine how much of the response could be transferred to another area.

The study had two important limitations. First, we were unable to collect data on the hourly pattern of electricity consumption under standard rates prior to the experiment; instead, we used data from experimental flat rates—2 cents or 5 cents per kwh—to estimate what each customer’s daily pattern of use would have been under standard rates. Second, this experiment could measure only the short-term response to TOD pricing; therefore, our findings may underestimate the full effect of TOD rates. Over the longer term—a decade or longer—widespread use of TOD rates, combined with consumers’ desires to use electricity at cheaper off-peak hours, could change the design of household appliances and perhaps residential construction practices. For example, manufacturers might put timers in water heaters, washing machines, and dishwashers, and homes might be wired with separate circuits and microelectronic load controllers. But these kinds of adjustments, which could have substantial effects on electricity consumption, take a long time to implement.
Fig. 6—Illustrative electricity rates in the Los Angeles study
BASIC FINDINGS

We can summarize our basic findings as follows:1

- TOD rates reduce peak-period use and tend to increase off-peak use.
- If the TOD rate raises the average price of electricity, consumers reduce their total use.
- Price responsiveness does not fall off in extreme weather; if anything, shifts due to TOD rates are greater in very hot weather.
- High-use households—those who consume 1000 kwh per month or more—respond more to TOD rates than do low-use households.
- Certain types of households—especially those with swimming pools and air conditioners—are much more responsive than other households.

The information we collected about household characteristics also produced findings about how electricity is used. Total use varies directly with the number and type of appliances, the type of housing, and the number of household members. Swimming pools and electric water heaters account for major differences in monthly use, followed by freezers, electric dryers, and frost-free refrigerators. Household characteristics also influence the importance of weather in energy consumption. In households that have electric air conditioners or heating, weather variations are the major determinants of both total consumption and the pattern of consumption over the day.

The Los Angeles experimental rate structures also included some seasonal rates—for example, a summer price of 8 cents per kwh, with a winter price of 2 cents per kwh. These price differences do induce households to change electricity consumption seasonally, but the response is smaller than was found with TOD rates.

COST-BENEFIT ASSESSMENT

We have just described the “consumer response” component of the cost-benefit evaluation for households in the Los Angeles area. To judge whether this response will produce net benefits to either consumers or utilities, we must consider the price levels of a particular TOD rate and the costs of installing TOD meters and of billing. For this

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1See Mitchell and Acton (1983) for the principal empirical findings.
purpose, we used TOD price terms very similar to the rate introduced in Los Angeles in the late 1970s. We also assumed that meters cost $150 installed and were amortized over 15 years, values representative of current practice.

When we compared these costs with the benefits gained from reduced or shifted consumption, we found that only a small but important fraction of the residential customers responded enough to TOD rates to offset the metering costs. For all households, the average monthly consumption had to exceed 1100 kwh before metering costs could be justified. Only 4 percent of Los Angeles residential users fall into that category; however, because of their high use they account for more than 17 percent of total residential electricity consumption. For those households that are more responsive to price—those with swimming pools or air conditioning—the benefits of TOD rates justify metering starting at a somewhat lower consumption level—about 800 kwh per month.

The break-even point in cost-benefit analysis depends upon the price levels and metering costs. In our Los Angeles assessment, we used a nine-hour peak period, Monday through Friday, at 9 cents per kwh, with an off-peak price of 3 cents per kwh. In utility systems with higher price levels—or greater differences between peak and offpeak costs—greater benefits result. Moreover, average electricity consumption in Los Angeles is around 400 kwh per month, considerably below the national average of 700 kwh. In utilities with a greater proportion of customers at higher levels of use, a cutoff of 1100 kwh per month would encompass more than four percent of the customers.

HOW TRANSFERABLE ARE THE LOS ANGELES FINDINGS?

In deciding whether to adopt TOD rates for its residential customers, each utility must assess the costs and benefits illustrated in Fig. 5. Each utility knows its own costs and how much electricity its customers habitually use. What it does not know is how its customers will respond. The Los Angeles experiment enables us to predict how a utility’s load will be affected by consumer response to TOD rates. But can other utilities confidently use the Los Angeles results to predict the response in their service area? Since, as we have seen, the magnitude and pattern of response crucially affect the benefit analysis, the issue of transferability is a central one for policymakers.

Transferability is even more important because several of the major experiments designed to determine the effectiveness of TOD structures
have reported widely differing results. This divergence seems to suggest that customer responses to TOD rates depend principally on local conditions; if true, any utility considering such rates would face the costly task of fielding its own experiment to assess consumer response, an unreasonable burden for any small utility.

To investigate the issue of transferability, we extended Rand’s Los Angeles work.\textsuperscript{2} The approach was to develop a general statistical model, based on the Los Angeles experimental data, for predicting consumer response to TOD rates, and to use this model to analyze the response reported for several other TOD experiments. The common statistical approach would make it possible to compare the responses for similar consumers, while taking into account the appliance mix in each household and the variation in weather conditions.

In the 1970s, a number of utilities fielded TOD pricing experiments. However, design flaws make them of little use to other areas. From the handful of adequate experiments, we chose the Los Angeles experiment and two others for the transferability analysis: the Wisconsin Time-of-Day Electrical Pricing Experiment, and the North Carolina Electric Demonstration Project. We had three basic reasons for our choice:

- These experiments were among the best-designed to measure consumer response over a variety of rates and conditions.
- The North Carolina and Wisconsin climates and less urban settings provided sharp contrasts to Los Angeles’ mild climate and metropolitan environment.
- The reported results from these experiments represented extremes of customer response: Wisconsin studies showed much stronger price response than we had found in Los Angeles, while North Carolina reported no price response at all. Thus, these two experiments presented a clear example of the policymakers’ dilemma of conflicting information.

As summarized in Table 2, the studies range in size from some 350 to nearly 1300 experimental TOD households. In both North Carolina and Los Angeles, test customers are geographically spread over different climate zones; in Wisconsin, all households experience virtually the same weather conditions.

The experimental rate structures differ markedly in several key features. In North Carolina, all 9 TOD rates have the same peak, intermediate, and base rate periods; the only variation is the price per

\textsuperscript{2}See Kohler and Mitchell (1983).
Table 2
FEATURES OF THE RESIDENTIAL TOD EXPERIMENTS

<table>
<thead>
<tr>
<th>Feature</th>
<th>North Carolina</th>
<th>Wisconsin</th>
<th>Los Angeles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of TOD households</td>
<td>354</td>
<td>597</td>
<td>1268</td>
</tr>
<tr>
<td>Duration of experiment</td>
<td>14–18 mo.</td>
<td>36 mo.</td>
<td>30 mo.</td>
</tr>
<tr>
<td>Number of weather zones</td>
<td>7</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Number of TOD rates</td>
<td>9</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Length of peak period</td>
<td>10 hrs.</td>
<td>6–12 hrs.</td>
<td>3–12 hrs.</td>
</tr>
<tr>
<td>Maximum difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between peak and off-peak price</td>
<td>6.5 cents</td>
<td>11.1 cents</td>
<td>11 cents</td>
</tr>
<tr>
<td>In average price/kwh</td>
<td>0</td>
<td>0</td>
<td>3 cents</td>
</tr>
<tr>
<td>Households with</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air conditioners</td>
<td>74%</td>
<td>30%</td>
<td>57%</td>
</tr>
<tr>
<td>Electric heat</td>
<td>25%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Swimming pools</td>
<td>0</td>
<td>0</td>
<td>19%</td>
</tr>
<tr>
<td>Electric water heaters</td>
<td>86%</td>
<td>41%</td>
<td>6%</td>
</tr>
</tbody>
</table>

kwh. In contrast, the Wisconsin TOD rates are grouped into 6-, 9-, and 12-hour peak periods; for each case, there are three different rate structures. However, experimental rate structures in both North Carolina and Wisconsin yield the same average revenue per kwh for a representative customer. This means that the experiments cannot measure the effect that electricity prices have on total electricity consumption, information that is needed to assess TOD rates for utilities with different average revenues, and they are limited in their ability to predict the effects of TOD tariffs not tested. The Los Angeles experiment, however, does permit these assessments.

In terms of household characteristics, each experiment contains a good representation for air conditioning. However, only North Carolina has enough households with electric space heating to measure the probable effects of TOD rates on such loads, and only Los Angeles has enough swimming pools.
COMPARING EXPERIMENTAL RESULTS

Why are the reported results from the three experiments so different? There are two possibilities: substantial differences in consumer response to prices, or differences in analytical approach. To discover the correct explanation, we constructed a statistical model to eliminate the effects of differences in analytical approach, enabling us to assess the different experimental results along comparable parameters.

The model has three categories of variables or features of interest:

- Environmental variables—for example, weather;
- Household-specific variables—for example, appliances;
- Monetary variables—for example, prices.

If we wish to measure consumer responses to prices, we must hold the effects of the other variables constant. In other words, the model must determine a reference pattern of electricity consumption—a load curve—for a household facing specified weather conditions and having a standard set of appliances. This model, which was initially developed to analyze the Los Angeles experiment, can be applied to other areas having comparable measures of these variables.

We used this model in two ways to test the transferability of the Los Angeles results. First, we used it to adjust for analytical differences among the experiments so that we could compare the price responses on common ground. We discovered that many of the apparent contradictions between the studies are explained by their different definitions of response and by data-handling problems—primarily the omission of variables, such as weather, that matter in electricity consumption. Second, we used the model to predict the experimental results that were observed in the other two sites, given the sort of customer response to price that we found in Los Angeles.

The results of both of these tests supported our initial hypothesis: the response of residential households to TOD rates is similar and transferable. More specifically,

- Residential consumers respond to higher peak-period prices by reducing peak-period use. The magnitude of their response in Wisconsin and North Carolina resembles that in Los Angeles: for example, a 6 to 20 percent reduction during peak hours.\(^3\)

\(^3\)As noted in Sec. I, utilities are interested in the actual change in electricity use when TOD rates are introduced. This change is measured by the full price elasticity. However, in some studies, response has been reported as a "partial elasticity," a measure that artificially inflates the actual percentage change in consumption.
Rural households in Wisconsin had a slightly higher response than urban households.

- If the average price of electricity is not increased when the TOD rate is introduced, then consumers increase their off-peak use while lowering their peak-period use. However, if average price does increase as a result of the TOD rate, consumers reduce total use, and possibly off-peak use as well. For Wisconsin and North Carolina rate structures it is not possible to measure this effect on total consumption.

- Weather has a similar effect in stimulating electricity use in all three sites. Specific appliances increase consumption in each site, but to degrees that vary by season and experiment.

- Implementing TOD rates is cost-effective for only a fraction of all households--those with high total use. The break-even point depends on the cost characteristics of the local utility.
III. BUSINESS RESPONSE TO TOD RATES

Time-of-day rates were first introduced in the United States for selected commercial and industrial customers in the mid-1970s. By the early 1980s, more than 12,000 of these larger businesses faced TOD rates on a mandatory basis, and others had them available as an option. Many utility commissions felt it was appropriate to make TOD rates mandatory for these consumers since they already had complex metering equipment in place; thus, no major additional costs were needed to change to TOD rate structures. Remember that the commercial customers are quite diverse—ranging from very large office towers or hospitals to small retail establishments—although TOD rates were generally applied only to the largest commercial customers.

Individual utilities have reported how TOD rates affected demand in the areas they serve, but an adequate assessment of the benefits of TOD rates for commercial and industrial customers requires more comprehensive analysis. Such an analysis must address the same kinds of questions we posed for residential customers: How much do customers change consumption patterns in response to TOD rates? Are TOD rates efficient for these customers? Are they good public policy?

An important consideration in answering these questions is the very different scale at which costs and benefits are measured for business customers. Because business customers use so much electricity, the benefits of even small percentage changes in consumption patterns are generally large relative to metering costs. Indeed, it is this large base of consumption that makes TOD rates cost-beneficial even in the face of modest overall response to date.

THE RAND STUDY OF LARGE BUSINESS CUSTOMERS

Our discussion of business response to TOD rates is based on Rand's study of the large customers in ten utilities across the country. The participating utilities are listed in Table 3. The goals of our study were:

- To assess the benefits of TOD rates by measuring how rates affect daily patterns of use.

The details of our study are reported in Park and Acton (1983).
### Table 3

**COVERAGE OF LARGE CUSTOMER STUDY**

<table>
<thead>
<tr>
<th>Utility</th>
<th>Customers</th>
<th>Years of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>California</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern California Edison</td>
<td>575</td>
<td>5</td>
</tr>
<tr>
<td>Los Angeles Department of Water and Power</td>
<td>262</td>
<td>5</td>
</tr>
<tr>
<td>Pacific Gas and Electric</td>
<td>1382</td>
<td>6</td>
</tr>
<tr>
<td><strong>Midwest</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin Electric Power Company</td>
<td>588</td>
<td>4</td>
</tr>
<tr>
<td>Madison Gas and Electric</td>
<td>32</td>
<td>4</td>
</tr>
<tr>
<td>Wisconsin Power and Light</td>
<td>407</td>
<td>4-1/2</td>
</tr>
<tr>
<td>Commonwealth Edison</td>
<td>540</td>
<td>2</td>
</tr>
<tr>
<td>Consumers Power Company</td>
<td>2065</td>
<td>4</td>
</tr>
<tr>
<td><strong>New York</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Island Lighting Company</td>
<td>429</td>
<td>5</td>
</tr>
<tr>
<td>Consolidated Edison</td>
<td>65</td>
<td>2-1/2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>6345</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** Customer counts are after exclusion of accounts with no SIC code information. All data extend through the end of 1980.

- To understand how different customers respond to TOD rates.
- To understand, if possible, why customer response varies.
- To support policymaking by predicting response in other utility areas.

We examined the patterns of electricity consumption for about 4000 of these customers who now face mandatory TOD rates. In many cases, we were able to compare average weekday load curves for the same customer before and after the introduction of TOD rates. To measure response, we contrasted their pattern of use before TOD rates with the pattern after the rates went into effect. We then analyzed response in terms of a number of factors that might influence it, including features of the rate structure, the customer's industrial classification, customer size, weather, and location.

Because this investigation was not a controlled experiment, it differs in some fundamental ways from the Los Angeles residential rate experiment.

First, in this analysis, we could not design the rate structures. However, there was wide variation in rates among the ten utilities we
studied. TOD electricity rates for business customers are typically more complex than are those for residential customers and include two or three different types of prices. For example, in addition to a charge for energy consumed during the peak period (cents per kwh), TOD rates usually impose a peak demand charge (dollars per maximum kw at peak hours during the month). Sometimes the rate structures also include a noncoincident demand charge (dollars per maximum monthly kw at any hour of the day). All three prices are represented among the ten utilities in our study. In addition, several utilities have shoulder period energy and demand charges. There is sufficient variation in all three prices, and in the length of the peak period, so that we could estimate the separate effect of each type of price.

Second, we do not have detailed information on the characteristics of individual customers. Therefore, we could not investigate how load curves of individual firms vary, for example, with number of shifts worked or the particular industrial processes used. We do, however, know industrial classifications (SIC codes) for individual customers, and we know the weather affecting all firms in a region. Thus, we can also investigate how these factors affect response.

Third, the business analysis also differs from the residential analysis in the nature of the response studied. In the Los Angeles residential analysis, rates were designed to examine changes in both pattern of consumption and total consumption. For business customers, we investigated only changes in pattern of consumption—that is, the proportion of daily electricity use occurring during the peak and off-peak periods. In this regard, the analysis is similar to the non-Los Angeles residential studies discussed in Sec. II. Without detailed data on the characteristics of individual firms, we could not expect to explain level of consumption very well. Focusing on the pattern of consumption directs our attention to factors that cause firms to shift from costly to inexpensive periods and "averages out" external factors that might cause total electricity consumption to increase or decrease—for example, a sudden upturn in regional economic activity.

**BASIC FINDINGS**

We can summarize our basic findings as follows:

- On average, business firms respond to TOD rates by reducing relative consumption in peak pricing periods and increasing relative consumption in off-peak periods. Although the magnitude of change is small—about a one percent reduction in
relative peak load\(^2\)—it is reliably estimated and not due to chance.

- Industrial customers account for all of the observed reduction to date. As a group, commercial customers have not yet responded to TOD rates in any measurable way.
- Particular industries—notably wood products, primary metals, and machinery manufacturing—respond much more than others. The average response in these industries ranges from 5 to 9 percent reduction in relative peak load.
- Within a single industry, firms differ in their responsiveness, and most firms do not appear to respond at all. Firms that do respond do so energetically. Only about four percent of all industrial customers respond in the first year of TOD rates, but on average, these firms reduce their relative peak loads by about 35 percentage points.
- Price plays a major role in response. Higher peak prices are significantly associated with larger reductions in peak load. This reduction occurs for both peak energy and peak demand prices.
- Larger customers respond more. This relationship between size and response is apparent after adjusting for prices, weather, region of the country, and industrial classification.
- Extremely hot or extremely cold weather decreases the response to TOD rates.

Figure 7 illustrates some of these findings. Response to TOD rates—reduction in relative consumption during the peak period—is plotted on the vertical axis. The difference between peak and off-peak price is plotted on the horizontal axis. Unresponsive firms—such as the average commercial customer—do not show much response at any price level and lie along the horizontal axis. The average firm in a more responsive industry—such as primary metals or wood products—lies along an upward-sloping line. For these firms, increasing the gap between peak and off-peak prices leads to a larger response. For example, if the off-peak price is held constant at 4 cents/kwh and the peak price is increased from 6 to 8 cents/kwh, the reduction in peak consumption for the average primary metals customer increases from 3.5 to 7 percentage points. Industrial classification determines which line

\(^2\)Relative peak load is the ratio of average hourly use during the peak period divided by average hourly use over a 24-hour period. This measure focuses on the daily pattern of demand and averages out the factors that shift overall consumption up or down.
the firm lies on; prices and other factors such as firm size and weather determine how far out on the line the firm is.

COST-BENEFIT ASSESSMENT

In our analysis, we address only the efficiency gains from TOD rates—whether the savings to customers and utilities exceed the costs of implementing the rate structure. As for residential users, the appropriate level of TOD prices will depend upon the underlying costs of the particular utility where they are being considered. We use average values of TOD prices across the ten utilities in the Rand data base. Our principal findings are:
• Overall, the benefits of introducing TOD rates for these large customers exceed the incremental costs. Gains in economic efficiency to the utilities and the customers average about $1000 per customer per year—even in the first year of TOD rates. When new meters are needed for TOD rates, suitable units are available at an installed cost between $300 and $600, depending on the complexity of the rate structure, and their cost would be recovered in less than one year. The annualized cost of such a meter is about $50, which is negligible compared with the $1000 average benefit.

• In principle, greater efficiency gains could be achieved by applying TOD rates only to responsive customers—for example, industrial but not commercial customers, or customers in particularly responsive industries. However, the choice between universal and selective application of TOD rates raises a number of difficult questions.

If customers are served at the same voltage level, and if other costs of serving them are identical, is it appropriate to charge them different TOD prices simply because one is a commercial customer and the other an industrial customer? As we noted in Sec. I, judging fairness in rate structures requires analyzing costs as well as balancing a number of other considerations; these are properly the responsibility of utility regulators and elected officials. But many regulators have endorsed the position that fairness means identical rates for all customers served at the same voltage level and time of day. Therefore, exempting some large businesses from TOD rates would violate this fairness notion.

Decisions about how to apply TOD rates must also consider the potential long-run effects of these rates. For example, the story for unresponsive firms might change over the longer run. Installation of computerized load management systems or storage devices for air conditioning could make commercial customers responsive. If these customers are exempted from TOD rates, their incentive to install such systems is reduced, and so are the potential long-run benefits of TOD rates. Other firms might show greater response in the long run as they experiment with changes in their production processes, create greater capacity to store energy-intensive intermediate products, or develop a middle management structure composed of individuals who “grew up” with TOD rates. If they were excluded from TOD rates, such firms might never begin this process of long-term adjustment. Our analysis of foreign data and interviews with industrial customers in other countries where TOD rates have been in effect for many years indicate
that response to the rates 10 to 15 years after their introduction was considerably larger than the early U.S. response we have observed.3

On balance, it appears that making TOD rates universal for all large business customers could yield substantial gain with little downside risk. The total benefits already exceed total meter costs for the group as a whole. If customers who did not respond in the short term are even slightly responsive after several years, then benefits will exceed costs for virtually all of these very large customers. Finally, even if some individual customers never respond to TOD rates, the risks in universally applying the rates are small. There are relatively few large business customers, and, as we have noted, metering cost is only about $50 per year per customer.

TOD RATES ON A NATIONAL SCALE

By 1981, mandatory TOD rates had been applied to fewer than 10,000 businesses—less than one-half of one percent of the business customers—in the five states we studied. Despite their small number, these firms consume more than 20 percent of the electricity used by all businesses in their states. If a similar proportion of the very largest customers in all 50 states were placed on mandatory TOD rates, about 35,000 customers would be involved. We estimate that overall benefits from applying TOD rates to these customers would exceed $32 million per year, less the required metering costs. If new TOD meters were needed for every one of these customers, the annual metering cost would be less than $2 million.

TOD rates could be extended to smaller business customers to produce additional net gains in economic efficiency. Given the response observed among customers in these ten utilities, customers with average weekday usage as low as 30 kwh per hour could, on average, produce benefits in excess of the implementation costs of a new TOD rate.

USING OUR RESULTS TO PROJECT RESPONSE FOR OTHER UTILITIES

Additional utilities and public service commissions are considering introducing TOD rates for their business customers. They can use our estimates to make a reasonable forecast of the effect of proposed rates on the load curve for that customer class. The forecast would be based

3See Acton and Mitchell (1981) and Acton and McKay (1983).
on the distribution of customers by SIC code and size, and on the
details of the proposed tariff—the magnitudes of the difference between
peak and off-peak prices and the peak demand charge. The projected
reduction in relative peak load would be applied to the present load
curve under standard rates to calculate a predicted load curve under
TOD rates.4

The projected overall response obtained by this procedure is the
result of a relatively large response by a small number of customers.
Thus, it is subject to variation if more or fewer customers happen to
respond in a particular utility's service territory. If a utility can deter-
mine which of its customers are likely to respond, it can adjust the
forecast from our model up or down as appropriate to its own particu-
lar circumstances.

We have summarized a large body of research on how residential
and large business customers respond to TOD rates. What do our
findings imply for policymakers and utility planners? In the following
section, we suggest some guidelines for policy.

4Park and Acton (forthcoming).
IV. POLICY RECOMMENDATIONS

We make the following policy recommendations, based on the findings summarized in Secs. II and III.

GENERAL RECOMMENDATIONS

The TOD rate structure should be tailored to the cost circumstances of the particular utility, with the peak period encompassing the hours of highest cost. In some utilities, TOD rates can be closely matched to peak and off-peak costs and yield about the same revenue as the current rate. In others, it will be necessary to deviate from cost-based rates to satisfy this "revenue requirement." In this case the maximum benefit from TOD rates will be obtained by setting rates to reflect consumer response.¹

Utilities and commissions considering the introduction of TOD rates can use our results to generate reasonable projections of response in their service territories. The mechanics of the projections differ for residential and business customers. Both, however, take account of the details of the tariff under consideration and some characteristics of the particular utility's customer base.

The projections will not exactly predict the results for any given utility. However, the closer the utility comes to matching its peak and off-peak electricity rates on costs, the less will deviations in use affect profits. When prices match marginal costs, increases (or decreases) in use produce identical changes in both revenue and costs to the utility, and TOD rates can be introduced with confidence that they will not harm the utility.

¹In general, the rate authority can preserve efficiency gains in two ways, keeping the price-responsive components of the rate structure as close to marginal cost as possible. The first is by adjustments across classes of customers that reflect price-responsiveness of different classes. Alternatively, within each group of customers, the greatest adjustments are made in the components of the rate structure that show the least paper-responsiveness—such as the customer charge.
RECOMMENDATIONS FOR RESIDENTIAL RATES

Since the Los Angeles findings are corroborated with consistent findings from two other experiments, we can draw on these experimental results to provide the following guidelines for policy.

*TOD rates for residential customers should be implemented selectively and designed to attract households for whom they are cost-effective.* Two approaches are feasible. TOD rates could be made mandatory for customers whose average use exceeds a given number of kwh per month, or for customers with specific major appliances. Or customers could be offered an optional TOD rate that includes an additional monthly charge to recover the cost of metering and billing.

*To establish the desirable minimum level of use for TOD rates, a utility needs to conduct a cost-benefit analysis that incorporates data on its local conditions.* For example, the utility needs to know how average use is distributed across its customers, what proportion of households have air conditioning, electric heating, or swimming pools, and how use and costs vary by time of day. Given these data, the utility can estimate the effect on its load curve by using the results of the experimental studies to predict how certain types of customers will respond to TOD rates.

Under current conditions, residential TOD rates make economic sense for a small but important fraction of customers. However, this fact reflects only short-term response to these rates; several changes might substantially alter any future cost-benefit assessment. For example, advances in metering technology may reduce the costs of TOD meters and thus lower the threshold level of total use at which TOD rates are beneficial. Over time, customers on TOD rates may purchase new appliances and load-control devices that enable them to take more advantage of variations in rates over the day. Already manufacturers produce dishwashers and swimming pool pumps with built-in timers that allow load shifting. These could easily be extended to other appliances, including water heaters, refrigerators, and freezers. Long-term shifts by households in placing long distance telephone calls, using off-peak airfare discounts, and the like suggest that customers often adapt dramatically to pricing signals. Planners should be alert to such technical and behavioral developments and adjust their TOD rate programs accordingly.
RECOMMENDATIONS FOR BUSINESS RATES

Our analysis of business response to TOD rates provides the following guidelines for policy.

*TOD rates should be required for all large business customers.* The changes in load observed to date, although small, yield annual benefits that greatly outweigh the annualized cost of TOD meters. Although slightly higher net benefits could be obtained in the short run by applying TOD rates only to responsive industrial customers, the resulting savings in metering costs would be small compared with the probable long-run gains from wider application. TOD rates for large business customers that are unresponsive in the short run will encourage long-term adjustments in practices and equipment, such as the installation of computerized load management systems. Even a small additional long-run response would repay the costs of metering all large customers, and more widespread long-run response would yield very large net benefits.

*Extension of TOD rates to smaller business customers will yield additional efficiency gains.* Our calculations suggest that even the observed short-run response justifies applying TOD rates to business customers with weekday average loads of 30 kwh per hour or more. In the long run, the cutoff point will probably be even lower.

In sum, universal application of TOD rates makes sense for large business customers but not for residential customers because of the very different scale at which these two groups of customers use electricity. The average residential customer uses only 700 kwh per month; at this level, the observed residential response to TOD rates is insufficient to offset the cost of a TOD meter. In contrast, the average large business customer consumes hundreds of times as much electricity; at this level of consumption, even the small observed average response easily pays for TOD meters. Although some modest meter costs could be avoided by limiting TOD rates only to responsive industrial customers, the savings are small in comparison with the potential gains from longer-run adjustments by other customers.

SUGGESTED ADDITIONAL READINGS

What should you do next if TOD pricing looks interesting but you want to know more about its applicability in your area? Part of the answer involves getting more utility-specific information about present and future costs of electricity, costs of supply at different times of the year, and patterns of consumer demand. These factors vary
importantly from one utility to another and may make TOD pricing a good idea for many customers in one situation and of more limited value in another situation.

In conjunction with the utility-specific cost and demand information, the results of Rand research and other research can help form the basis for benefit-cost comparisons and improved policy judgment. The bibliography includes a full listing of Rand reports on the subject.

These are our suggestions for a few of the most important studies we and others have produced in each of the major subject areas.

**Residential**


**Business**


*Quantitative Aspects of Industrial Use of Electricity Under Time-of-Use Rates in France, England, and Wales*, Jan Paul Acton and Derek


General


LISTING OF RAND ELECTRICITY REPORTS

RESIDENTIAL

Time of Day and Seasonal


Electricity Consumption by Time of Use in a Hybrid Demand System, by Bridger M. Mitchell and Jan Paul Acton, The Rand


Lessons To Be Learned from the Los Angeles Rate Experiment in Electricity, The Rand Corporation, R-2113-DWP, by Jan Paul Acton,

**Non-Time-of-Day**


**Lifeline and Distributional**


BUSINESS

Evidence from Other Countries


U.S. Evidence


Demand Forecasting and Revenue Requirements, with Implications for Considerations in British Columbia, The Rand Corporation, P-6872, by Jan Paul Acton, May 1983.


GENERAL ANALYTICAL METHODS


