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Consumer Response to Time Varying Prices for Electricity

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Abstract

We report new experimental evidence of the household response to weekday differentials in peak and off-peak electricity prices. The data come from Auckland, New Zealand, where peak residential electricity consumption occurs in winter for heating. Peak/off-peak price differentials ranged over four randomly-selected groups from 1.0 to 3.5. On average, there was no response except in winter. In winter, participant households reduced electricity consumption by at least 10%, took advantage of lower off-peak prices but did not respond to the peak price differentials. Response varied with house and household size, time spent away from home, and whether water was heated with electricity.

Keywords: Electricity pricing, Time of Use, Price elasticity

Introduction

As in most parts of the world, residential electricity prices in New Zealand do not closely reflect the variation over time in marginal production cost. There are three types of schemes that have a time based component. Some suppliers offer seasonal pricing options because production costs are higher in winter due to the widespread use of electricity for heating. Also, to take advantage of lower-cost production at night, households have had the option of installing a second electricity meter usually wired to a special heater that stores heat at night, and releases it slowly over the day. In return for a slightly lower price many households also accept 'ripple control' which allows the electricity supplier to switch their water heater off remotely (and without their knowledge) during high-cost peak periods. However, even when considered together all these schemes amount to small variations on a 'flat' retail pricing structure.

The roll-out of new meters that record electricity consumption at half hourly intervals provides opportunities to tune prices more closely to production costs. At one extreme, the retailer could vary prices half-hourly in response to variation in wholesale prices and stress on the distribution system. This 'dynamic' or 'real time' pricing challenges households to monitor prices. One option is a display mounted in a prominent place in the home. Another option, given time and investment, is enabling technology, such as a computer that monitors prices and controls appliances. At the other extreme, if patterns in electricity demand are fairly regular, the retailer could vary prices daily across a relatively small set of time periods, which is commonly referred to as time-of-use (TOU) pricing. The simplest version gives two prices for peak and off-peak periods.

This strategy is being discussed at both industry and a political levels in many countries as a means of 'managing demand'. For example, Section 1252 of the 2005 United States Energy Policy Act affirms that "… time-based pricing and other forms of demand response, whereby consumers are provided with electricity price signals and the ability to benefit by responding to them, shall be encouraged". This makes of interest the extent to which households will respond to daily variation in price. Studies conducted over the last forty years in various places and under various conditions indicate that peak demand is, on average, price inelastic. Nevertheless, even seemingly small responses can have significant effects on marginal peak production costs, potentially reducing investment in expensive peak generation or additional transmission or distribution capacity.

In this paper we report the results of a time-of-use pricing experiment conducted in Auckland, New Zealand. The study has at least three novel aspects. First, this study is not concerned about summer air conditioning. Electricity demand in New Zealand peaks in winter for heating, rather than in summer for cooling. Auckland, the largest urban area in New Zealand, is in the relatively mild north (about the latitude of Virginia Beach, Virginia and Seville, Spain). Mild summer temperatures and breezes mean very little air conditioning in summer. Winters, however, are cool, though not cold, and most heating is done with electricity. Wood is the most common alternative energy source.

With a comprehensive survey of participating households we were also able to collect a more extensive range of personal and household data than has been collected in previous TOU experiments. This has enabled the examination of some new variables to test their influence on peak and off-peak demand. A final difference is that our study, with the cooperation of a major New Zealand electricity retailer, was deliberately aimed at the 'meat of the market' as opposed to attempting to be nationally representative. The roll-out of smart meters by geographic area means that a nationally representative sample is not possible, but the selected area involves prime customers in relatively new housing occupied by somewhat older and relatively high-income households. This last factor is important if TOU policies are to be implemented on a voluntary as opposed to mandatory basis. The area under consideration in our study would be regarded as a prime target in which to encourage the early adoption of TOU pricing and the residents regarded as more capable of adjusting lifestyles to suit compared with those in more deprived neighborhoods, for example.

The study lasted for one year. Each participant household was assigned randomly to one of four pricing groups. The peak to off-peak price ratio ranged from 1.0, no price differential, to (approximately) 1.25, 1.75, and 3.5. We had access to daily peak and off-peak consumption data and half-hourly readings from both the experimental period and the previous year. We were thus able to conduct differences-in-differences analyses. Results indicate no response by participants relative to a control group that was unaware of the experiment, except in winter. During winter, participant households conserved an average of about 12% relative to control. Higher peak prices surprisingly had no effect on peak consumption, on average, but lower off-peak prices encouraged less conservation off-peak.

The level of conservation is surprising. Faruqui et al. (2009) report that in-home displays of energy consumption encourage conservation of about 7%. Thus 12% conservation in this case is relatively large, especially given that the information households received consisted only of a set of energy saving tips at the start of the experiment and a chart in their monthly bill showing daily peak and off-peak consumption over the month. The same information was also made available online if people wished to view it. That there was no variation in peak consumption with price suggests that, on average, households in all of the groups were taking the steps they could to conserve.

There was, of course, variation in the response to the pricing across the households in each group. All else constant, peak price elasticity increased with household size and decreased with floor area and electric water heating. Off-peak price elasticity also fell with the number of hours household members spent away from home. This suggests that the average responses would likely have been different if our sample houses and households varied more in their characteristics, in line with the variation in the country over all.

The remainder of the paper is organized as follows. The next section briefly summarizes the results from existing studies of time-varying prices. After this we describe the sample and experimental setup and then report the results from three sets of analysis of monthly, daily, and half-hourly data, respectively. Finally we discuss implications for electricity retailing and complementary government policy.

Background Literature

There is a small but established body of literature on the responsiveness of households to changes in the price of electricity. In this literature there are studies that examine TOU pricing (e.g. Woo 1985, Faruqui and George 2002) and others that examine critical period pricing (CCP) (e.g. Matsukawa 2001, Herter et al 2006, Herter 2007). With TOU pricing plans customers know when and by how much price varies. With CCP, the customer agrees to a pricing plan where the retail price rises, usually substantially, when the wholesale price reaches a critical point.

The conclusions from the literature on the price elasticity of electricity demand can be summarized as follows:

- Demand is price inelastic: typically, a 100% price change might produce around a 20% change in demand (EPRI 2008). Faruqui and Sergici (2009) report responses to peak period prices under a standard TOU pricing system of 2% to 6%, translating to own price elasticities of 0.02 to 0.1. This seems unsurprising: electricity prices are typically low enough that electricity payments make up only a small portion of the average household's budget, and consumers likely perceive electricity as a necessity during peak times. Price elasticities within TOU schemes seem to increase over time as people are able to adjust their lifestyle to suit the scheme. People become both more experienced at managing their life around regularly time-varying electricity prices and also are able to acquire appliances that enable them to control the timing of electricity usage.

- Several TOU studies report overall conservation effects in electricity usage (EPRI 2008). This may reflect a "Hawthorne" effect induced by knowingly participating in an experiment. As noted earlier, it may also result from receiving better information about electricity consumption.

- There appears to be considerable variation in sensitivity to electricity prices across segments of the market. Reiss and White's (2008) six year study of the Californian market indicates that nearly half (44%) of households show no short-run response to price fluctuations. Households who heat with electricity tend to be more sensitive and higher-income households less sensitive to price. Bernstein and Griffin (2006) report differences in price elasticities across the regions of the United States which they speculated result from variation in climate, available substitutes and demographic characteristics. Archibald (1982) reports that price elasticities vary seasonally.

- Some studies report estimates of the elasticity of substitution between higher-price peak and lower-price off-peak periods. Caves et al. (1984, 1989) report average within day substitution elasticities of 0.12, but with considerable variation across households. A later study by Midwest Electricity Systems reports a somewhat larger range in substitution elasticities, 0.39 to zero, partially explained by ownership of major appliances (Baladi and Herriges, 1998) while a more recent study in California reports large differences between households with and without air-conditioning.

Experimental Design

We partnered with Mercury Energy, one of the major New Zealand electricity retailers, to undertake an experiment in TOU pricing. Mercury was in the process of replacing conventional residential electricity meters with meters that send readings wirelessly every half hour.[1] Approximately 4000 meters had been installed at the time of the study, all in a suburban area to the south of the Auckland CBD.

Invitations to participate in the study were sent to 1,400 of these 4000 households. Recruiting ceased when 400 households had agreed to participate. This was the maximum sample size that the company was willing to support over the course of the project.

The process began with a face-to-face survey of the member of each household who was responsible for managing the electricity account. The survey was conducted by professional staff employed by a market-research company. Data were collected on the characteristics of:

- the house
- energy-using appliances
- household energy behaviors
- household composition and demographics.
- householder attitudes toward energy and the environment[2]

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[1] The signals from sent from each meter are received using antennas places strategically around the neighbourhoods. If a signal is blocked, the meters store information temporarily or relay the signal through meters on neighbouring houses.

[2] The environmental values scale used was the New Environmental Paradigm Scale (NEP) developed by Dunlap,Van Liere, Mertig and Jones (2000).

Sample characteristics

Table 2 provides information about household size. Most of the single-person households were older females while the largest single type of grouping is married (or partner couples) without children. On average, participants in the sample are older (median age is in the 50–54 bracket) while the mode lay in the 60-64 bracket. They are more affluent than the average New Zealand household with the median before-tax household income for the sample falling between $90,000 and $100,000 per annum before tax.

Consistent with the relatively high income, only 62 (18.7%) of the households include someone who does not work at least part time. About a third of households (35.5%) have at least two people in full-time paid employment. Across all of the people in all of the households, the average time spent away from home on a normal weekday is six hours.

Table 1: Household Composition

Number of people	Number of households	Percent of sample
1	42	12.7
2	116	34.9
3	60	18.1
4	69	20.8
5 or more	45	13.5
Total	332	100.0

There are few Māori (22) or Pacific Island (12) respondents in the sample. New Zealanders of European descent constitute by far the largest proportion of the sample (72.1%). Respondents from 233 of the 322 households have lived the majority of their lives in the city and a further 21 households have moved to the study area from other parts of New Zealand. Residents in the other 68 households have moved to the area from a wide variety of countries with the main origins being China (19), India (10) and the U.K. (9).

Comparing these figures to the New Zealand census data, the sample is older, wealthier and with fewer Māori and Pacific Islanders than the national average.

Experimental setup

Each of the participant households received two types of information. Prior to the start of the TOU pricing period, each household received a one-page list of tips for conserving energy. In addition, the monthly power bill included a simple bar chart where the height of the bar showed total daily power consumption and colors indicated the proportion of the total consumed during peak and off-peak periods.

The price paid per kilo-watt hour prior to the experiment varied across participant households. Mercury customers choose from an array of pricing plans. Some plans are tailored for low electricity users. Some plans trade off a higher fixed daily charge for a lower unit charge. A household can decrease their unit charge by agreeing to allow the power to their water heater to be switched off remotely, and without their knowledge, during periods of peak demand. Prices varied from essentially 17¢ to 21¢, with the average and the mode being just over 19c per kWh. Roughly three-quarters of the households paid either 19.9¢ or 17.4¢ per kWh.

Each of the 400 participant households was assigned randomly by Mercury staff to one of four groups:

1. Information-only group: these households were interviewed and received the initial information sheet and monthly consumption chart, but they did not face time-varying prices, so the peak/off-peak price ratio equals 1.
2. Low price differential group: A peak/off-peak price differential of 4¢. That is, peak and off-peak prices equal the household's current price plus or minus 2¢, respectively.
3. Medium price differential group: A peak/off-peak price differential of 10¢.
4. Large price differential group: A peak/off-peak price differential of 20¢.

The experiment started on 1st August 2008 (winter time in the southern hemisphere) and finished at the end of July 2009. The peak period was defined as 7 am to 7 pm Monday to Friday. All other times and public holidays were off peak.

Of the 400 initial participants, 332 remained in the study through the duration of the trial. Mercury supplied daily peak and off-peak electricity consumption and half-hourly consumption for each household over both the year of the experiment and the previous year. Mercury also supplied similar consumption information for 55 'control' households from the same suburb who were unaware of the experiment, were not interviewed, and did not receive any additional information their about consumption.

Unfortunately, not all of this data was usable. Some of the half-hourly and daily data from August through November 2007 had been 'backfilled' due to technical problems and were unreliable. Our year-on-year comparisons are consequently restricted to the eight months December through July.

Year-on-year analysis of monthly averages of daily consumption

We start by analyzing observations on the daily household consumption of the participants in the experiment averaged over each month. In response to the characteristics of the data we estimated a basic linear mixed effects (LME) model.[3] Table 3 lists the variables from the household survey that best explain the variation in the monthly average of daily electricity consumption. There are 20 monthly observations for each of the 332 participant households. Households in the control group are not included because they did not complete the household survey. There are two dependent variables: the square root of daily consumption averaged over the month and the square root of the proportion of daily consumption consumed during the off-peak period. A complicating factor emerged in that average and median electricity consumption differ significantly across experimental groups prior to the experiment. However, the distributions in consumption over-lap, and we expect much of the overall variation to be explained by variation in house and household characteristics and season. Because of these pre-existing differences in consumption between the groups noted above, the models were estimated separately for data from **before** and **during** the experimental period.

The first seven independent variables listed in Table 3 are fairly obvious, but a few require explanation. A series of monthly dummies are, not surprisingly, highly significant due to the seasonality of electricity consumption. As expected, average daily consumption increases with the size of the house and whether water is heated using electricity. Household characteristics also matter: consumption increases with household size and income and when someone in the house has special health needs that require electrical appliance to treat. Not surprisingly, average consumption decreases when householders spend more weekday time away from home.

Of interest is that the estimated coefficients on several of these variables change during the experimental period. In particular, larger estimated coefficients suggest that those with higher incomes, more people in the house, and those heating water with electricity responded relatively little to participation in the experiment.

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[3] Assumptions in the model include: random coefficients (intercepts and slopes of time within household), correlation of residuals modeled by AR (1), heteroscedasticity of residuals modeled by a power function.

Table 3: Determinants of average daily electricity consumption

Variable	Average daily consumption				Proportion off-peak			
	Before		During		Before		During	
	p-value	β	*p-value*	β	*p-value*	β	*p-value*	β
Month	0.000	—	0.000	—	0.000	—	0.000	—
Floor Area	0.013	0.001	0.002	0.001				
Electric water heating	0.002	0.404	0.000	0.611			0.002	0.033
Number of people	0.031	0.066	0.012	0.086				
Income (in bands)	0.002	0.678	0.000	0.798				
Special health needs	0.025	0.437	0.015	0.535				
Hours away from home	0.012	−0.028	0.004	−0.036	0.000	0.006	0.000	0.006
Environment values	0.011	−0.112	0.036	−0.103				
Pricing plan	0.000	—	0.000	—				

The two remaining independent variables are a bit unusual. The first indicates that, all else constant, households who profess relatively strong environmental values on average consume less electricity. It seems that in this case values translate to behavior in a significant way. Of interest is that the magnitude of the coefficient falls during the experiment; those with environmental values consume less, but not quite as much less relative to the others in the experiment. The conservation effects we report later suggest that it is the others that are changing their behavior to be more like those that express strong environmental values.

Finally, the pricing plan chosen by the household correlates strongly with consumption. This seems unsurprising because we would expect that households choose their plan based in part on their consumption patterns. That this comes out in the statistics, however, indicates that households are indeed sensitive to the differences in the pricing plans.

The right-hand side of the table indicates that surprisingly few of the variables collected in the survey explain the cross-sectional variation in the proportion of the daily consumption consumed off-peak. Not surprisingly, those who spend less time at home tend to consume a higher proportion their energy off-peak. Of potential interest is that off-peak water heating is significant only during the experiment. Some households may have been able to restrict water heating to take advantage of lower off-peak prices.

Table 4 provides goodness of fit measures for the models above in addition to other models of interest, and tests for differences across in groups. Two goodness-of-fit (GoF) measures are distinguished for each model. The first, GoF (B), measures the proportion of cross-sectional variation explained by the model, i.e., the differences across households averaged over time. The average daily consumption models fit fairly well for a cross-sectional analysis and are as good as other similar estimates, for example the study of domestic Californian consumption reported by NETL in 2009. Note that the fit for the control sample is relatively low as we lack explanatory variables taken from the household survey. Not surprisingly, the fit of the models explaining cross-sectional variation in the proportion of consumption off-peak is smaller.

The second goodness-of-fit measure, GoF (W), measures the proportion of time series variation explained by the model, i.e., the variation within each household from month to month. In this case the goodness of fit measures are relatively high because most of the time series variation is seasonal and is easily captured by the time variable.

The right-hand column labeled "Group Effect" lists the *p*-values for the differential effect of being in one of the groups exposed to TOU pricing (*i.e*., in one of the low, medium, or high price differential groups). The row labeled 'control' compares all the experimental groups against the control group and the row labeled 'info' compares the groups with a pricing treatment against the information only group. The effects should **not** be significant **before** the experimental period, and this is achieved with the possible exception of the comparison to the control group for the proportion of off-on peak usage (p=.062). Surprisingly, we would expect to see more significant differences between groups during the experiment, and that is not the generally the case, though the significant of the difference between the control group and the experimental groups becomes slightly more significant during the experimental period. It should be borne in mind that the models explaining the variation in control group consumption contain fewer explanatory variables (mainly just month and pricing plan).

Table 4: Summary of Results of Modelling Total and Proportional Usage

Dependent	Period	Comparison	GoF (B)	GoF (W)	Group Effect?
Average daily consumption	Before	Control	0.59	0.91	0.781
		Info	0.66	0.90	0.315
	During	Control	0.52	0.82	0.853
		Info	0.60	0.82	0.396
Proportion of consumption off-peak	Before	Control	0.06	0.78	0.062
		Info	0.24	0.79	0.127
	During	Control	0.05	0.64	**0.045**
		Info	0.21	0.64	0.187

The interpretation is that there is no significant annual impact of TOU pricing on either average electricity consumed or on the average proportion of daily consumption consumed off-peak.

Seasonal variation in peak and off-peak consumption

The apparent lack of response to TOU pricing reported in the previous section is surprising, but the aggregation may hide a seasonal response. In addition, the results reported above may be influenced by unobserved house or household characteristics. We can treat the problem of unobserved variables by comparing daily consumption for each household from the year before the experiment with consumption during the experiment. That is, we conduct a differences-in-differences analysis: we estimate the average *differences* across each experimental and control group in the year-to-year *differences* in each household's electricity consumption during peak and off-peak periods. Specifically we estimate the following equation using OLS:

$$\ln(Q_i) = \alpha + \sum_{g=1}^{4} \beta_g \, dG_g + \varphi \, d2009 + \sum_{g=1}^{4} \rho_g \, d2009 \times dG_g + \gamma \, temp + \varepsilon$$

Where:

Q_i is the quantity of electricity consumed each day during the peak or off-peak period by household *i*. (Taking the natural log of consumption generates estimates of the coefficients that are interpretable as percentage changes.)

α is a constant term that is the average daily peak or off-peak consumption of the households in the control group.

dG_g is a dummy variable that equals 1 if the household is in one of the experimental groups. For example, if g = 1, then the household is in the information only group. The coefficients β_g measure the difference in the average daily consumption of the households in each experimental group from that of the control group.

d2009 is a 'dummy' variable that equals 1 if the day is in 2009 (*i.e.*, during TOU pricing). The estimates coefficient φ measures the average percentage difference in control-group consumption in 2009 relative to that in the same period in 2008. We expect φ to be positive in winter because the winter of 2009 was colder than the winter of 2008.

$d2009 \times dG_g$ interacts *d2009* with a dummy that equals 1 if the household is in each of the four sample groups. Thus ρ_1, ρ_2, ρ_3, and ρ_4 measure the average percent changes from 2008 in consumption by the households in each experimental group *relative to* that of the households in the control group. These are the estimates of interest.

temp is the maximum for peak or minimum for off-peak daily temperature, so the estimate of γ measures the overall average percentage effect on consumption of a one degree change in temperature.

ε is the "error term". It represents all of the variation in household consumption not explained by the variation in temperature, the group, or the year.

To detect seasonal effects we run a series of regressions on six weeks of weekday observations of each household's consumption. The first regression uses data from late summer when vacation season has ended. Each subsequent regression starts one day later, with the last regression centered on a day in mid-winter (early July). We then plot each of the four coefficients on the $d2009 \times dG_g$ interaction variable for every regression. Thus, each of the plots shown consists of a series of six-week moving-average estimates of the percent difference in each experimental group's year-to-year consumption *relative* to that of the control group.

Figure 1 and 2 show the results of most interest. Figure 1 shows how the weekday peak-period consumption of each of the experimental groups differs from that of the control group from summer to winter. The left side of the graph indicates little systematic response to the TOU pricing experiment in summer and autumn. The standard errors vary slightly around 3%, so differences between group averages are largely insignificant.[4]

The abrupt drop in all of the curves in May corresponds to the onset of winter in the southern hemisphere and shows a significant response to participation in the experiment. Surprisingly, the variation in the price of peak electricity (from about 18 to 28 cents/kwh) seems to have no effect on peak consumption. Participant households conserved significantly in winter, but the peak-period price elasticity is essentially zero.

[4] Showing 95% confidence intervals clutters the diagrams excessively.

Figure 1: Moving six-week average difference from control in weekday peak consumption

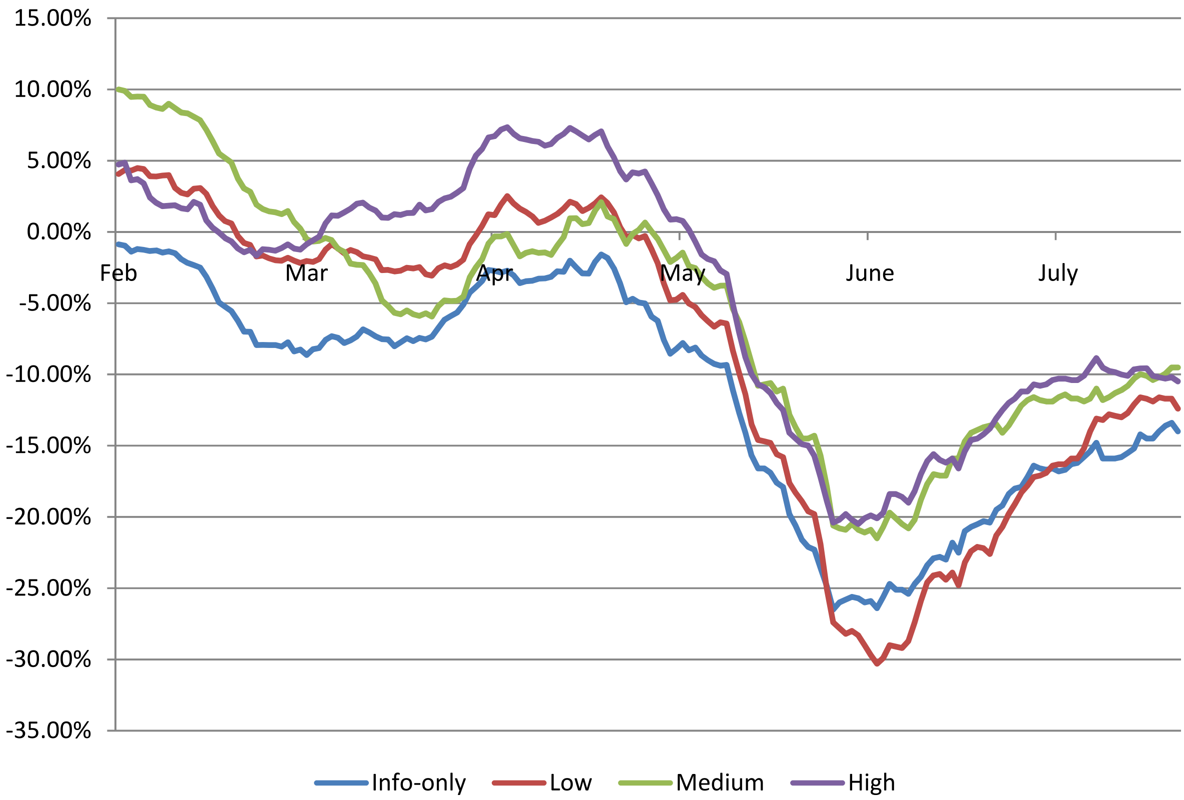
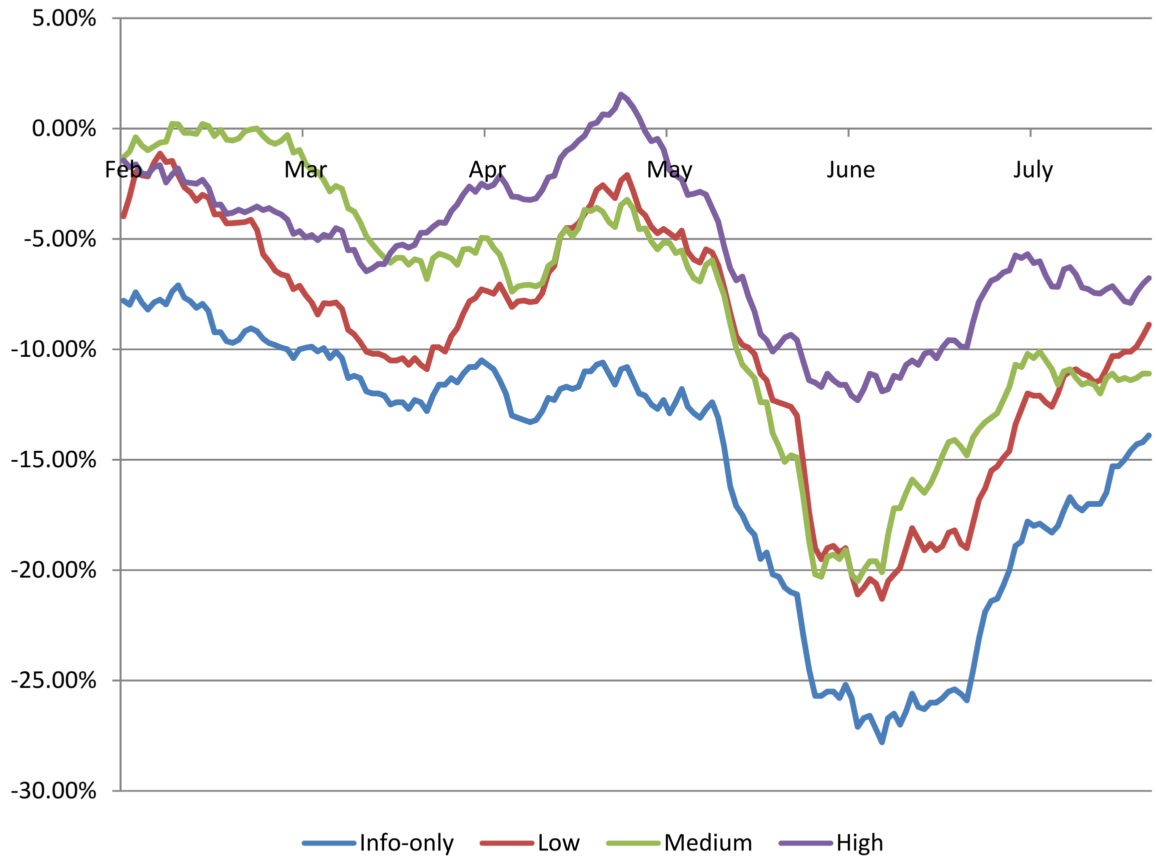


Figure 2 is the same as Figure 1 except that it shows relative changes in year-on-year weekday *off*-peak consumption, relative to control. On average, each of the experimental groups again conserves relative to control. Standard errors again vary around 3%, so conservation in summer and autumn is at least border-line significant. Conservation grows in percentage terms in winter; larger winter-time bills apparently encourage more effort at conservation, averaging about 15% relative to Control. In contrast to peak-period consumption, the groups that experience lower off-peak prices respond by conserving less than those in the Information-only group. The positions of the curves imply an off-peak price elasticity in the range of 0.1 to 0.15.

Note that the estimates from Figures 1 and 2 indicate substitution elasticities in winter in the range of 0.08 to 0.10, with a standard error of about 0.02.

Figure 2: Moving six-week average difference from control in weekday <u>off</u>-peak consumption



The year-on-year responses of individual households in each group vary from the averages shown in the figures above. Some of that variation is systematic as shown in Table 5. The table shows the house and household characteristics that are significant in winter when interacted with price. The numbers in bold are those that are statistically significant at the 5% level (or better). Households in larger houses with electric water heaters and fewer people in the household tend to respond less to increases in peak electricity price. For example, the numbers indicate that two-person households who occupy houses with 180 m^2 of floor space and who use electricity to heat water have a price elasticity of 0; this household, which is rather typical in this sample, doesn't react to higher peak prices.

The middle column of numbers reveals the characteristics that affect off-peak price elasticity. Households in larger households who spend more time away from home tend to respond less to changes in off peak prices. Households who heat water with electricity appear to take advantage of the lower off-peak prices.

The right-hand column of numbers reveals the characteristics that affect the substitution elasticity. These results indicate that households with larger homes, higher incomes, who heat water with electricity and spend more hours away from home, tend to react *less* to changes in relative prices.

Table 5: Trend in average year-to-year off-peak period price elasticity

	Price elasticity		Substitution elasticity
	Peak	Off peak	
Floor area (10 m^2)	**0.0190**	**0.0083**	**0.0100**
Household income ($10,000s)	0.0040	0.0028	**0.0069**
Household size	**-0.0650**	-0.0061	**-0.0310**
Hours away from home	0.0076	**0.0073**	**0.0063**
Electric hot water	**0.3000**	**-0.1500**	**0.0650**

Response to the peak/off-peak boundary

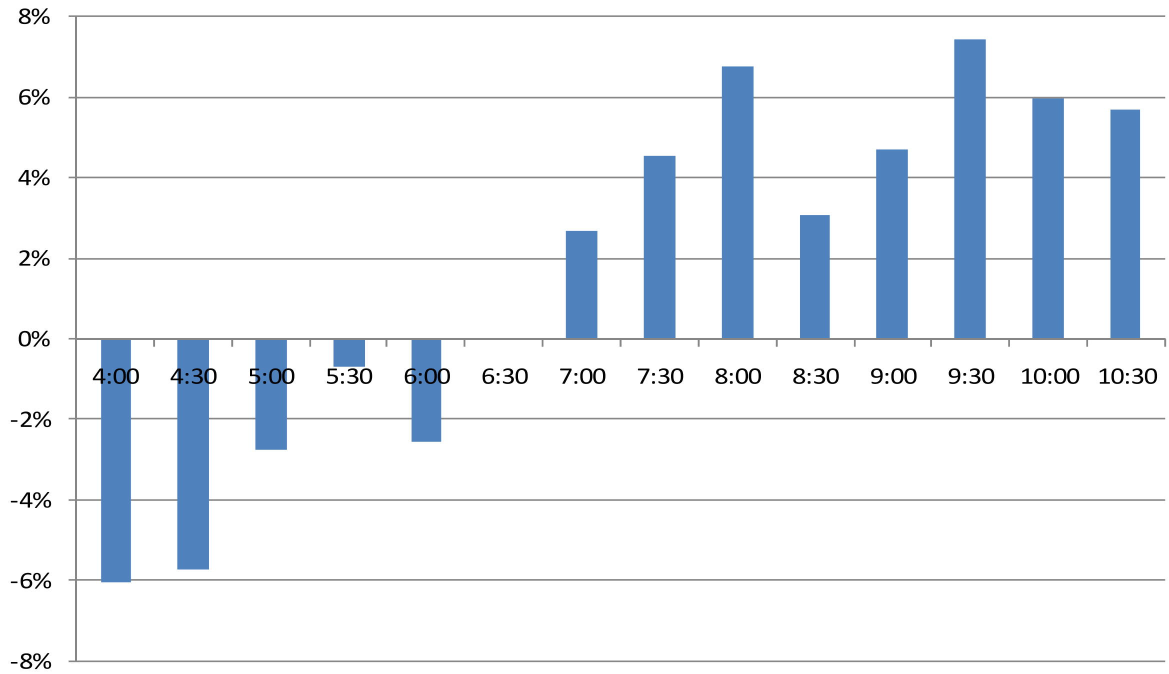
In this section we take advantage of the half-hourly readings to look more closely at changes in the pattern of consumption across the 7 pm peak/off-peak time boundary. Half-hourly residential consumption peaks at about 6:30 pm. TOU pricing should, in theory, encourage a drop in consumption prior to and a rise in consumption after 7 pm.

To investigate, we look at electricity consumption at half-hourly intervals from 4:00 pm to 11:30 pm on twenty consecutive weekdays in July 2008 (prior to TOU pricing) and the corresponding weekdays in July 2009 (during TOU pricing). Our estimating equation measures the average percentage difference in consumption during TOU pricing in 2009 from that in 2008 in each half hour of the evening peak. We expect these differentials to be negative prior to the 7:00 pm price change (households use less during the high-priced peak period), and positive after (households take advantage of lower prices off peak).

The results are shown in Figure 3. The figure indicates precisely the expected pattern of load shifting in response to TOU pricing: consumption was lower in 2009 relative to 2008 prior to and higher after 7:00 o'clock (standard errors are about 3%). Relevant is that that all three groups with a price differential respond similarly. The magnitude of the price differential did not affect the size of the shift. Again, the absolute magnitude of the price response is modest, but meaningful; consumption increased by an average of about 6% relative to the 6:30 peak.

We also conducted a similar analysis of half-hourly data around the morning off-peak/on-peak price boundary. Here the pattern of changes around the morning boundary is less tidy, but there is a significant 7% drop in consumption between 7:00 and 7:30, again indicating a significant and meaningful response to higher peak prices.

Figure 3: Average year-on-year % change in daily evening-peak consumption



Summary and conclusions

To summarize, Mercury Energy recruited 400 households to participate in an experiment in time-of-use pricing. The sample households opted-in to the experiment. The demographic characteristics of the sample households are not nationally representative: they are on average older, wealthier, and live in better insulated houses. Each sample household received a list of energy-conservation tips and a chart in their monthly bill showing daily peak and off-peak consumption. Peak to off-peak price ratios varied from 1.0 (no differential) to about 3.5, with the average of the peak and off-peak prices equal to the non-TOU price (so average peak price ranged from 18 to 28 cents per kilowatt hour and off-peak price ranged from 8 to 18 cents per kilowatt hour). The control group consists of households chosen at random from the same neighborhood who had no knowledge of the experiment. The experiment ran for one year, beginning in mid-winter.

Analysis of the data indicates:

- House and household characteristics explain variation in average daily electricity consumption, as expected, though largely fail to explain variation in the proportion of electricity consumed off-peak. Of interest is that households who profess environmental values on average consume less electricity, other characteristics held constant.
- No significant effect of TOU pricing on average daily electricity consumption or, surprisingly, on the proportion consumed on-peak when averaged over the entire year.
- Significant peak-period conservation in winter across all experimental groups relative to the control group. Winter peak conservation averages in the range of 10 – 15%. This is consistent with existing reports of seasonality in response rates.
- No significant variation in peak conservation with price across experimental groups; peak price elasticity of demand is very low.
- Similar levels of off-peak conservation, but off-peak conservation does vary with price; households on average took advantage of lower off-peak prices.
- Variation in response around the peak/off-peak boundary, with a relatively large average increase in consumption off-peak.

- Response to price varies with the floor area of the house, household income, household size, the amount of time the household spends away from home and whether the household heats water with electricity.

Of interest is the extent of winter-time conservation. Overall demand peaks in winter, so a drop of 10 – 15% could significantly decrease stress on the supply system. This conservation could result from the rather modest and low-cost information provided to participant households, or it might be the result of a so called 'Hawthorne' effect, a response that occurs simply as a reaction to participating in the experiment. While we are in the usual situation of not being able distinguish these two effects, recent reevaluations of Hawthorne effects show that they are usually small (Merrett 2007). Also, the effects we detect are occurring nearly a year after the onset of the experiment, a lag long enough to expect Hawthorne effects to have dissipated.

From a policy perspective, the information conventionally provided to households with regard to electricity prices, costs and consumption seems remarkably limited. The typical monthly bill provides no information about daily consumption patterns. All households know is that they consume more in winter (as evidenced by the larger bill). The additional information provided to these participant households costs little to supply (given half-hourly meter readings): a simple bar chart showing peak and off-peak consumption each day of the month. Yet this modest amount of extremely low-cost information appears to have encouraged significant conservation during the months of most stress on the supply system. This seems likely to represent 'low-hanging fruit'; households who haven't given much thought to electricity consumption that does not demand a large part of their household budget apparently give it some thought.

A surprise is that substantial percentage variation in peak prices (from 18¢ to 28¢/kWh) has no effect, on average, across participant groups. This appears to suggest that TOU pricing is ineffective as a demand management instrument. To understand consider the situation of a typical sample household in winter. To keep the arithmetic simple, but still relevant, assume that prior to the experiment an individual household might have paid $200 for energy (excluding the fixed daily charge) per winter month at 20¢/kWh and consumed 600 kWh during peak ($120 total) and 400 off-peak ($80). Next assume that participation in the experiment combined with better information encouraged peak conservation of 10% (the low-hanging fruit). If peak price during the experiment is 30¢/kWh, then the peak bill rises to $162/month. If the household takes advantage of the 10¢/kWh off-peak price by not conserving at all (or, more likely, by conserving on low-value consumption – the low-hanging fruit – and enjoying additional high-value consumption), then the off-peak bill falls to $40/month, for a total of $202/month, essentially no change in the monthly bill.

While our results indicate very modest responses to our TOU pricing experiment we do not believe that it is the end of the story. Our experiment was relatively short and those who were inclined to economize did what they could regardless of the price differential. Existing evidence indicates that price elasticities grow over time. If the household had committed to this pricing plan, over time one would expect to see alterations in both behavior – such as changes in work schedules – and investments in technology – such as more energy-efficient appliances equipped with timers – that help the household avoid relatively high peak prices. As noted earlier, we cannot and would not want to try to generalize our findings to the country as a whole. As a demand management technique, time-of-use pricing could be introduced as a market led product that could be developed to appeal to a segment of the population, or it could be introduced on a compulsory basis. The political complexion of New Zealand currently suggests that the former is more realistic than the latter and would avoid issues around the social consequences of forcing change upon consumers who may lack the ability to respond to time-varying prices. In that context generalisabilty to the total population is not an issue and our sample is likely to be representative of the segment that is the prime target for time-of-use pricing options by retailers.

Of interest is the large variance across the sample in when households consume electricity. We had a singular lack of success in explaining this compared to overall use. When averaged our sample did yield the recognized pattern of diurnal peaks in the morning and evening with the expected seasonal change from summer to winter. However, examining individual households reveals hardly a single dwelling that conforms closely to the aggregated pattern. There is seemingly little uniformity in the way people live, even in a fairly modern and homogeneous Auckland suburb. This is a feature that reinforces the point made in the previous paragraph that as a policy instrument TOU pricing could be politically difficult to implement in a uniform way across a whole population, and certainly research is needed to better understand the influences of electricity usage by time of day.

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