Appendix 5: Price Elasticity of Demand

General Elasticity Theory

(i) Definition and Types of Elasticity

Standard economic theory dictates that customers react to changes in prices by adjusting their demand for the goods in question. As prices rise, customers reduce the quantity demanded. As prices drop, customers increase the quantity demanded. The responsiveness of customers to price changes is called their **price elasticity of demand**.

The **own price elasticity of demand** is simply the percentage change in consumption due to a one percentage change in price. For example, if price doubles - an increase of 100 percent - and usage declines by 30 percent, then the own price elasticity equals -30 percent/100 percent, or -0.30. Elasticities are expressed as fractions and have no units.

Price elasticity of demand is therefore given by the following formulae:

$$\varepsilon = \frac{\%\Delta quantity}{\%\Delta price}$$

For a price increase along a demand curve from price P_0 to P_1, the elasticity can be calculated from the corresponding change in quantity, using the averages of prices and quantities, from:

$$\varepsilon = \frac{(Q_1 - Q_o)}{(average Q_1 + Q_2)} \div \frac{(P_1 - P_0)}{(average P_1 + P_0)}$$

In terms of its application to electricity demand, the own price elasticity of electricity typically measures the change in energy consumption arising from a change in energy price. The primary measure of interest is the change in peak period energy consumption caused by a change in peak energy price (own price elasticity: peak energy), usually as a result of a shift to a ToU or Critical Peak Price (CPP) structure. However, the change in off-peak energy stemming from a change in off-peak price (own price elasticity: off-peak energy) may also be of interest.

The own price elasticity of electricity demand may also be calculated as the change in coincident peak demand arising from a change in peak energy price (own price elasticity: peak demand). However, as the preliminary results of the Californian Statewide Pricing Pilot (SPP) showed (discussed later on), these values are very similar to (and arguably interchangeable with) the own price elasticity- peak energy estimates. It is often easier to work with consumption rather than demand, as this avoids the need to estimate coincidence and diversity factors when applying elasticity estimates.

In general, the cross price elasticity of demand measures the change in demand for one product caused by the change in price of another:

$$\varepsilon_{crossprice} = \frac{\%\Delta quantity_X}{\%\Delta price_Y}$$

If two goods are substitutes (compliments), their cross price elasticity of demand is positive (negative).

In relation to electricity demand, there are two possible applications of cross price elasticities:

- Cross price elasticity: peak/off-peak - the change in peak (off-peak) consumption resulting from a change in the off-peak (peak) price; or
- Cross price elasticity: gas (or other fuel source) - the change in electricity consumption resulting from a change in the price of a potential substitute fuel source (such as natural gas).

Taking the cross price elasticity: peak/off-peak, a positive (negative) cross price elasticity means that peak and off-peak energy consumption are substitutes (compliments) – i.e. as peak price increases, off-peak energy consumption increases (decreases).

Intuitively, you would expect that an increase in the off-peak price would result in a decrease in peak period consumption as well as off-peak consumption (as the peak price would most likely be even higher). Peak consumption would therefore have a negative cross price elasticity with off-peak price (peak and off-peak periods are complimentary).

An increase in the peak price could result in an increase in off-peak consumption, along with a decrease in peak period consumption, as customers shift usage to cheaper time periods. This would result in a positive cross price elasticity of off-peak consumption with peak price (peak and off-peak periods are substitutes). If the price elasticity of off-peak consumption with peak price was negative (peak and off are compliments), this would imply energy conservation from a peak price increase, as opposed to substituting usage to cheaper time periods.

The cross price elasticity of electricity with gas is likely to be positive - if the gas price increases then electricity consumption will increase, as most domestic gas applications have a corresponding electricity option (e.g. cooking, space heating). The cross price elasticity of gas with electricity is likely to be lower – if the electricity price rises, customers can only substitute gas appliances for certain applications – there are limited practical substitutes for applications such as internal lighting.

A closely related measure to the cross price elasticity, although measured via a different equation, is the elasticity of substitution. In the case of electricity demand, this measures the percentage shift in a customer's consumption across time periods (such as peak to off-peak) in response to price changes that alter the price relationship between the two time periods (e.g. changing the price ratio from 1:1 to 2:1). For example, in the case of a ToU rate, the peak to off-peak elasticity of substitution represents the percentage change in the ratio of peak to off-peak usage that occurs in response to a given change in the ratio of peak to off-peak prices, all other factors held constant.

An elasticity of substitution value of 0.10 implies that a peak to off-peak price ratio of 150 percent (e.g. with peak and off-peak prices of $0.25 and $0.10/kWh respectively, and calculating the percent change as the natural logarithm of the price ratio) will produce a reduction in peak to off-peak usage of 15 percent relative to the case for a flat price (i.e., -0.10 * 150 percent = -15 percent).

In economic terms, the elasticity of substitution measures the shape of the indifference curves that underlie the consumer's utility function. It is related to the own price and cross price elasticities of demand through the Slutsky equation in microeconomics:

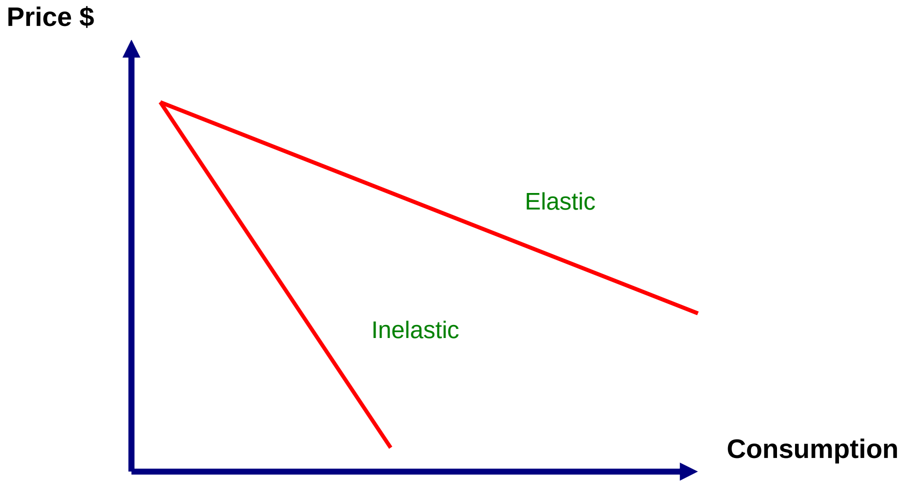
> *Own price elasticity of demand = compensated own price elasticity of demand + (income elasticity of demand * budget share of commodity in question).*

Hence own price elasticities and substitution elasticities may be compared when the necessary data are available. Caves and Christensen (1980) showed that an elasticity of substitution of 0.17 was consistent with a peak-period own-price elasticity of approximately -0.30.

(ii) Properties of Elasticity

Elasticity estimates can be classified as either **elastic** or **inelastic**. Generally, a demand response is referred to as being elastic (or highly elastic) if the elasticity is greater than 1, i.e. if a 1% change in price corresponds to a greater than 1% change in quantity. Conversely, a demand response is referred to as being inelastic if the elasticity is less than 1, i.e. if a 1% change in price corresponds to a less than 1% change in quantity. A **unit elastic** demand response occurs where a 1% change in price results in a 1% change in quantity.

Figure A5.1: Elastic versus Inelastic Demand



Knowledge of elasticities is important for pricing purposes, in terms of the effect of a price change on total revenues. If price increases along an elastic demand curve, revenue will decrease. If price increases along an inelastic demand curve, revenue will increase. If price increases along a unit elastic demand curve, revenue will be unchanged. Ramsey pricing strategies employ these concepts to maximise revenue by raising prices where demand is inelastic.

If a demand curve has a constant slope (i.e. a straight line), the elasticity is not constant and will vary at each price level. Generally, elasticity increases along the demand curve as price rises. A logarithmic shaped demand curve will have different slopes at every point but it will exhibit constant elasticity – i.e. elasticity will be constant all price points.

In general, the nature of the good, the availability of close substitutes, the fraction of income absorbed and the passage of time will all affect the magnitude of the demand elasticity.

(i) Empirical Estimates of Elasticity (Pricing Experiment Analysis)

Own Price and Cross Price of Elasticity of Demand

In econometric analysis, the elasticity at a certain range can be estimated from a typical linear regression model using the slope coefficients and the price and quantity estimates. However, in practice it is more convenient to estimate these elasticities by applying a double-log functional form (or log-linear model), as the elasticities (which will be constant) can be estimated directly from the slope coefficients:

$$\ln K_p = \ln \beta_1 + \beta_2 \ln P_p + \beta_3 \ln P_o + ... \beta_n X_n$$

Where:

K_p = consumption in ToU peak;

P_p = price of on-peak usage;

P_o = price of off-peak usage;

β_2 = the own peak price elasticity of demand, with respect to the change in peak quantity.

β_3 = the cross price elasticity of demand, with respect to the change in peak quantity.

$\beta_n X_n$ = a matrix of all other significant variables, such as appliance holdings and weather variables.

In the above model, the own price elasticity of peak energy (or off-peak energy) is estimated from the coefficient of the log of peak (or off-peak) price, based on peak (or off-peak) consumption data.

The cross price elasticity of peak energy (or off peak energy) is estimated from the coefficient of the log of off-peak (or peak) price, based on peak (or off-peak) consumption data.

Note that the above discussion represents a much simplified illustration of the analysis task to be undertaken for the pricing experiment.

(iii) The Elasticity of Substitution

The most common functional form for estimating the elasticity of substitution is that adopted in the Constant Elasticity of Substitution (CES) method. This has been used in the Californian SPP experiment and the Southern Californian Edison experiment.

A generalised form of the CES model commonly used in economics is depicted below.

$$\ln\left(\frac{K_p}{Ko}\right) = \ln\left(\frac{W_p}{1-W_p}\right) - \beta * \ln\left(\frac{P_p}{P_o}\right) + ..\beta_n X_n$$

Where

K_p = consumption in ToU peak;

K_o = consumption in ToU off-peak;

P_p = price of on-peak usage;

P_o = price of off-peak usage;

β = elasticity of substitution between peak and off-peak periods.

W_p = share of usage consumed during on-peak pricing under standard rates (anytime rates, control group).

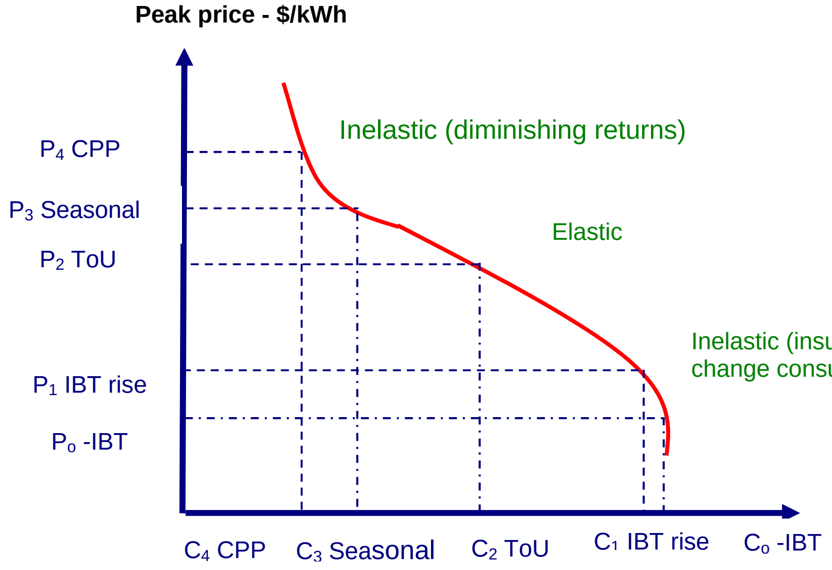
$\beta_n X_n$ = a matrix of all other significant variables, such as appliance holding and weather variables.

(iv) Elasticity of Electricity Demand

Theoretical Electricity Demand Elasticities

Based on a priori information and previous studies, it seems reasonable to assume that the demand curve for electricity across the gamut of possible pricing structures will appear as follows:

Figure A5.2: Electricity Demand Curve and Elasticity Ranges



As shown above, at lower price levels (such as the Inclining Block Tariff (IBT) level), a price rise is unlikely to produce a significant change in demand. This is because the price level is very low and represents a small proportion of the household budget. In addition, the three-month information delay effect from accumulation meters will further stifle behaviour change.

If the customer is then placed on a ToU or seasonal tariff with a significant change to the peak price, there will be a noticeable change in behaviour and the percentage change in volume will be high compared to the change in price (hence the elasticity will be larger).

However, as the price moves into the CPP realm, there is likely to be a limit on the extent to which customers are able to change peak consumption. Therefore, even though a CPP price rise will result in a greater reduction in peak demand than under the ToU rate, the reduction compared to the percentage change in price could be less, resulting in a lower elasticity value (the longer term effect may be greater).

(iv) Factors Influencing Electricity Price Elasticity of Demand

The magnitude of the price change

The principal determinant of demand response to a price signal is the magnitude of the price change itself. A change in price will result in a movement along the electricity demand curve – a change in other non-price variables (such as an increase in disposable income) will result in a shift of the demand curve.

Price elasticity of electricity demand is unlikely to be constant for varying magnitudes of changes in price (i.e. it may be non-linear). The magnitude of the price change will affect the price elasticity of demand since small price changes are likely to elicit only minor adjustment to customer behaviour while large changes may instigate changes to stocks of electric devices or more radical behavioural change.

Dynamic Pricing (e.g. CPP, RTP)

Dynamic pricing refers to tariff structures that recognise uncertainty and high cost events in wholesale supply costs and network provision of services, including real time pricing (RTP) and critical peak pricing (CPP). Price levels and time periods are variable over short periods of time.

At high peak price levels, electricity costs represent a larger proportion of household expenditure or business input costs, therefore consumers are more likely to adjust behaviour to minimise costs. However, there is likely to be a threshold level – for price rises above this level, consumers will not be able to reduce any further peak demand consumption as there is no more discretionary load available. The demand curve will become extremely price inelastic above this point - customers will be forced to pay the peak rate for all appliances that must be switched on.

Time

The short run is defined as a period in which consumers make no changes in appliance holdings to respond to price changes (usually less than 12 months) - this condition is relaxed in the long run where capital expenditure is no longer fixed. This longer-term effect involving capital expenditure on more energy efficient appliance stock is unlikely to be observed in Ausgrid Network's planned pricing experiment.

Short run elasticities take into account immediate behavioural changes such as turning lights off or reducing air conditioner usage. Long run elasticities are usually higher, on the other hand, since they take into account utilisation changes as well appliance replacement decisions.

However, some pundits suggest that the short run response can exceed that in the long run, especially where short run estimates are derived from pricing experiments. The influence of the media can have a noticeable effect here – if a pricing experiment generates substantial press coverage, there will be a greater consciousness and incentive for people to change behaviour. In time, the enthusiasm for energy efficiency diminishes.

Therefore, short run elasticity estimates may exceed their long run counterparts if a pricing experiment does not adequately adjust for the "Hawthorne effect". The Hawthorne effect[1] generally refers to the tendency under conditions of observation (usually during an experiment) for a particular test characteristic to be artificially raised.

(v) Appliance Holdings

Household usage of electricity is dependent upon both the type and quantity of appliances being used. This is because electricity is not consumed directly by households - rather, its demand is derived from the flow of services provided by a household's durable energy using appliances.

Previous customer surveys have shown that switching off lights is the most frequently nominated energy conservation measure, followed by turning other appliances off. Of course, it is the increasing penetration rate and use of air conditioners that has the most profound effect on peak energy demand in Ausgrid's franchise area. Ownership rates of other high energy consuming appliances such as clothes driers and dishwashers have levelled off in recent years.

(vi) Discretionary Consumption

The extent that electricity consumption is deemed essential will constrain the ability of households to reduce demand in response to price rises. Perceptions as to what constitutes 'necessary' consumption may be affected by a number of factors, such as appliance holdings, demographic or lifecycle related variables.

Electricity Consumption as a Proportion of Income

Electricity is a "normal" good in the sense that as income increases, consumption also increases. However, as income increases, electricity assumes a lower proportion of total household expenditure.

Income elasticity of demand estimates (which measure the percentage change in demand divided by the percentage income change) show that in the majority of cases, demand increases less than proportionally to the income change. Since electricity is a greater proportion of household expenditure for those on lower incomes, they may be more sensitive to electricity price changes than those on higher incomes. However, this potentially greater responsiveness is offset by the fact that those on higher incomes have greater discretionary electricity use (e.g. air conditioners, pool pumps).

Substitutability of Electricity

Household's responsiveness to changes in electricity prices will increase if they are able to substitute their consumption with other fuels such as gas or wood. In Victoria, for instance, utility surveys have found that the majority of households used gas for cooking, hot water and heating. This suggests a possibility of a high

[1] Originally named after a productivity study at AT&T's Hawthorne plant in Chicago.

degree of substitutability of electricity for certain activities, yet for other purposes such as lighting or electrical appliance usage there will be little or no substitutability.

This form of substitutability is only evident in the long run, where appliance stock is able to change.

Information

Customers with a Type 6 accumulation meter on an IBT only receive information on their electricity usage and cost via their bill, which for Ausgrid is issued every three months. This lag between behaviour and the price signal will dampen the response rate to a price change.

In contrast, previous CPP trials have incorporated in-house display units linked to the “smart” meter. These units provide a host of information including tariff rates, average price (including the effect of switching off appliances on average price), consumption, and technical specifications. A trial conducted by Northern Ireland Electricity, undertaken in conjunction with pre-payment meters, showed that customers on a IBT structure reduced consumption by 11% purely through the installation of in-house display units (i.e. with no change to their existing tariff). This figure reduced to 4% when a larger-scale rollout was completed, but this still highlights the potential influence of information on price responsiveness.

The media can also exert a strong influence on price responsiveness through raising customers’ awareness of energy conservation issues. Also, if a pricing experiment were to receive significant media coverage, this could raise the short run elasticity above the true equilibrium rate.

However, the SPP experiment highlighted the importance of price signals in eliciting demand reductions, as the available of information on its own does not tend to produce sustainable load shifting behaviour.

(vii) Summary of Australian Studies of Elasticity of Electricity Demand Studies

NIEIR Estimates

NEMMCO commissioned the National Institute of Economic and Industry Research (NIEIR) in 2002 to provide advice on the long run price elasticity of demand for electricity in the NEM region, as part of the preparation of the 2002 Statement of Opportunities. Based upon a review of overseas and Australian literature, using data from 1980 to 1995, NIEIR (2002) recommended the following long run elasticities of demand in Australia:

- Residential -0.25
- Commercial -0.35
- Industrial -0.38

It is interesting that in the long run, the commercial and industrial estimates for Australia are higher than the residential sector. This is in contrast to the view held by some that, in the short run, residential own price elasticities exceed the commercial and industrial values.

It is understood that these estimates could be taken to indicate the change in peak energy consumption likely to result from a given change in peak price.

For NSW and Victoria, NIEIR estimated the following long run price elasticities:

Table A5.1: Long Run Price Elasticity of Demand for NSW and Victoria

Long Run Price Elasticity of Demand	Low	High	Mean
NSW	-0.22	-0.52	**-0.37**
Victoria	-0.23	-0.53	-0.38

Since elasticity estimates are contingent upon the magnitude of price rises, NIEIR reported that these could rise to –0.4 if prices changed by 30-40% (in other words, to elicit a 4% drop in demand for electricity, price changes in the order of 30-40% would be required). This confirms that the long run estimate could be higher for higher peak price structures. However, the NIEIR study has not shed light on the issue of a “cap” on maximum demand response, which would require a lower elasticity at high critical peak rates.

Akmal and Stern (2001)

Using ABS data from 1969 to 1999, Akmal and Stern (2001) examined the residential price elasticity of demand across all types of energy in Australia. For electricity, they estimate a long run elasticity of -**0.95**. Akmal and Stern (2001) also report values from other Australian studies (mainly produced in the 1980s using data from 1960 to 1982). These studies estimated elasticities in the range **–0.55** to **–0.86**. These results appear to be unusually high.

ESC Cost Benefit Analysis of Type 5 Meter Rollout 2002

In its position paper on the assessment of costs and benefits of interval metering for electricity companies, the Victorian Essential Services Commission (ESC) adopted the following elasticity values to calculate deferral benefits:

Table A5.2: Own Price Elasticity of Demand (Applicable to New ToU Tariff Structures)

Customer Group	Standard Elasticity	Two-way communication
Residential	-0.1	-0.15
Business*	-0.025	-0.025

*It is assumed the standard business rate is correct. There is a suspected error in the appendix of the report.

The estimates used by the ESC are short run own price elasticity estimates, however, they appear to have been consistently applied across the 15 year time horizon of the study (i.e. no attempt appears to have been made to incorporate long run estimates).

The ESC obtained the residential figures by adopting the lower end of a range of possible elasticity values between –0.1 and –0.3 identified by their consultant (CRA) from a survey of studies largely from the US. The ESC decided that the lower values were justified on the basis of lower penetration of air conditioning and electrical appliances in Victoria compared with the US. For business customers, the ESC adopted a lower value of –0.025, consistent with the findings of its consultant’s literature review.

ESCOSCA Assessment of Demand Management and Metering Strategy Options 2004 (CRA)

In its report for the Essential Services Commission of South Australia (ESCOSA), the Charles River Associates (CRA) used the following elasticity values to calculate load reductions for various demand scenarios:

Table A5.3: Own Price Elasticity of Demand (Based on CPP Rates)

Customer Group	Elasticity
Residential	-0.025
SMEs	-0.004

E.g. for residential demand, this assumes that a 100% price increase would result in an average change in electricity consumption of minus 2.5%. These estimates were based on a literature review, including the recent trials in the US (SPP) and CRA’s experience with rate design.

These elasticity figures are clearly lower than the other elasticity estimates reported thus far. However, these elasticity estimates appear to be the ones used for CPP rates not ToU prices (the residential figure of –0.025% is taken from the SPP CPP rate). In the discussion in Appendix B of the report, CRA notes that the elasticities pertaining to CPP programs are very different to those reported for ToU rates – the latter ranging from –0.2 to –0.3 (in line with other estimates).

As an illustrative example, if a 5% price increase produces a 1.5% decrease in electricity consumption, elasticity will be –0.3. However, a price increase in a CPP program of 333%, using the elasticity of –0.3, would result in a 100% peak period reduction. Clearly, this is unlikely. Therefore, to capture the threshold issue, CRA apply lower price elasticities for CPP.

CRA state that CPP programs to date have resulted in consumption decreases in the order of 10% to 40%, leading to elasticities in the order of –0.02 to –0.08.

However, it is noted that there are a lot of CPP studies which support CPP elasticity values of a similar magnitude to those estimated under ToU tariffs – i.e. in the range of –0.1 to –0.3.

AGA Research Paper 1996

The Australian Gas Association (AGA) undertook a study of price elasticities for gas and electricity based on data from 1973-74 to 1993-94. The AGA computed both long and short run estimates, as well as own price and cross price elasticities. Note that in this study, cross price elasticities were defined as the percentage change in the quantity of gas (electricity) demanded in response to a one percent change in the price of electricity (gas).

The price data was based on annual ABARE data, which is comprised largely of flat rate tariff structures for the residential sector. It seems logical to expect there would be a slight difference in results between this type of long run study and a short run study such as a pricing experiment, based on higher-priced ToU tariff structures.

Table A5.4: Key Results of AGA Study on Price Elasticities

Customer Group	Elasticity Type	Time Period	Elasticity
Residential - Electricity	Own price	Short run	-0.23
Residential - Electricity	Own price	Long run	-0.24
Residential - Electricity	Cross price - (gas)	Long run	0.15
Comm. & Industrial - Electricity	Own price	Long run	-0.32
Comm. & Industrial - Electricity	Cross price - (gas)	Long run	-0.01

Overall, the study found very little difference between short run and long run estimates, which is at odds with the results of other studies. It found that the electricity long run own price elasticity for the commercial and industrial sector was higher than the corresponding value for the residential sector (-0.32 compared to –0.24).

Given its author, the study was focused on the gas market. The results showed that gas is more elastic than electricity, and electricity is a strong substitute for gas (confirmed by a long run cross price elasticity of demand with electricity of 0.83). The most reasonable explanation for this is that there are some applications (e.g. lighting) for which there are no electricity alternatives, whereas for gas there are alternatives in virtually every application.

(viii) Summary of International Studies of Elasticity of Electricity Demand Studies

<u>California Statewide Pricing Pilot</u>

The objectives of the Californian Statewide Pricing Pilot (SPP) were to estimate usage (kWh) and demand (kW) impacts from different time differentiated rate forms, estimate price elasticities and establish customer preferences for current and dynamic rate forms. It was undertaken by CRA and it involved a sample of about 2,500 customers from three different utilities (SCE, PG&E and SDG&E). The major regulatory bodies were also involved.

The following rate structures were tested (illustrated below in figure 6):

- Existing Inverted Tier – control group, based on the current 5 tier inverted block rate (levied on monthly consumption);

- Time of Use (ToU) – a new seasonal ToU two-rate structure was trialed, with a different rate for fixed on-peak (2pm-7pm working weekdays) and off-peak time periods;
- Critical Peak Fixed (CPP-F) – ToU rate with additional critical peak rate that can be dispatched during the peak period up to 15 times a year, with day ahead notice; and
- Critical Peak Variable (CPP-V) – ToU rate with additional critical peak rate that can be dispatched during the peak period for 1-5 hours, with 4 hours advanced notice (linked to existing thermostat control pilot program).

Figure A5.3: Illustrative Residential ToU and CPP-F Rates Used in SPP (in $US)

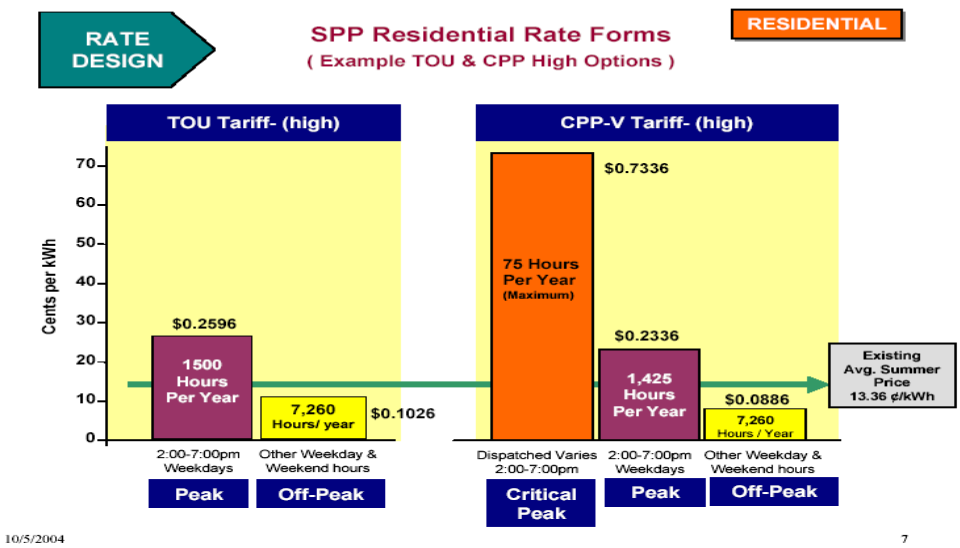


Figure A5.4: Small and Medium Enterprise Commercial Tariffs – ToU and CPP-V

Commercial / Industrial

Small and Medium Commercial Rate Forms

SPP TOU & CPP High Options

Average Prices For C&I Customers During Treatment Period ($/kWh)

Customer Segment	Rate Treatment	Price Ratio	Non-CPP Day Peak Period	Non-CPP Day Off-Peak Period	CPP-Day Peak Period	CPP-Day Off-Peak Period
Less Than 20 kW	Avg. Inverted Tier	n/a	Average Tier 0.186		Average Tier 0.186	
	TOU	High	0.272	0.094	0.272	0.094
		Low	0.325	0.159	0.325	0.159
	CPP-V	High	0.200	0.095	1.070	0.091
		Low	0.256	0.169	0.813	0.166
Greater Than 20 kW	Avg. Inverted Tier	n/a	Average Tier 0.154		Average Tier 0.154	
	TOU	High	0.224	0.100	0.224	0.100
		Low	0.254	0.144	0.254	0.144
	CPP-V	High	0.187	0.086	0.820	0.084
		Low	0.212	0.137	0.629	0.136

Source: SPP Summer 2003 Update Analysis, Charles Rivers Associates, June 9, 2004.

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Residential and small and medium sized commercial firms were tested, covering four different geographic zones:

- Zone 1 – Coastal
- Zone 2 – Inland
- Zone 3 – Inland - hot
- Zone 4 – Desert – hottest zone

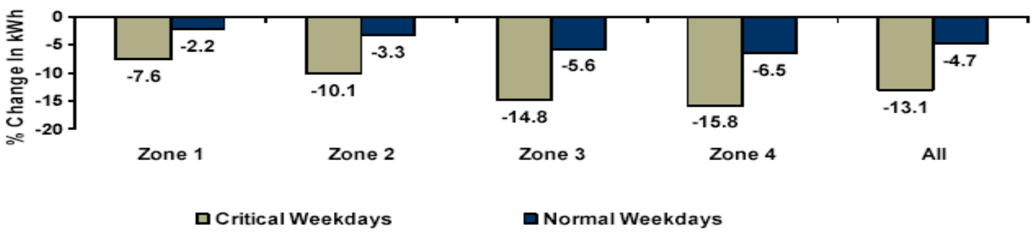
The following elasticities were tested through econometric demand models (controlling for non-price determinants of consumption such as weather, appliances holdings, etc.):

- Demand Model: Own price elasticity (for peak and off peak);
- Demand model: Cross price elasticities (for peak and off-peak);
- Constant Elasticity of Substitution model – Elasticity of substitution.

Overall results

The overall effect of the CPP-F tariff on peak energy consumption is described below.

Figure A5.5: Percentage Change in Residential Peak period Energy Use (Average CPP-F Prices, Average 2003-04 Weather)



The main overall conclusions from the SPP experiment are outlined below. No final estimates of elasticities based on the final results have been found at the time of writing.

- The CPP-F rate produced an average peak consumption reduction on CPP days of about 13%.
- Critical peak impacts on peak consumption were greater during the summer months (-14%) than the winter months (-8.1%).
- The ToU (seasonal) rate produced an average state-wide reduction in peak energy consumption of around 6% in 2003, which reduced to near 0 in 2004. There were some technical issues with the ToU results. However, the ToU rates lead CRA to question whether benefits from the seasonal ToU tariffs were sustainable over time.
- For customers on the CPP-V rate with air conditioning and smart thermostat control technology, peak consumption was reduced by about 27% - about two-thirds of this reduction was due to the smart thermostat technology, the remainder due to behavioural changes due to the higher CPP price signal.
- The price elasticity varied with income, education level, and appliance holdings – particularly air conditioning.
- The peak consumption reduction was more than twice as large in the hotter climate zones than the cooler climate zones.
- Price signals were important – providing greater information and verbally requesting load curtailment in the absence of price signals did not result in sustainable energy reductions.

- The CPP-F tariff did not have a measurable effect on overall annual energy usage – the residential reduction in peak periods was almost identical to the increased energy use during off-peak periods – the substitution effect outweighs the conservation effect.

SPP Summer 2003 Results:

The SPP summer 2003 results contained more detailed information on the calculation of elasticity values.

Figure A5.6: Actual Residential Peak Impacts by Tariff – Summer 2003

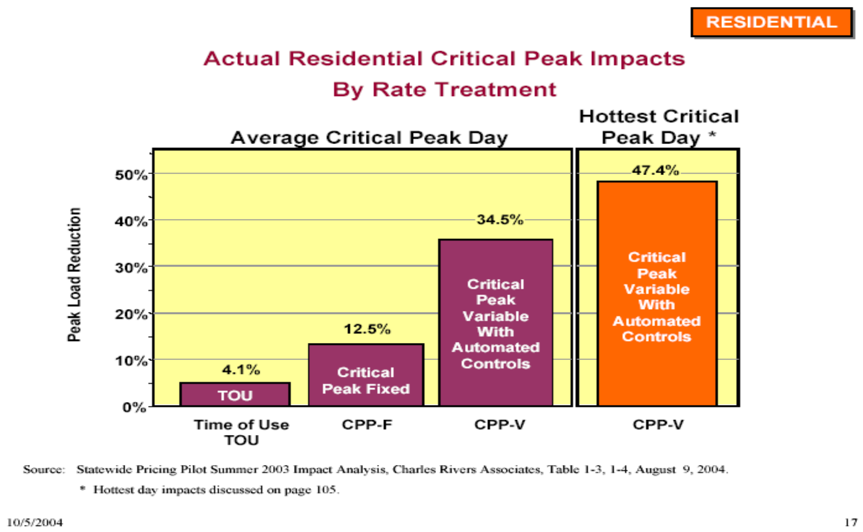
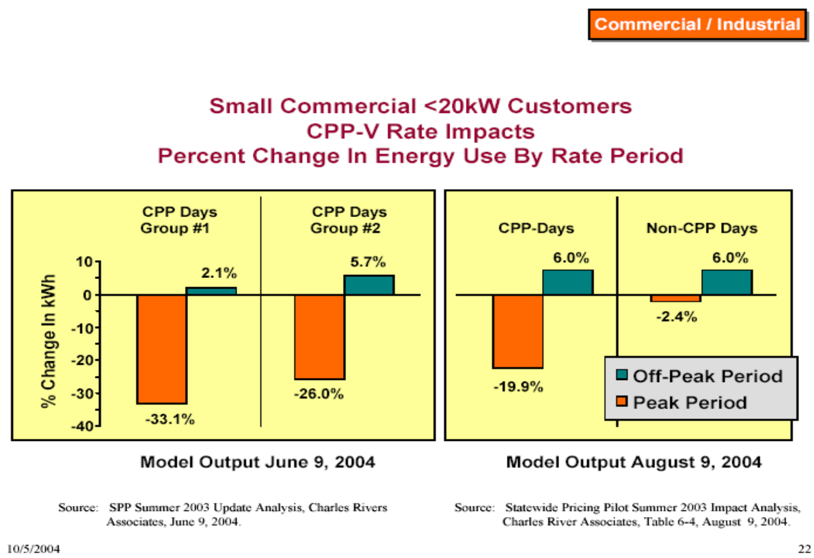


Figure A5.7: Small Commercial Customers – CPP-V Rate Impacts



The elasticity estimates are shown in the table below:

Figure A5.8: Preliminary Summer 2003 Elasticity Results

Customer Group/ Zone	Tariff Type	Quantity Measure (Cons. or Dem)	Peak Period Elasticity		Off-Peak Period		Elasticity of	Own_Price
			Own Price	Cross Price	Own Price	Cross Price	Substitution	Daily Cons.
Residential								
Critical Peak Rates								
Zone 1	CPP-F (on CPP Day)	Energy Consumption	-0.14	-0.28	-0.32	-0.13	0.02	-0.46
Zone 2	CPP-F (on CPP Day)	Energy Consumption	-0.24	-0.34	-0.24	-0.01	-0.16	-0.29
Zone 3	CPP-F (on CPP Day)	Energy Consumption	-0.34	-0.52	-0.37	-0.07	-0.16	-0.61
Zone 4	CPP-F (on CPP Day)	Energy Consumption	-0.25	-0.32	-0.27	-0.04	-0.15	-0.46
Zone 1	CPP-F (on non CPP Day)	Energy Consumption	-0.21	-0.21	-0.22	-0.25	0.02	-0.44
Zone 2	CPP-F (on non CPP Day)	Energy Consumption	-0.26	-0.11	-0.19	0.02	-0.19	-0.22
Zone 3	CPP-F (on non CPP Day)	Energy Consumption	-0.5	-0.37	-0.32	-0.17	-0.14	-0.62
Zone 4	CPP-F (on non CPP Day)	Energy Consumption	-0.25	-0.11	-0.16	-0.05	-0.12	-0.27
Smart Therm. C.G. (Z3)	CPP-V (on CPP Day)	Energy Consumption	-0.39	-0.03	0.07	-0.12	-0.39	0.07
Smart Therm. C.G. (Z3)	CPP-V (on non CPP Day)	Energy Consumption	-0.66				-0.26	
Zone 1	CPP-F (on CPP Day)	Coincident Peak Dem	-0.17	-0.41				
Zone 2	CPP-F (on CPP Day)	Coincident Peak Dem	-0.22	-0.29				
Zone 3	CPP-F (on CPP Day)	Coincident Peak Dem	-0.37	-0.57				
Zone 4	CPP-F (on CPP Day)	Coincident Peak Dem	-0.25	-0.41				
Smart Therm. C.G. (Z3)	CPP-V (on CPP Day)	Coincident Peak Dem	-0.51	-0.24				
ToU Rates								
Zone 1	ToU Rate (all w'days+CPP)	Energy Consumption	0.03	-0.18	-0.24	-0.02	0	-0.33
Zone 2	ToU Rate (all w'days+CPP)	Energy Consumption	-0.13	0.38	0.15	0.07	-0.2	0.17
Zone 3	ToU Rate (all w'days+CPP)	Energy Consumption	-0.59	-0.31	-0.29	0.38	-0.1	-0.55
Zone 4	ToU Rate (all w'days+CPP)	Energy Consumption	-0.27	-0.28	-0.37	0.02	-0.24	-0.46
Zone 1	ToU Rate (CPP days)	Coincident Peak Dem	-0.02	-0.3				
Zone 2	ToU Rate (CPP days)	Coincident Peak Dem	-0.13	0.43				
Zone 3	ToU Rate (CPP days)	Coincident Peak Dem	-0.51	-0.17				
Zone 4	ToU Rate (CPP days)	Coincident Peak Dem	-0.28	-0.52				

Source: CRA, "Statewide Pricing Pilot Summer 2003 Impact Analysis" (January 2004), CRA, California

The main conclusions drawn from the preliminary SPP summer 2003 elasticity results were:

- The own price elasticities for CPP-F rate on CPP days lie within an interval of –0.14 and –0.34.
- The own price elasticity for CPP-V rate is –0.39 on CPP days and –0.66 on non-CPP event days.
- The cross price elasticity of peak demand (off peak) is negative in many cases, indicating goods are compliments not substitutes. This is intuitive also – if the price of off-peak consumption is reduced, customers will not use more at peak times. If the off-peak price increases, the peak period price will probably be even higher so peak consumption will decrease.
- For ToU elasticity on weekdays, the elasticities lie within an interval of 0 and –0.59.
- Elasticity of substitution figures are significant for most zones and lie between –0.11 and –0.25, with a median value of –0.14 (this is close to value found by EPRI). Customers are definitely price responsive.
- Own price elasticities for peak consumption are very similar to own price estimates for coincident peak demand. This implies these figures can be applied to either analysis. This is intuitive – if demand is lower during all peak periods (assuming substituted peak consumption does not cause a new peak during off-peak hours, due to the shape of the load duration curve), it will be lower during the peak period.
- The preliminary summer results showed that elasticity estimates on non-CPP days were higher than on CPP days. CRA note that this suggests that average responsiveness diminishes as prices increase significantly and suggests that caution when applying elasticity values based on moderate, non-CPP pricing to predict changes in energy demand associated with price ratios that typically apply on CPP days.

Other International Studies

King and Chatterjee (2003) reviewed 56 papers on electricity demand published since 1980. These studies expanded on earlier studies by using additional methodologies for analysing price response and by testing dynamic pricing structures such as CPP. The results are shown below in Figures 13 and 14.

Table A5.4: Range of Estimates of Residential Own-price Elasticities of Demand

The Low and High Values Bracket the 80 Percent Confidence Band					
	Short-Run			Long-Run	
Low	Medium	High	Low	Medium	High
-0.12	-0.20	-0.35	-0.60	-0.90	-1.20

Table A5.5: Summary Statistics for 56 Elasticity Studies

The Low and High Values Bracket the 95 Percent Confidence Band				
Geography	n	Short-Run Own-Price Elasticity		
		Low	Medium	High
California	13	-0.13	-0.21	-0.28
U.S.	36	-0.23	-0.28	-0.34
Other industrialized countries[2]	7	-0.28	-0.47	-0.66

These results suggest that the ratio of long run to short run elasticities ranges from 3.5 to 1 for high elasticity range down to 5:1 for the low elasticity range, with a medium ratio of 4.5 to 1.

Several researchers, including Caves, Christensen, and Herriges (1983), have looked at the transferability of elasticity estimates from one geographical area to another. Caves et al. use a modelling approach based on a hybrid demand system. The key price effects are estimated as an elasticity of substitution between peak and off-peak periods. Table 15 shows the consistency of elasticity results calculated form the data collected in five residential time-of-use experiments.

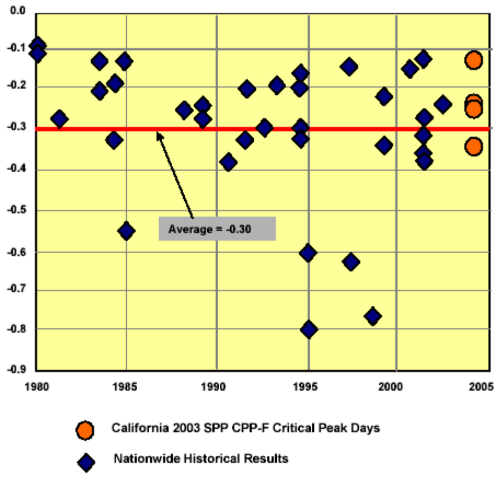
Table A5.6: Residential Response to ToU rates Across Several Experiments Calculated as Substitution Elasticities

In a California Energy Commission presentation in August 2004, Rosenfeld, Herter, Hungerford, Jaske,

Experiment	Estimate of Elasticity of Substitution
Carolina Power & Light	0.19
Connecticut	0.10
Los Angeles 1	0.19
Los Angeles 2	0.16
Los Angeles 3	0.13
Los Angeles 4	0.10
Los Angeles 5	0.13
Los Angeles 6	0.12
Los Angeles 7	0.11
SCE 1	0.14
SCE 2	0.16
Wisconsin 1	0.13
Wisconsin 2	0.13
Wisconsin 3	0.13
Pooled Estimate	0.13

McAuliffe, Messenger and Wilson update King and Chatterjee's (2003) US-wide historical estimates with the summer results of the Californian SPP experiment. This provides a summary of the range of own-price elasticities in the US, with an average elasticity of -0.3.

Figure A5.9: Own Price Elasticities, California SPP versus US Wide Historical Results



Source: Predicting California Demand Response, Chris King and Sanjoy Chatterjee, Public Utilities Fortnightly, July 1, 2003, p.27-32 w/ CPP-F data added by Roger Levy, May, 2004

ESC (2002) reports the results of a CRA survey of empirical studies that have been conducted primarily in the US to measure the responsiveness of customers to time-varying rates. The key findings of that survey were:

- The demand for electricity by time-of-use is inelastic in the short run, with most values for own-price elasticity of peak-period energy usage falling between –0.1 and –0.3.
- The own-price elasticity of demand for on-peak usage is typically larger than the own price elasticity of demand for off-peak usage.
- Price elasticities will be higher for households that have air-conditioning systems than for households that do not.
- Price elasticities for residential customers are significantly larger than for small to medium business customers.

Filippini (1995) examined how responsive demand is to time-of-use tariffs for peak and off peak periods in Switzerland. He estimated that the short-run own price elasticities are -0.60 during the peak period and -0.79 during the off-peak period (this is in contrast to the common finding that on-peak elasticity of demand is more elastic than off-peak demand).

The elasticities are higher in the long-run, -0.71 during peak and -1.92 during the off-peak period. Filippini also found that cross price elasticities - the responsiveness of peak period consumption to changes in the off-peak price and vice versa - were positive. That is, in response to a rise in the peak period price, consumers will tend to reduce their consumption in the peak period and increase their consumption in the off-peak period, so peak and off-peak consumption are substitutes. Filippini concludes that time-of-use pricing seems to provide consumers with a strong incentive to find a substitute for peak-period consumption, serving to reduce the need for extra capacity.

A later study by Filippini (1999) found that the overall price elasticity (combined peak and off-peak) to be around -0.3. This suggests that when the overall price rises (in both peak and non-peak periods) opportunities for substitution are lessened and overall price response is lower.

Reiss and White (2002) examined household electricity demand in California using data from 1993 and 1997. In their study, they estimate a mean annual own price elasticity for electricity of –0.39. They suggest that their result is slightly higher than the typical range estimated using utility data of –0.15 to –0.35 and close to an earlier study of Los Angeles households that identified a price elasticity of –0.35.

Reiss and White (2002) also generate estimates of price elasticities for households of different characteristics. The key results are:

- Households with electric space heating or air conditioning exhibit higher price elasticities (-1.0 for space heating and –0.6 air conditioning) than households without such systems (close to zero for households without either of these systems);
- Lower income households tend to be more sensitive to energy prices than households with medium to high incomes; and
- Elasticities are lower for households that use high amounts of electricity (the authors recognise that this is a slightly unusual result in light of the two previous conclusions and suggest that it reflects both a weak correlation between household income and ownership of space heating/air conditioning and the fact that households tend to substitute toward more price-inelastic electricity use as income rises).

Summary of Elasticity of Electricity Demand Studies

Name of Study/Author	Year	Customer Group	Type of Elasticity	Short run/long run	Quantity Measure	Elasticity Value/Range	Price Type/Level	Comments
Australian								
NIEIR	2002	Res. - Aust.	own price	long run	consumption	-0.25	IBT-ToU range (?)	Based on lit. review, data 1980-95
NIEIR	2002	Commercial - Aust.	own price	long run	consumption	-0.35	IBT-ToU range (?)	Based on lit. review, data 1980-95
NIEIR	2002	Industrial- Aust.	own price	long run	consumption	-0.38	IBT-ToU range (?)	Based on lit. review, data 1980-95
NIEIR	2002	Res.(?) - NSW	own price	long run	consumption	-0.37 mean (low - 0.22, high-0.52)	IBT-ToU range (?)	Based on lit. review, data 1980-95
NIEIR	2002	Res.(?) - Vict.	own price	long run	consumption	-0.38 mean (low - 0.23, high-0.53)	IBT-ToU range (?)	Based on lit. review, data 1980-95
Akmal and Stern	2001	Res. - Aust.	own price	long run	consumption	-0.95		ABS data 1969-99, no experiment, unusally high.
ESC (Type 5 rollout case)	2002	Residential (normal)	own price	both (?)	peak cons.	-0.1 (range -0.1 to -0.3)	ToU	
ESC (Type 5 rollout case)	2002	Residential(2 way comms)	own price	both (?)	peak cons.	-0.15	ToU	
ESC (Type 5 rollout case)	2002	Business	own price	both (?)	peak cons.	-0.025	ToU	
ESCOSA (CRA) -	2004	Residential	own price	both (?)	peak cons.	-0.025	CPP	CRA lit. review, low due to CPP effect.
ESCOSA (CRA) - DM Options	2004	Business (SME)	own price	both (?)	peak cons.	-0.004	CPP	CRA lit. review, low due to CPP effect.
AGA	1996	Residential - Electricity	own price	short run	consumption	-0.23	Flat, some ToU	Study based mainly on flat tariffs - may differ for ToU elasticities.
AGA	1996	Residential - Electricity	own price	long run	consumption	-0.24	Flat, some ToU	Hardly any difference with short run estimates.
AGA	1996	Residential - Electricity	cross price - (gas)	long run	consumption	0.15	Flat, some ToU	Indicates long run substitution with gas (not significant)
AGA	1996	Comm. & Industrial - Electricity	own price	long run	consumption	-0.32	Flat, some ToU	Comm. & Industrial more elastic than residential in long run.
AGA	1996	Comm. & Industrial - Electricity	cross price - (gas)	long run	consumption	-0.01	Flat, some ToU	Indicates long run compliment with gas (not significant)
AGA	1996	Residential - Gas	own price	long run & short run	consumption	-0.78	Flat, some ToU	For residential, gas is more price elasticitic than electricity.
AGA	1996	Residential - Gas	cross price (electricity)	long run	consumption	0.83	Flat, some ToU	Electricity is a strong substitute for residential gas use.

Name of Study/Author	Year	Customer Group	Type of Elasticity	Short run/long run	Quantity Measure	Elasticity Value/Range	Price Type/Level	Comments
Statewide Pricing Pilot								
SPP - summer prelim, CRA(Cal.)	2002-04	Residential	own price	short run	peak cons.	-0.14 to -0.34	CPP - Fixed	
SPP - summer prelim, CRA(Cal.)	2002-04	Residential	own price	short run	coincident peak demand	-0.17 to -0.37	CPP - Fixed	Almost the same as peak cons. values.
SPP - summer prelim, CRA(Cal.)	2002-04	Res.(thermostat CG)	own price	short run	peak cons.	-0.39 on CPP days, -0.66 non-CPP days	CPP - Variable	
SPP - summer prelim, CRA(Cal.)	2002-04	Residential	own price	short run	peak cons.	0 to -0.59	ToU (weekdays)	
SPP - summer prelim, CRA(Cal.)	2002-04	Residential	cross price	short run	peak cons.	-0.11 to -0.52	CPP - Fixed	Negative value - compliment not subst.
SPP - summer prelim, CRA(Cal.)	2002-04	Residential	substitution	short run	P to OP cons.	mean -0.14, (low-0.11, high -0.25)	CPP - Fixed	Close to EPRI research

Name of Study/Author	Year	Customer Group	Type of Elasticity	Short run/long run	Quantity Measure	Elasticity Value/Range	Price Type/Level	Comments
Other International								
King and Chatterjee	2003	Residential - all	own price	short run	consumption	mean -0.2, (low -0.12, high -0.35)		Reviewed 56 electricity demand studies since 1980, 80% confidence interval.
King and Chatterjee	2003	Residential - all	own price	long run	consumption	mean -0.9, (low -0.6, high -1.2)		
King and Chatterjee	2003	Residential - US	own price	short run	consumption	mean -0.28, (low -0.23, high -0.34)		36 studies in US, 95% confidence interval.
Caves, Christensen, Herriges	1983	Residential	substitution	short run	P to OP cons.	0.1 to 0.19	ToU	
Sayers and Shield	2001	Commercial	own price	long run	consumption	-0.435 to -0.8313		
Wade	1999	Commercial	own price	long and short run	consumption	-0.24 short run & -0.25 long run		Used in US Dept. of Energy modelling study of energy industry
Wade	1999	Residential	own price	long and short run	consumption	-0.23 short run & -0.31 long run		
Fatai, Oxley and	2003	Residential (?)	own price	short run	consumption	-0.18 to -0.24		Expect higher than Aust., >space
Fatai, Oxley and Scrimgeour	2003	Residential (?)	own price	long run	consumption	-0.44 to -0.59		Expect higher than Aust., >space heating.
American Electric Power	1992						CPP (in-house display)	
GPU			Substitution	short run		-0.31 to -0.4	CPP (in-house display), 50c/kWh P	significantly higher than normal ToU
Gulf Power "Good Cents Select", California	2002	Gulf Power		short run		-0.37	ToU P $0.093/kWh	
Gulf Power "Good Cents Select", California	2002	Gulf Power		short run		-0.11	CPP $0.29 kWh, load control device	high customer satisfaction, limited warning of critical peaks
Electricite de France (EdF) Tempo	1996 onwards			short to long run		-0.79 peak, -0.18 off-peak.	CPP type - 2 intra-day rates, red, white, blue days, different expenses	peak and off-peak found to be substitutes (ie no conservation), but cross price elasticites small, much higher rates than in US studies, trial rates higher than actual rates
Swiss Households (Fillipini)	1995	Filippini	own price	short run		-0.6 peak and -0.79 off peak	CPP ??	results appear to be counter-intuitive
Fillipini (Swiss households)	1999	Residential	substitution	short run		-0.3		suggests compliements - earlier Filippini studies showed + subst., suggests substitutes.
Reiss and White	2002	Residential	own price	all		-0.39 (range -0.15 to -0.35)		Electric space heating, a/c - higher elasticities.
Nan and Murray	1991	Residential	own price	short run		-0.611		
Beenstock et al.	1999	Residential	own price	long run		-0.579		
Tiwari	2000	Residential	own price	short run		-0.7		
Herriges and King	1994	Residential	own price	short run		-0.2 (summer)		
		Residential	own price	short run		-0.4 (winter)		
Archibald et al.	1982	Residential	own price	short run		-0.4 (summer)		
		Residential	own price	short run		-0.48 (winter)		
Barnes et al.	1981	Residential	own price	short run		-0.55		
Dubin	1985	Residential	own price	short run		-0.16		
Dubin and McFadden	1984	Residential	own price	short run		-0.25		
Goett and McFadden	1982	Residential	own price	short run		-0.17		
Houston	1982	Residential	own price	short run		-0.28		
McFadden et al.	1977	Residential	own price	short run		-0.37		
Chang and Hsing	1991	Residential	own price	short run		-0.33		
Silk and Joutz	1997	Residential	own price	short run		-0.62		
Bjorner et al.	2002	Residential	own price	short run		-0.4 to -0.13		
Vaaga	1993	Residential	own price	long run		-0.27		

Use of Price Elasticities for Avoided Cost Analysis

Where elasticity estimates are to be used in conjunction with long run marginal cost (LRMC) estimates to calculate network avoided costs resulting from a new tariff structure (e.g. expansion of ToU rollout programs, Advanced Metering Infrastructure business case), the following formulae is to be applied:

$$Deferral_{j,k} = NPV\ @WACC \sum_{t=1}^{n} \left[Cost_{j,k} \times Elasticity_{t} \times ElasticityFactor_{j} \times \right.$$

$$\left. \left[\%\Delta Price_{j,k} \times \%Energy_{j,k} \right] \right]$$

Where:

Deferral$_{j,k}$ = avoided network costs (capital and operating expenditure) in ToU period j (i.e. peak, shoulder or off-peak) for pricing structure k (i.e. ToU, CPP);

WACC = Discount rate, which is the Weighted Average Cost of Capital from Network Determination;

n = number of years in the marginal cost study (typically 10-15);

Cost$_{j,k}$ = network LRMC allocated to ToU period j under tariff k using method of intercepts analysis and *%Energy*$_{j,k}$;

Elasticity$_t$ = own price elasticity of electricity consumption estimate for year t;

ElasticityFactor$_j$ = elasticity scale factor based on time period – 1 for peak, 0.8 for shoulder and off-peak;

% Δ *Price*$_{j,k}$ = percentage price change at ToU period j under tariff k compared to existing tariff; and

%Energy$_{j,k}$ = proportion of total energy usage at ToU period j under tariff k.

When LRMC is applied in this manner, the elasticity estimates are applied cumulatively, not on an incremental basis. Appendix 1 provides empirical proof of this application.

(viii) Key conclusions and recommendations

- Based on domestic and international studies, the common range for short run estimates of the own price elasticity of electricity (peak consumption) is –0.1 to –0.3. Estimates may be as low as –0.025 and as high as –0.6.
- Long run estimates of the own price elasticity of residential demand exceed the short run measures, as consumers purchase more energy efficient appliance stock. The long run value can be around –0.6, although some studies have placed this value above 1.
- There are less studies available on the own price elasticities of commercial and industrial customers. In the short run, some have suggested a very inelastic response (in the order of –0.005). However, in the long run, some studies suggest that the elasticity value can exceed the residential estimates (-0.35 to –0.8). More information on this sector would be useful.
- Although even the typical higher end of these estimates (e.g. -0.3 range) is still considered to be relatively inelastic in economic terms, it is sufficient to defer enough demand to save a substantial amount in avoided costs (especially when all upstream and downstream benefits are factored into the analysis). Hence a planned network project can still yield a positive NPV value on the back of a relatively inelastic price response.
- The results of studies by CRA suggest that although the elasticity increases with higher price levels, the elasticity value can actually decrease at high CPP prices, as there are diminishing returns as discretionary load is limited.
- The summer 2003 SPP results suggest that own price elasticities for peak consumption are practically the same as own price elasticities based on peak demand. This implies elasticity figures can be applied to either analysis. This is intuitive – if demand is lower during all peak periods (assuming substituted peak consumption does not cause a new peak during off-peak hours, due to the shape of the load duration curve), it will be lower during the peak period.
- The substitution effect associated with peak price rises dominates the conservation effect (positive cross price elasticities of off-peak consumption with peak price).
- Elasticities in warmer climates can be as much as double those in cooler climates.
- High air conditioning penetration rates drive higher elasticities.
- Although the provision of information can affect elasticity response, price signals are necessary in order to produce sustainable load reductions.

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