Peak Pricing

An analysis of the South Australian Electricity Market

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This thesis is submitted to the University of Adelaide as a partial fulfillment for the Degree of Bachelor of Economics (Honours)

Declaration

Except where appropriately acknowledged this thesis is my own work, has been expressed in my own words and has not previously been submitted for assessment

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Abstract

This paper examines whether there is justification for the implementation of peak pricing in the South Australian electricity market. Peak pricing in the South Australian electricity market appears to improve social welfare by improving consumer surplus, but this analysis is based on strong assumptions that include constant marginal cost and zero cross elasticity of demand. An analysis of peak pricing was investigated with varying cross elasticity of demand. It was found that a greater cross price elasticity value the greater the social welfare improvement in the off-peak model due to a greater increase in off-peak electricity consumption. However, the converse happens for the peak model. In the analysis of benefits outweighing costs, the estimated metering charge to consumers is approximately $120, but the savings on household bills due to time of use pricing almost covers the charge. However, the total expenditure on metering is likely to exceed savings on network costs of approximately $134 million over ten years. Hence, the costs are likely to outweigh the benefits of metering, the case for time of use pricing based is weak.

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1. Introduction

In the South Australian electricity market, peak demand is generally 1.1 to 1.2 times greater than average demand. However, peak demand between 3.00pm and 8,00pm almost doubles the average demand on a few days in the year, as shown in Figure 1. In order to meet peak demand, there is over-investment in network and generation capacity, of which a significant proportion is underutilized for majority of the time.

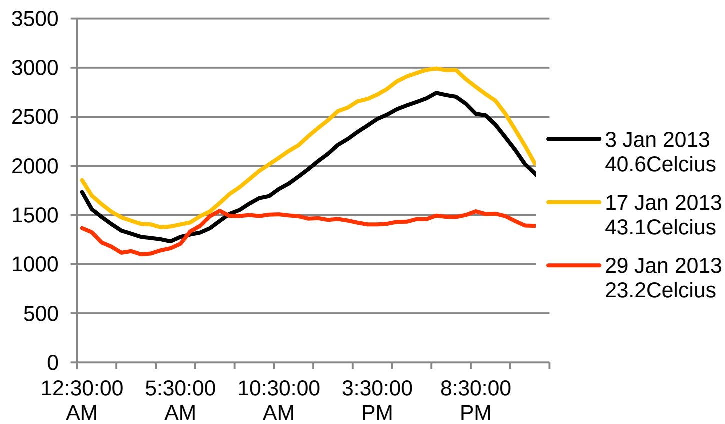

Figure 1 Daily Electricity Demand (AEMO, 2013)

Variations in electricity are due to many different factors, including but not limited to seasonal changes in weather, humidity, time of day, and ambient light. When different categories or types of demand are served jointly, and involve different costs of service—as is the case with electricity—then there may be efficiency gains from differential pricing—or price discrimination. However, the current retail tariff imposed on residential and most commercial consumers is a flat tariff, using a simple accumulation metering system.[1] The flat tariff does not reflect an accurate price signal and is priced such that the off peak electricity customers compensate for peak usage.[2] The flat tariff is priced higher than the efficient price during off-period, leading to a lower off-peak consumption and inefficiency due to dead weight loss. Furthermore, peak users on the flat tariff have no specific incentive to reduce electricity usage during

[1] This is a simplification: there is a higher flat rate for summer, and a low, over-night, “Controlled Load” tariff for hot water systems.

[2] The South Australian Government deregulated electricity and gas retail prices on 1 February 2013 and as a result the regulator (ESCOSA) no longer has responsibilities in the setting of gas or electricity standing contract prices or electricity reselling prices.

peak times, which contributes to the peak demand problem of overinvestment in capacity. This thesis examines the case for peak pricing in the South Australian electricity market from efficiency and distributional aspects. In particular, this paper will concentrate on the simplest form of time of day (TOU) pricing, estimating its efficiency benefits, to be set against the costs of implementation of a new metering system.

1.1 Industry Background

The South Australian electricity market is a participant in the National Electricity Market (NEM), which includes New South Wales, Victoria, Queensland, South Australia and Tasmania. In the NEM, the power systems in each state are interconnected, which enable electricity transmission between states. However, for the purpose of this thesis, the South Australian electricity market is examined in isolation.

The five main players in the electricity industry are the generators, transmitters and distributors, retailers, customers and regulators. Generators supply electricity to retailers in the wholesale market, who on-sell this to the end-users or consumers whom participate in the retail market. The electricity supplied by generators is transported by transmission networks at high voltage over long distances to reach consumers. Approaching the vicinity of consumers, high voltage electricity is converted to low voltage for distribution to households, commercial offices and industrial use. The regulators in the South Australian electricity market ensure fair pricing and reliability in the wholesale market, network and distribution systems and retail market.

1.1.1 Regulatory Arrangement

The Australian Energy Regulator (AER) regulates the wholesale energy market, transmission and distribution networks in South Australia and other NEM states. The AER monitors bidding, dispatch and prices, network constraints and outages, and forecasts demand and capacity in the NEM wholesale market. The transmission and distribution network operators submit proposals to the AER, who then determine the maximum tariff transmitters and distributors can charge and the maximum revenue they can earn.

The Essential Services Commission of South Australia (ESCOSA) regulated South Australian retailer's tariffs up to February 2013. The Commission has since deregulated retail pricing on grounds that the retail market in South Australia is sufficiently competitive. The Commission currently acts as a price monitor to prevent anti-competitive behavior amongst the retailers (ESCOSA website, 2013).

The problem of peak load can be attributed to the failure of regulators to implement strategies that minimize the growth in peak load. In addressing the issue of peak demand, regulators have only ensured that peak demand is met by an over-investment in generators and network infrastructure. Alternative strategies that involve demand side management (DSM) could have been implemented to prevent the development of the peak load problem. When the installation of air conditioners became more popular amongst households, the Commission should have taken the opportunity to address the possible growth in peak demand by introducing peak pricing. Currently, 90 per cent of households in South Australia have sunk costs in air conditioners (Duffy, 2011) and could regret their investments if peak-load pricing was introduced. Households made their decision to invest in air conditioners based on the flat tariff at that time, but may have decided otherwise if differential pricing were introduced.

1.1.2 Generators

In South Australia, generators include large scale commercial generators that use fossil fuels such as brown coal and gas. South Australia also has power generated from renewables, such as wind farms and distributed non-commercial photovoltaic panels. Brown coal provides for base load electricity in South Australia because these generation plants could take up to 48 hours to start up (AEMO, 2010). On the other hand, gas-fired generation plants can be fired up in 20 minutes (AEMO, 2010) and thus can provide for peak load. However, there are some instances where gas-powered generation also provides for base load. Renewable energy is non-controllable, so cannot be relied upon to provide for peak, hence only gas-powered generation provides for any peak load not met by other sources. The following table provides a summary of electricity generation in South Australia by fuel type:

Table 1 SA Electricity Generation by Fuel Type (AEMO, 2013)

Financial year	Coal Technology share	Gas Technology share	Wind Technology share	Interconnectors Technology share	Rooftop PV Technology share	Other Technology share
2008-09	34%	50%	14%	2%	0%	1%
2009-10	31%	47%	17%	4%	0%	1%
2010-11	29%	45%	21%	4%	0%	0%
2011-12	21%	44%	25%	8%	2%	0%
2012-13	15%	47%	24%	10%	3%	0%

The generators participate in the wholesale electricity spot market operated by the Australian Energy Market Operator (AEMO). AEMO ensures that electricity dispatched by the generators meets demand. The generators submit their bids, which include the quantity of electricity supplied at a particular price to AEMO. The bids for generation are prioritized in order, from the lowest to highest price. AEMO then determines the required quantity of electricity supply and selects the generators for dispatch (in increasing prices) to meet demand and the spot price for every half hour based on the bids. Hence, as total demand increases, the generators with relatively higher prices are dispatched. The half-hour wholesale price paid to the generators is the price of the bid from the generator that supplies the last unit of electricity as per demand, that is the highest-price source that is utilised.

1.1.3 Transmission and Distribution

ElectraNet is South Australia's only transmission network service provider, and is regulated by the AER. ElectraNet's transmission network consists of 5,600 kms of transmission line and has 88 high-voltage substations. SA Power Networks is the distributor in South Australia. ElectraNet and SA Power Networks charge retailers such as Origin Energy and AGL Energy transmission and distribution tariffs respectively, for transporting electricity through their networks.

1.1.4 Retailers

The retailers purchase electricity from the wholesale market at spot price and on-sell to end-users, such as households and commercial customers on a flat tariff. Retailer's costs comprise of wholesale energy costs, transmission costs, distribution costs, green policy costs and retail costs, which for example includes administration costs, customer retention and acquisition costs. The retail tariff is a flat rate that is revised each financial year and hence does not reflect the half-hour spot price in the wholesale market

Table 2. Residential Customers: Average Consumption and Average Price (ESCOSA, 2012)

Year	Average Consumption (kWh)	Average Price - NOMINAL (c/kWh)
1989/90	5,483	9.68
1990/91	5,423	10.09
1991/92	5,231	10.64
1992/93	5,510	10.94
1993/94	5,258	11.15
1994/95	5,478	11.19
1995/96	5,403	11.21
1996/97	5,712	11.72
1997/98	5,828	11.86
1998/99	5,994	12.12
1999/00	6,093	12.37
2000/01	6,390	13.94
2001/02	6,085	14.24
2002/03	5,980	16.06
2003/04	5,963	18.27
2004/05	5,656	18.00
2005/06	6,060	17.46
2006/07	6,000	18.25
2007/08	5,979	18.72
2008/09	5,909	19.65
2009/10	6,215	21.27
2010/11	5,965	23.24
2011/12	5,434	27.25

1.1.5 Customers

Retail customers mainly consist of residential, small commercial and in some circumstances small industrial customers. The larger customers that include government institutions, universities and industrial customers buy on contract. The main contributor of peak demand is residential customers, as their electricity consumption is greatly influenced by ambient temperature. Commercial and small industrial customers' energy use is less dependent on weather. On average, industrial and commercial customers take up to approximately 72 percent of energy use (AEMC, 2012). However, on a peak day, residential customers account for 50 percent of peak demand due to a high usage of air conditioners during hot summers (AEMO, 2010).

2. Literature Review

2.1 Theory of Peak Pricing

Peak pricing is a form of differential pricing on non-storable goods with periodically variable demand, such as electricity (Crew et al, 1995). The problem with a flat tariff would be that the fluctuations in demand would result in excessive spending on supply capacity, of which a substantial proportion will be underutilized in times of low demand. Blackouts or brownouts could also occur if there is insufficient capacity. Thus, there is a case for peak pricing to improve efficiency and welfare distribution, depending on the costs of implementation and any distributional considerations. The cost of serving peak demand for the retailers would be greater than off-peak demand as peaking generators charge a higher price to recover their capital costs. Hence, during the period in which demand for a good is expected to be high, the price of electricity should be higher to provide more accurate price signals.

2.1.1 Ramsey Welfare Maximization

The optimal price for electricity can be derived using the Ramsey approach that involves the maximization of a social welfare function, which draws on the exposition in Crew et al (1995). The maximization problem is provided in the following equation:

$$\max_p W = TR + S - TC \qquad (1)$$

where W is the net social welfare, given by the sum of consumer surplus (S) and the producer surplus (difference between total revenue and total costs, TR-TC). (1) is typically subject to the zero profit breakeven constraint for the producers.

Peak-load pricing can be seen as a form of Ramsey pricing, with the unique feature in which the maximization of welfare is concerned with the provision of a vector of products (in this case electricity) differentiated only by the time of consumption.

Consumers' preferences are expressed in separable form using equation (2):

$$U(x, m, \theta) = V(x, \theta) + m, \qquad \theta \in \Theta \qquad (2)$$

where x =(x_1, x_2, ….,x_n) is the vector of goods supplied and *m* is the Hicksian aggregate that represents the utility from all other consumption. The θ term accounts for the various types of consumers and the density of θ consumers is expressed as $f(\theta)$.

The Ramsey maximization problem can be expressed as:

$$\max_{p\geq 0} W(p) = \int^{\theta}[V(x(p,\theta),\theta) - \sum^{T} p_i x_i(p,\theta)]f(\theta)d\theta + \pi(p) \qquad (3)$$

Subject to

$$\pi(p) = \sum_i^T p_i x_i(p) - C(x) \geq \pi_0 \qquad (4)$$

Where *C(x)* is the cost function, $\pi(p)$ is profit and $\pi_0$is a desired profit level (retailers are assumed to break even in the long run so profit level is zero). The first expression in (3) represents consumer surplus, which is the aggregate excess of willingness-to-pay over price.

The solution to this maximisation problem is

$$\sum_{j\in T} \frac{p_j - c_j}{p_j} \varepsilon_{ij} = -\kappa \qquad \forall i \in T \qquad (5)$$

Where ε_{ij} is the cross-elasticity of demand between consumption in two different periods and κ is the Ramsey number, which is positive except for when the profit constraint is not binding. Since the assumption is that retailers break even, the Ramsey number is assumed to be zero.

2.1.2 Steiner Peak Pricing Model

For the purpose of this thesis, there will be two sub-aggregations of demand, into a ‘peak’ period, and ‘off peak’, with two corresponding ‘time of day’ prices. This allows Steiner’s model of peak pricing (1957) to be applied, by using the following assumptions:

I. Demand curves are assumed to be independent and the cross price elasticity of demand is zero. This means that price charged in one period does not have an impact on the quantity demanded in the other period

II. The cost function is assumed to be linear and only one technology is available. *b* is the operating marginal cost and β is the per day cost of providing a unit of capacity.

III. There is no uncertainty in demand and supply.

IV. There is no extra cost involved in implementing the pricing scheme.

Figure 1 and Figure 2 displays Steiner's peak pricing model, with two demand curves for off-peak demand (D_{OP}) and peak demand (D_{PEAK}). The flat tariff at P_F corresponds to an off peak demand at Q_{op} and a peak demand at Q_p. Pricing at the flat tariff is inefficient as there is dead weight loss due to the overconsumption of peak demand and the under-consumption of off-peak demand. The dead weight losses are illustrated by the shaded areas in Figure 2.

At a lower off-peak price of P_{op}, consumers will consume more relative to the consumption at the flat tariff equilibrium – Q'_{op} is greater than Q_{op}. Furthermore, at a price that is greater than the flat tariff, the peak tariff, P_p would lead to a reduction in demand during peak period. The allocation resulting from the peak pricing system is more efficient, if priced correctly, as the overconsumption is reduced during peak period and the under-consumption at off-peak period has increased.

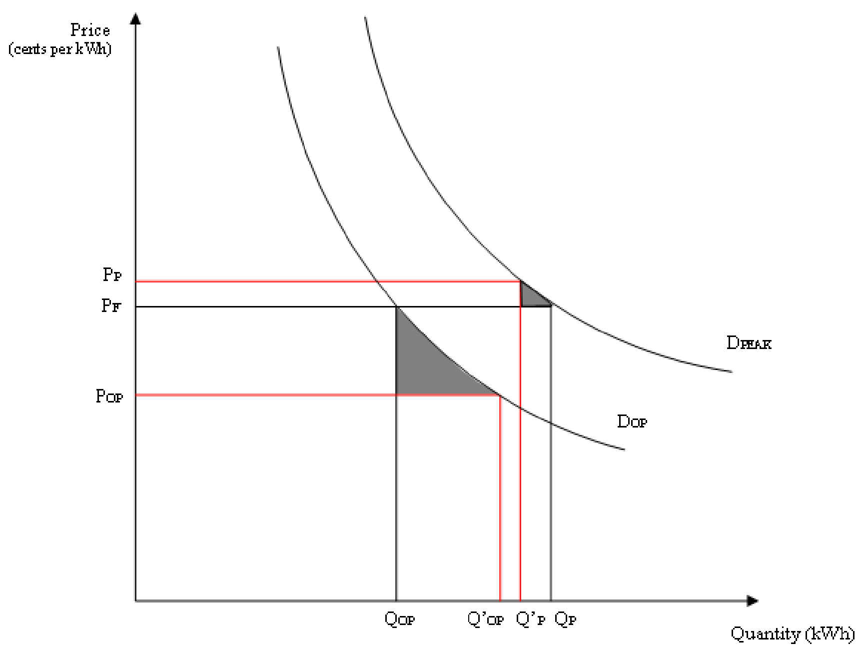

Figure 2 Steiner's Peak Pricing Model

2.2 Survey of Applications to Electricity

Fluctuations in the price of electricity are captured in the wholesale market as prices are continuously changing every half hour. However, the variation in prices is not passed on to the retail market, in which only a time-invariant tariff is implemented. Since the retail price of electricity does not reflect the demand-supply of the electricity market efficiently, retail customer's demand for electricity is therefore independent of the costs of the actual system load. Differential pricing under this circumstance can serve as a demand-side management tool to discourage consumption of electricity during peak times. There are several surveys that have applied peak pricing theory to the electricity market, such as Borenstein et al (2002) and Abrate (2004).

The three main systems of peak pricing that Abrate (2004) discussed in his survey paper are real-time pricing (RTP), time of use pricing (TOU), and critical peak pricing (CPP). In the system under RTP, retail electricity prices fluctuate in line with wholesale electricity prices. In Abrate's (2004) findings, the RTP is the system that provides most accurate signaling for supply-demand balance, capturing a greater proportion of variation in the wholesale market compared to other pricing systems. However, time lags between the price announcement and price implementations could affect the accuracy of RTP; the greater the time lag, the less effective RTP is as a price signal (Borenstein et al, 2002).

Compared to the RTP pricing mechanism, the TOU system does not reflect variation in wholesale energy price very accurately, only capturing 20 percent of this variation (Boreinstein, 2002). Under the TOU system, a fixed price is allocated to each time block, and this price is set months in advance. Hence, TOU does not capture the price variation within the time block as the RTP pricing system does. However, the TOU system is more commonly implemented than RTP for residential households and small businesses because it minimizes the risk of these small customers' exposure to the extreme swings in electricity prices. The cost of implementation of metering for the TOU system is also cheaper than for the RTP system.

Critical peak pricing is implemented when the predicted electricity demanded will be critically high, the system operator will notify users of the steep hike in price on short notice. CPP is normally implemented on days with extreme weather; the number of times this occurs is quite infrequent, approximately 15 days a year or under (Etrog Consulting, 2012). CPP is usually five to eight times greater than off peak prices and is effective in reducing peak usage (AEMC, 2012). This system can be implemented alongside TOU.

The effects of dynamic pricing are highly dependent on the elasticity of the consumer's demand curve. Consumers with more elastic demand will have more flexibility in reducing peak load, and will benefit from a lower price during the off-peak period. However, consumers with inelastic demand during the peak period will be unable to reduce peak demand, and will have to pay more for electricity at a higher price. This raises distributional concerns and it has been argued that the dynamic pricing system should be optimal. Hyndman and Fan (2009) have done an econometric study on price elasticity of demand in South Australia. The paper found that demand in the peak period is more elastic than demand in the off-peak period. Their findings are described in more detail in section 3.1.3.

2.3 Thesis Contribution

The objective of this thesis is to examine the impacts of peak pricing in the South Australian retail electricity market, from an efficiency and distribution point of view. This paper will investigate the question of whether or not the benefits outweigh the costs in the implementation of a two period TOU pricing system in South Australia. If the benefits do not outweigh the costs of implementation, is peak pricing still worth imposing?

In this paper, the impacts of TOU pricing are only of interest in the retail electricity market, which includes residential and small business customers that are on a flat tariff. Industrial customers that are on a complex time-variant tariff and residential controlled load (hot water system) tariffs will not be addressed. A two period TOU pricing system will be investigated and is sufficient for the objectives of this paper. Although the RTP pricing system may be more efficient in capturing price-variation in the electricity market, the RTP system has too many price variations within a period and will be too complex for the analysis of this paper.

3. Methodology

3.1 Time of Use Pricing

Time of use pricing in this paper examines the effect of a two-period peak pricing system for peak and off-peak, however further studies can add complexity by including three-periods in the time of use system; peak, shoulder and off-peak.

3.1.1 Demand

The demand curves are the aggregated hourly-demand for an average household in a year. A peak demand curve would thus represent aggregated demand of an average household at 3.00pm up to 8.00pm. An off-peak demand curve would represent aggregated demand for an average household for off-peak period, which is any other time aside from 3.00pm to 8.00pm.

The demand curves are estimated using the average household consumption per annum, which is approximately 5500kWh and percentage use of peak demand, found as 30 percent (AEMO Data, 2013) of average consumption. The price of electricity was 33.7 cents per kWh (AEMC, 2013) in nominal 2012/13 value was also used to estimate the demand curve price elasticity of demand (PED) in Table 3 and Table 4. Hyndman and Fan (2010) found the PED for electricity in South Australia using the following model:

$$\log(\bar{y}_i) = \sum_{j=1}^{J} c_j \log(z_{j,i}) + \epsilon_i \qquad (6)$$

Where,

$\bar{y}_i$ is the average annual demand. $z_{j,i}$ is the economic variables of price, population, gross state product, and degree days at time t; and the respective impacts on demand is measured by the coefficients c_j. The impact of price on demand is thus measured by c_p.

The own price elasticity of demand is determined using the following equation:

$$\varepsilon = \frac{\delta \ln(q)}{\delta \ln(p)} = c_P \qquad (7)$$

where ε is the own-price elasticity of demand.

Hyndman and Fan (2010) obtained alternative results using the following model:

$$\log(\bar{y}_i) = \sum_{j=1}^{J} c_j z_{j,i} + \epsilon_i \quad (8)$$

The own price elasticity of demand is determined using the following equation:

$$\varepsilon = (e^{C_p} - 1) z_{p,i}, \quad (9)$$

where c_p is the coefficient of price that is estimated using equation (8), different from the c_p in equation (6) and $z_{p,i}$ is the price in year i.

Their findings using equation (7) were classified by time and seasons. The average of the elasticities at 4pm and 7pm in summer will be used for the purpose of determining the peak demand curve; and the elasticities at midnight and noon will be used to estimate the off-peak demand curve.

Table 3 Price Elasticity of Demand, using (7)

Time of Day	Entire Year	Winter	Summer
Midnight	-0.505	-0.515	-0.375
Noon	-0.405	-0.365	-0.425
4pm	-0.370	-0.240	-0.540
7pm	-0.600	-0.635	-0.595

Similarly, their findings using equation (9) were classified by time and seasons.

Table 4 Price Elasticity of Demand, using (9)

Time of Day	Entire Year	Winter	Summer
Midnight	-0.455	-0.510	-0.295
Noon	-0.335	-0.395	-0.270
4pm	-0.310	-0.260	-0.355
7pm	-0.490	-0.645	-0.435

Since Fan and Hyndman (2009) have estimated two sets of elasticities, two sets of demand curves will be estimated using these values and their differences will be compared.

3.1.2 Retailer's Cost

In Steiner's model of peak pricing, the retailers are assumed to break even, hence the optimal price structure is such that marginal cost is the off peak price and the marginal cost plus capital cost is the peak price. However, the pricing system proposed in this paper will vary the variable price at peak and off-peak. The case for the proposed pricing system is that the wholesale energy cost component of the variable tariff varies every half-hourly throughout the day, with notable fluctuations. Hence, passing on the wholesale energy costs to households provides a more accurate price signal to them as a demand side participation management system. The price at peak and off peak will be assumed to equal the marginal cost of peak and off-peak respectively.

There are two parts to the existing retail electricity tariff structure; the variable charge and the daily supply charge, which is a fixed service charge extended to consumers regardless of their usage. This paper focuses on the variable tariff for peak and off-peak periods, whilst the fixed charge is assumed to cover any fixed costs. The variable charge to the retailer consists of the wholesale energy cost, transmission cost, distribution cost, retail costs and renewable policy costs. Table 5 summarizes the breakdown in current time-invariant retail price.

Table 5 Price Breakdown (AEMC, 2013)

Price Breakdown	Units	Flat Tariff	Peak Tariff	Off-Peak Tariff
Wholesale	c/kWh	9.4	11.4	4.1
Transmission	c/kWh	3.2	3.2	3.2
Distribution	c/kWh	11.8	11.8	11.8
Retail	c/kWh	4.4	4.4	4.4
Green Schemes	c/kWh	5.9	5.9	5.9
Total	c/kWh	33.7	35.7	28.4

In this analysis, the transmission cost, distribution cost, retail costs and renewable energy cost will be assumed to be the same for peak and off-peak tariff. The wholesale energy cost will be considered in two parts; the off-peak price and peak-load price. The average wholesale energy cost during the off peak period is 4.1 cents per kWh, which results in an off-peak price of 28.4 cents per kWh. The average wholesale energy cost during peak load is 11.4 cents per kWh, which leads to a peak price of 35.7 cents per kWh.

This is a modification on Steiner's model, in which he found efficient off peak price to equal marginal cost and optimal peak price to equal the total of marginal cost and per unit capital cost. The similarities between Steiner's model and this pricing mechanism is that wholesale energy cost during peak periods are priced highly so that the peak capacity generators are recover their costs in the short amount of dispatch time they provide. Under the circumstance in which peak pricing reduces demand, there are concerns that the generators will change their bidding strategies to recover capital costs. This will be address in more detail in Section 0.

3.1.3 Cross Price Elasticity of Demand (CED)

Filippini (2010) found positive values of CED for residential electricity demand in Switzerland. The cross price elasticity of off-peak to peak demand was estimated to be in the range of 0.793 and 0.917; the cross price elasticity of peak to off-peak demand was estimated to be between 0.363 and 0.407.

There were no values of cross price elasticity in Australia, only values for elasticity of substitution were available. The CED in Australia is most probably different from the CED in Switzerland due to factors such as climate. In this paper, the welfare effect of CED is examined by varying CED from a value of 0.1 to 1.

4. Time of Use Pricing and Implications

The implications of time of use (TOU) prices on social welfare using Steiner's peak pricing models will be examined in this section. Section 4.1 will discuss the change in social welfare analysis using the Steiner base model of peak pricing. The fundamental basis of the Steiner peak pricing model is that welfare is maximized subject to the condition that firms break even. The producer surplus will be zero since the price is set to equal the marginal costs.

4.1 Steiner Model of Peak Pricing

The models using Steiner's assumptions are illustrated in Figure 3 and Figure 4. As mentioned previously, the welfare analysis is examined with the assumptions that the demand functions are independent and the cost function is constant. The demand functions represent an average household's hourly-demand for electricity[3]. The separate analyses stem from demand curves that were estimated using two sets of elasticities in Table 3 and Table 4. In both models, the flat tariff is set at 33.7 cents per kWh, with peak demand at 308 kWh and off peak demand at 208 kWh. The average household bill at the flat tariff is approximately $1,853 per annum.

4.1.1 Analysis of Model 1

Figure 3 displays the demand-supply model with peak elasticity -0.395, and off peak elasticity –0.28. The peak price is 35.7 cents per kWh and the off peak price is 28.4 cents per kWh. The electricity use in peak period at the peak price is 301 kWh after the increase in price, which is 7 kWh of electricity less than the peak consumption at the flat tariff. The decrease in off-peak price led to a rise of 218 kWh in electricity consumption during off peak period, which is 10 kWh greater than off-peak consumption at the flat tariff.

[3] Supporting calculations for the demand curve can be found in Appendix A.

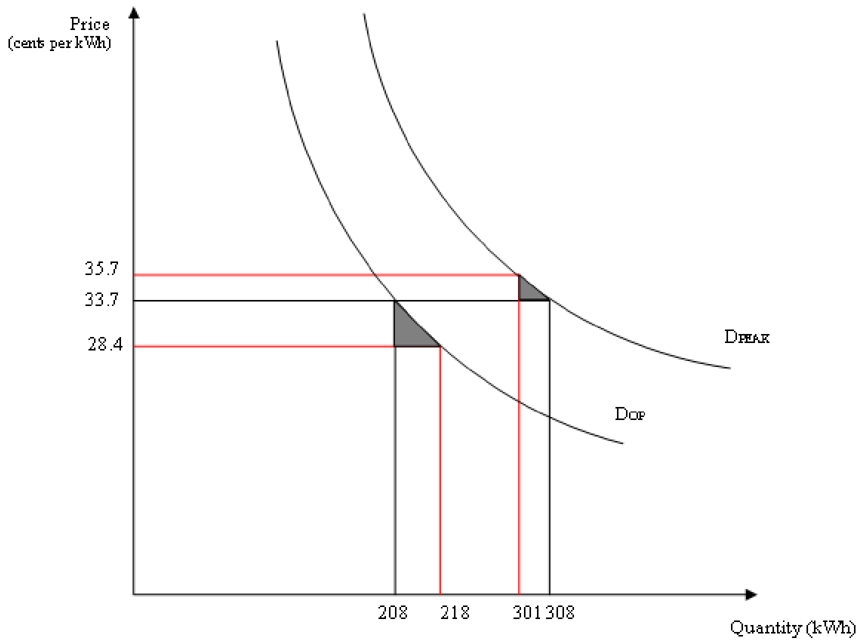

Figure 3 Model 1

The consumer surplus loss in the peak model is 610 cents, whereas the gain in consumer surplus is 1128 cents. The overall consumer surplus gain is 518 cents, of which 500 cents is from transfer gains. The efficiency gains are represented in the shaded area in Figure 3. The efficiency gain in the peak model is 8 cents, whereas the efficiency gain in the off-peak model is 26 cents. At TOU pricing, the household bill is $1,713 per annum[4], which is a saving on the household bill of $140 per annum. Thus, TOU pricing improves consumer surplus and decreases average household expenditure on electricity bills.

4.1.2 Analysis of Model 2

Figure 4 illustrates the demand-supply model with peak elasticity -0.568, and off peak elasticity –0.4. Similarly, the optimal peak price is 35.7 cents per kWh and the optimal off-peak price is 28.4 cents per kWh. The electricity use in peak period at the optimal peak price found to be 299 kWh, which is 9 kWh of electricity less than the peak consumption at the flat tariff. The electricity consumption in off peak period was found to be 223 kWh, which is 15 kWh greater than off-peak consumption at the flat tariff.

[4] Supporting calculations for the household bill can be found in Appendix B

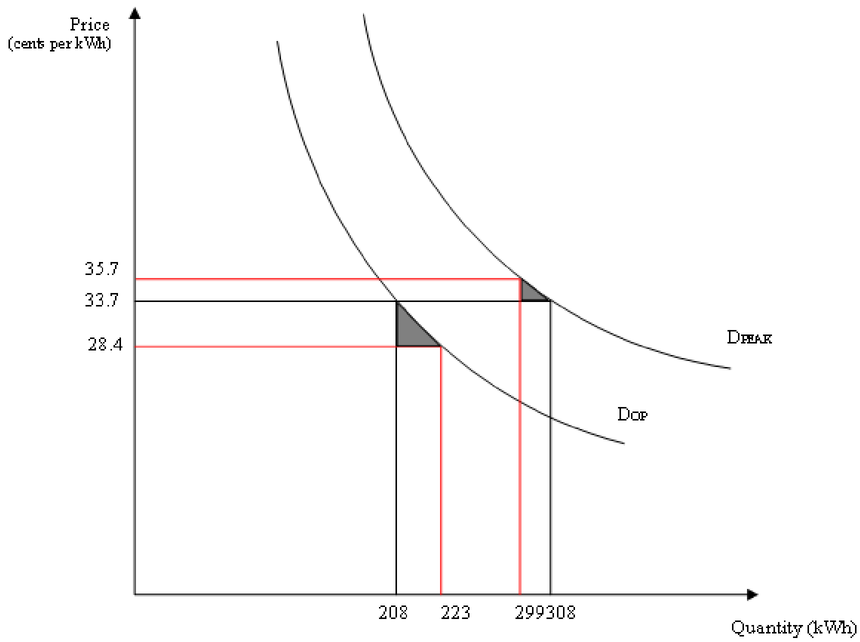

Figure 4 Model 2

The consumer surplus of the off-peak period is found to increase by 1139 cents, whereas the consumer surplus in the peak period decreased by 607 cents. The overall consumer surplus has improved by 532 cents as a result of TOU pricing, of which 504 cents is from transfer gains. The efficiency gain represented in the shaded area in Figure 4 is 46 cents. At TOU pricing, the household bill is $1,737 per annum, which is a saving on the household bill of $116 per annum. Thus, TOU pricing improves consumer surplus and decreases average household expenditure on electricity bills.

In comparing the two models, the social welfare improvement resulting from TOU pricing in Model 2 is approximately greater than the social welfare improvement in Model 1. However, the savings on the electricity bill is greater in Model 1 compared to Model 2. This demonstrates that the elasticity of the demand function affects the welfare analysis. The effects of elasticity on the welfare analysis will be further discussed in Section 0.

4.2 Non-Independent Demand

In this segment, the welfare analysis is investigated with the relaxation of the independent demand function assumption. When the electricity tariff during peak period is higher than off peak, consumers will shift their usage from peak to off-peak period. For example, a user who normally uses the dishwasher or washing machine during peak times will use the electrical appliance during off-peak period when electricity prices are cheaper. Hence, this would cause the peak demand curve to shift left and the increase in off-peak demand would see the demand curve shift right. In this scenario, the marginal cost is still assumed to be constant.

Electricity during peak and off-peak periods can serve the same function, which is to supply energy to power electrical appliances (e.g. a washing machine can run in the morning or in the evening peak). For the purpose of this analysis, electricity in peak period and off peak period will be assumed to be substitutes and cross price elasticity of demand will be positive. There will be an increase in consumption of off-peak electricity due to an increase in electricity price during peak period. A positive cross price elasticity of demand would also imply that the consumption of peak electricity will also decrease as a result of the fall in off-peak tariff.

Since there is no literature on CED values in South Australia, three scenarios will be investigated, with CED values for peak to off-peak and off-peak to peak of 0.1, 0.5 and 1.0 are investigated[5]. The model with peak elasticity of -0.568 and off-peak elasticity of -0.4 is investigated. Similar to Section 4.1, the optimal peak price is 35.7 cents per kWh and the optimal off-peak price is 28.4 cents per kWh.

This welfare analysis examines the change in consumer surplus resulting from TOU pricing and a shift in the demand curve. Due to the nature of the demand curve – a power function, the area under the curve is not bounded and will tend towards infinity, hence the consumer surplus was found by assuming a maximum price at 500 cents per kWh[6]. Even though the absolute value for the consumer surplus is not accurate, the change in consumer surplus can still be analyzed and compared amongst models.

4.2.1 CED of 0.1

In this segment, the welfare effects of a change in prices on peak demand and off peak demand with a CED of 0.1 is analyzed. Figure 5 illustrates the impacts on peak demand and

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[5] Supporting calculations for CED can be found in Appendix C.

[6] Calculations for change in consumer surplus and deadweight loss can be found in Appendix B.

displays the impacts on off-peak demand.

4.2.1.1 Peak Demand

In Figure 5, the demand curve shifts left from D_1 to D_2 due to a reduction in price of electricity in the off-peak period. The shift in demand caused a 1994 cents fall in consumer surplus. The simultaneous increase in price to 35.7 cents led to a decrease in consumption of electricity to 293 kWh. At the new equilibrium point, the fall in consumer surplus due to the rise in price is 585 cents. There is an overall decrease of 1409 cents in consumer surplus. The decrease in consumer surplus is greater in the model with cross price elasticity than the model with independent demand due to a greater reduction in peak electricity consumption.

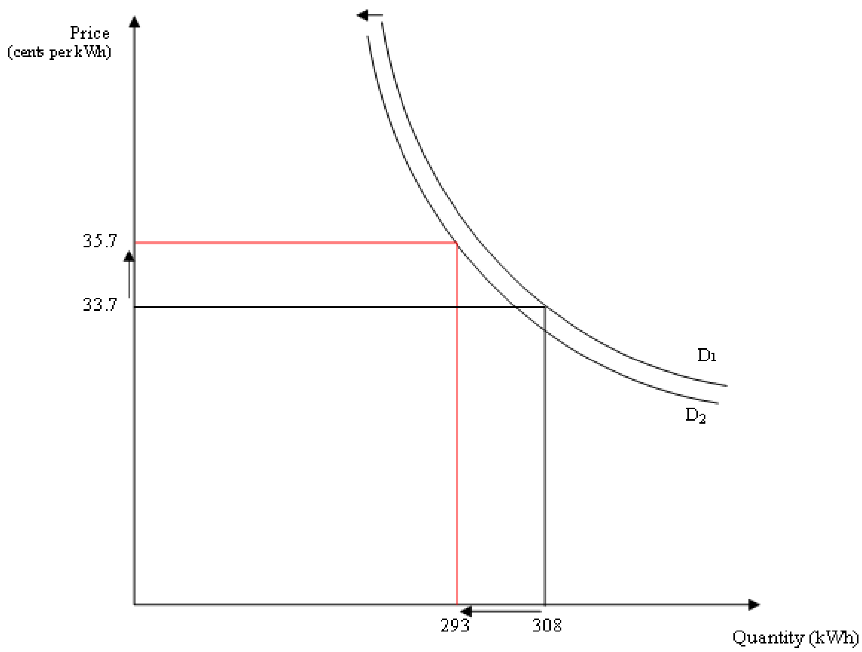

Figure 5 Peak Demand (CED=0.1)

4.2.1.2 Off-Peak Demand

In Figure 6, the demand curve shifts right from D_1 to D_2 due to an increase in price of electricity in the peak period. The shift in demand caused a 267 cents increase in consumer surplus. The simultaneous fall in price to 28.4 cents led to an increase in electricity consumption to 224kWh. As a result, the consumer surplus increases by 1146 cents. There is an overall increase of 1412 cents in consumer surplus. The increase in consumer surplus is greater in the model with cross price elasticity than the model with independent demand, due to a greater increase in electricity consumption during the off-peak period.

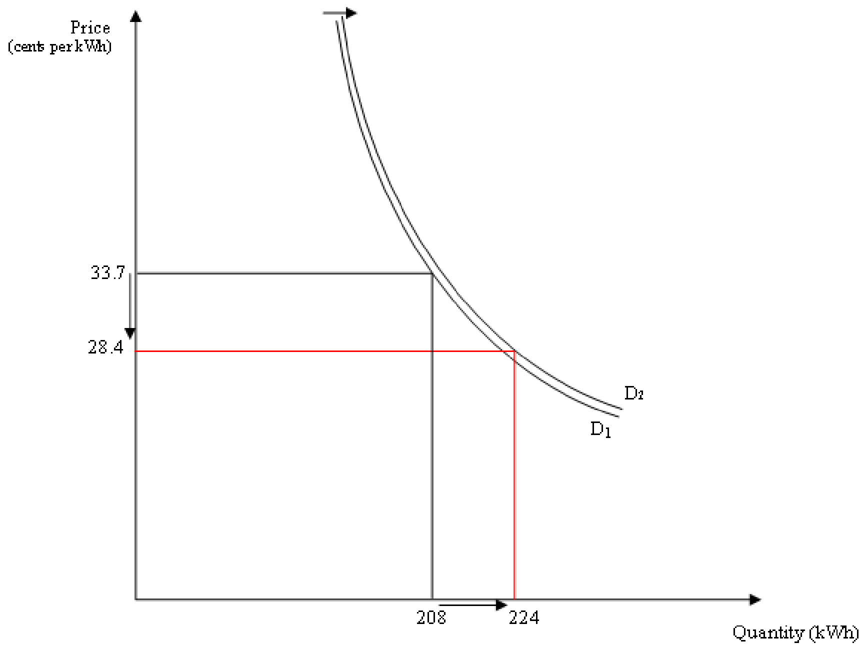

Figure 6 Off-Peak Demand (CED=0.1)

4.2.2 CED of 0.5

4.2.2.1 Peak Demand

In Figure 7, the demand curve shifts left from D_1 to D_2 resulting in a fall in consumption of electricity. The shift in demand caused 4235 cents fall in consumer surplus. The simultaneous increase in price to 35.7 cents led to a decrease in consumption of electricity to 274 kWh. At the new equilibrium point, the fall in consumer surplus is 555 cents due to increase in peak price. There is an overall decrease of 4790 cents in consumer surplus is greater when compared to the model with a CED of 0.1, due to a greater fall in peak electricity consumption.

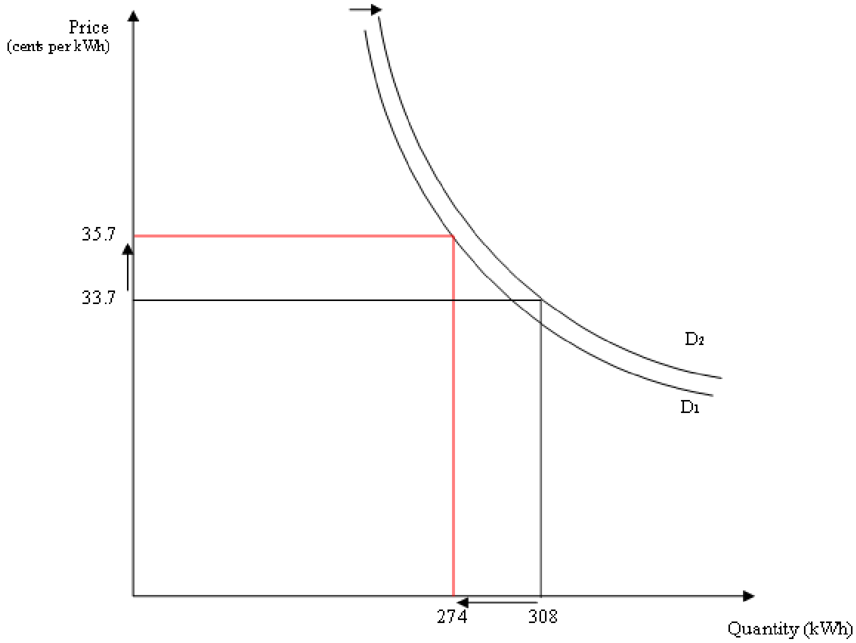

Figure 7 Peak Demand (CED=0.5)

4.2.2.2 Off-Peak Demand

In Figure 8, the demand curve shifts right from D_1 to D_2, resulting in an increase in electricity consumption. The shift in demand caused a 1386 cents increase in consumer surplus. The simultaneous fall in price to 28.4 cents led to an increase in electricity consumption to 229 kWh at the new equilibrium. As a result, the consumer surplus increases by 1188 cents and the overall improvement is 2574 cents. Compared to the model with a CED of 0.1, the electricity consumption during off peak has increased and thus has a greater consumer surplus.

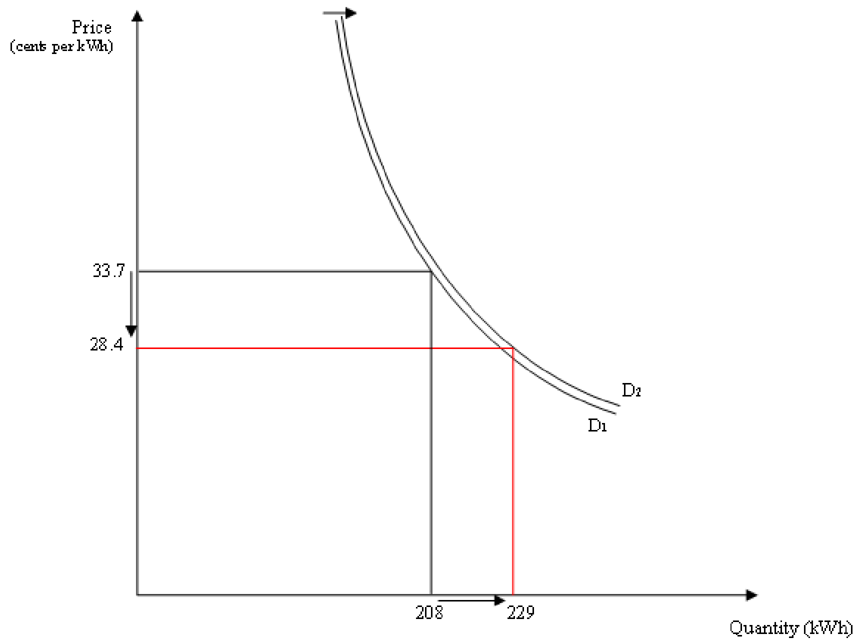

Figure 8 Off-Peak Demand (CED=0.5)

4.2.3 CED of 1

4.2.3.1 Peak Demand

In Figure 9, the demand curve shifts left from D_1 to D_2 resulting in a fall in consumption of electricity. The shift in demand caused a fall in consumer surplus of 8244 cents. The simultaneous increase in price to 35.7 cents led to a decrease in consumption of electricity to 251 kWh. At the new equilibrium point, the fall in consumer surplus is 312 cents, hence the overall consumer surplus loss is 8556 cents.

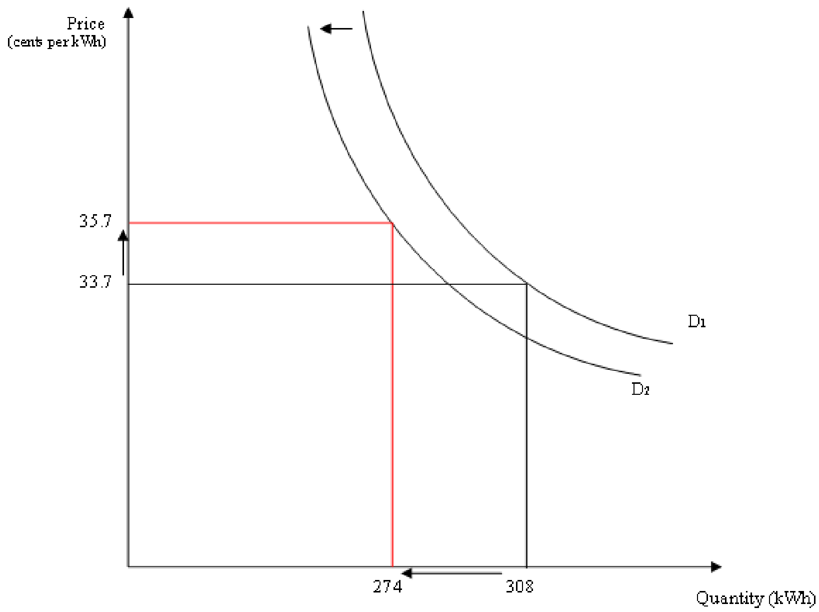

Figure 9 Peak Demand (CED=1)

4.2.3.2 Off-Peak Demand

In Figure 10, the demand curve shifts right from D_1 to D_2, causing an increase in electricity consumption. The shift in demand caused a 2726 cents increase in consumer surplus. The simultaneous fall in price to 28.4 cents led to an increase in electricity consumption to 236 kWh and a consumer surplus gain of 1205 cents. The overall improvement in consumer surplus is 3931 cents.

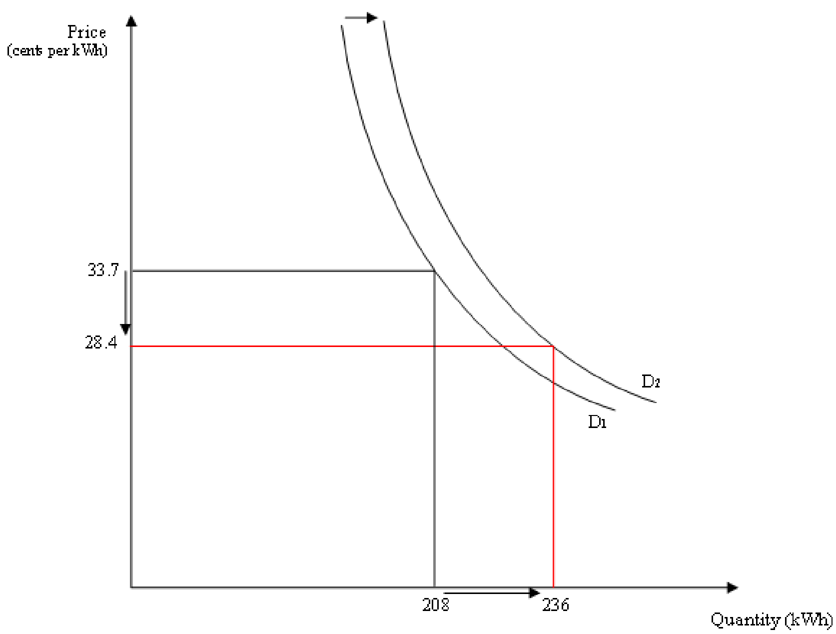

Figure 10 Off-Peak Demand (CED=1)

Assuming ceteris paribus and provided the fall in off-peak price is the same in all situations, the greater the CED, the consumer surplus in the peak demand model falls more as the electricity consumption decreases more. On the contrary, the greater the CED, the greater the increase in consumer surplus in the off-peak model as the increase in electricity consumption is greater.

5. Discussion

5.1 Implications of Time of Use Pricing on Social Welfare

The results in section 4 demonstrate that TOU pricing can contribute to the objective of maximizing welfare through the reduction of electricity consumption during peak period and also an increase in demand for electricity in the off-peak period. There is also an overall improvement in social welfare, as consumer surplus increases more in the off-peak model than the decrease in the peak model. Expenditure on the average household electricity bill also decreases due to the implementation of TOU pricing. These findings are based on a few crucial assumptions of estimated elasticity values for peak and off-peak periods, independent demand curves and constant marginal cost.

For independent demands curves: a given fall in price generates more addition to consumer surplus if the demand curve is more elastic. This analysis could be improved with elasticity of demand that reflect South Australian residential and small business consumer behavior more accurately. The elasticities in the models were estimated as an average of the peak or off-peak time block, however this may not be the case since elasticity of demand for electricity could vary every hour. More accurate consumer response and elasticities can be obtained for this welfare analysis if trial runs of TOU pricing were implemented to residential and small business consumers in South Australia. It must also be noted that the elasticity of demand vary for households with different characteristics, this will be discussed in the next section, section 5.2.

The social welfare analysis was also examined when the assumption of zero CED is relaxed. The cross price elasticity is dependent on the consumer's ability to shift peak-use to off-peak. For example, the use of the dishwasher can be delayed to off-peak period but cooking has to be at meal times and if it happens to fall on peak-period, this load cannot be shifted. The analysis examines the impact of a decrease in off-peak price on peak demand and also the implications of a rise in peak price on off-peak demand.

Consumption of electricity during peak period decreases with an increase in peak price and would further decrease due to positive CED and a fall in off-peak price. Consequently, the decrease in consumer surplus is greater when CED or the decrease if off-peak price is greater. The off-peak demand for electricity increases with a decrease in off-peak price and further increases when there is an increase in peak price and the CED is positive. This results in an increase in consumer surplus that is greater than when CED is zero. Similarly, trials should be implemented to obtain values of CED, as CED is crucial to the welfare analysis and should be investigated more thoroughly before the implementation of TOU pricing.

Another core assumption in the welfare analysis is that marginal cost is assumed to be constant. The relaxation of this assumption is difficult to analyze as cost structures of retailers are mostly confidential, especially now that the retailers are no longer regulated, they do not have to report their costings to the regulators. Further research could incorporate the effects of non-constant marginal costs in this analysis, however due to time constraints, this was not included in this paper. However, it is important to note that if TOU pricing reduces peak demand and also surpluses, the generators will change their bidding strategies and cost structures in attempt to cover their costs. Presumably this will change the marginal cost of generation for peak and off-peak, which costs will be passed on to the retailer, subsequently changing the retailers' cost structures.

5.2 Alternative Demand Side Participation

There are several alternative DSM systems such as the CPP and RTP, which were described in section 2.3 that are effective in reducing peak demand. In this section, the cost and benefits of these systems are compared to TOU pricing. Another form of DSM system is known as direct load control (DLC), in which the operators can monitor and control consumer's consumption.

The main weakness with TOU pricing is that the pricing system barely captures price variation within a time block; peak and off-peak period. CPP can be implemented alongside TOU to enhance the effect of differential pricing. As mentioned previously, CPP is usually priced five to eight times the average retail price, and is thus effective in reducing electricity consumption on days when demand is extremely high (Abrate, 2004). Announced on short time notice prior to the period when demand is exceptionally high, the timing of CPP enables CPP to serve as a good price signal and will discourage or minimize the use of electricity. Similarly, there are distributional concerns with the implementation of such pricing system for vulnerable households, both financially and health-wise. Concession and rebates can be offered to these households so that they do not incur the burden of the CPP costs.

Real time pricing can be implemented such that the price of electricity varies according to the wholesale energy prices, hence this system provides more efficient price signal than TOU as it captures more price variation. Assuming the time lag between the announcement and implementation of the price is small, this mechanism is ideal for efficient pricing and price signaling. However the implementation of this system has its difficulties as concerns for residential and small business customers will be subject to the risks in the price fluctuations. The metering costs of RTP could also be greater than a more simple TOU metering system.

In the direct load control system, from the monitoring and direct control of consumer's electricity usage, the operator can interrupt energy supply to a household if there is overconsumption. Direct load control is implemented by ETSA Utilities in several South Australian suburbs including Mawson Lakes, Northgate and the regional center of Murray Bridge (ETSA Utilities, 2010). ETSA Utilities found that the group that benefit from this system are the customers, energy retailer and the transmission company. However, the distributor and the generators bear the burden of the costs.

5.3 Network and Generation Costs Implications

The reduction in peak demand resulting from optimal pricing would defer future investment in expansion of network and generation capacity. However, these saving will most probably be immaterial since there has already been substantial over-investment in electricity generation and networks in the past years to meet peak demand. The trend in peak demand has fallen in the last couple of years and the AEMO predicts moderate growth in peak demand for the next ten years, as shown in

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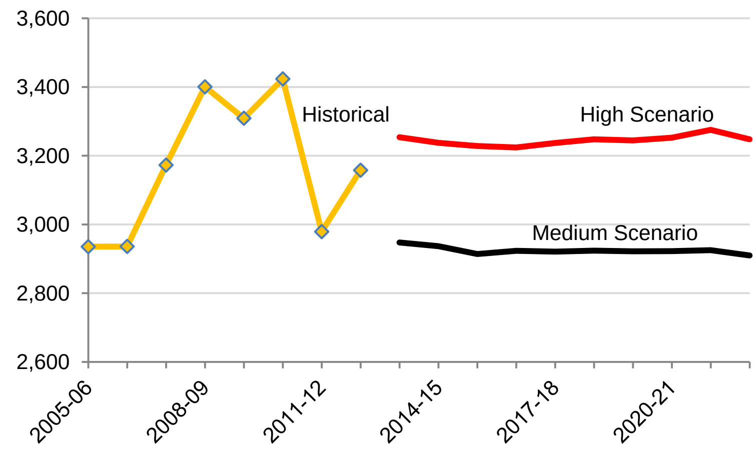

Figure 11 Historical and Projected Peak Demand (AEMO, 2013)

In South Australia, the current existing and committed generation capacity is 4,708 MW, of which the summer scheduled capacity is 3,452 MW and semi-scheduled capacity is 711 MW, and non-scheduled capacity constitutes the remaining capacity. Scheduled capacity is generation capacity that AEMO can schedule for dispatch instantaneously, whereas semi-scheduled capacity includes renewable energy sources such as wind farms, which AEMO can schedule but has less control over due to inconsistency in the source of wind. The scheduled capacity in South Australia alone is approximately 300 MW greater than the 3,158 MW peak demand in 2012/2013. Figure 11 displays AEMO's outlook on peak demand growth, which is expected to be moderate, with current capacity capable of meeting peak demand for the next ten years.

There has also been significant investment in transmission and distribution networks in South Australia, especially in year 2010/2011 with an investment of approximately AUD 160 million just on augmentation projects. In the 2013 South Australian Transmission Annual Planning Report (TAPR), ElectraNet proposed augmentation projects for FY14 up to FY23 to meet peak demand based on AEMO's forecasts. The following table summarises the projects by region and its net present value (NPV).

Table 6 ElectraNet Augmentation Projects

Region	NPV (AUD M)
Munno Para	42.6
Hummocks	4.2
Kincraig	37.8
Mt. Barker	10.4
Kadina East	3.3
Dalrymple	21
Baroota	14.8
Total NPV	134.1

The increase in peak pricing in these regions could see a fall in the growth of peak demand such that the delay of such augmentation projects could save an NPV of $134 million over 10 years. However, these costs are rather insignificant considering in 160 million was spent in one year. This shows that if peak pricing were to be implemented, it should have been implemented before the all the investment in network and generation capacity occurred.

Furthermore, the savings in network costs may be cancelled out by the implementation costs of metering. Accumulation meters in households will be replaced with smart meters, information technology systems will have to be installed to keep track of electricity consumption and the retraining of skills is required to adapt to the new system. The average smart meter charge in Victoria is approximately $120 in 2013, and forecasted to be $140 per meter in 2014 and total expenditure is estimated to be approximately $1.1 billion for the period 2012 to 2015 (AER, 2013). The household electricity savings on TOU variable charge almost compensates for the additional metering charge, but it is unlikely that the savings in the network costs will outweigh the cost of metering. South Australia has a smaller population than Victoria - approximately a quarter of population, thus the expenditure on metering could be lower, perhaps a quarter of $1.1billion, which is $275 million. The savings on network costs of $134 million over 10 years is much less than 15 percent of the Victorian estimates for metering costs over three years and is likely to be less than the estimates for South Australia too.

6. Conclusion

This paper has found that a two block TOU pricing improves social welfare and also shows that there will be a reduction in household bills due to TOU pricing. However, this finding is dependent on several crucial assumptions that include zero CED and constant marginal costs. The social welfare was also examined with the relaxation of the zero CED assumption. The consumer surplus is greater for the off-peak model with positive CED compared to the model with zero CED. On the contrary, the surplus is smaller for the peak-model with positive CED compared to the model with zero CED. It has been suggested that trial runs should be implemented to determine consumer response and elasticities for different household characteristics in South Australia.

The metering charge for the retail customer in Victoria in 2013 is found to be approximately $120 per meter. If the charge is similar in South Australia, the savings on household bills due to TOU pricing could almost cover the metering charge. The fall in peak demand due to peak pricing could defer investment in networks, which will save approximately a net present value of $134 million over ten years. However, the cost of metering is likely to be much greater than the savings. In Victoria, the AER had approved $1.1billion of expenditure on the roll out of smart meters for the regulatory period of 2012-2015. Assuming the expenditure is proportional to population, the estimated expenditure in South Australia would be around $275 million over three years, which is much greater than the savings of $134 million over ten years. Hence, the case for time of use pricing based on benefits outweighing the costs is weak.

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Appendix A: Demand Curve Estimation

In this section, detailed explanations and sample calculations for the demand curves are presented. The demand curve is estimated using the average hourly household consumption, the retail price of electricity and the price elasticity of demand. The price elasticity of demand is assumed to be constant.

The annual consumption of electricity per household is assumed to be approximately 5500 kWh, of which 30 percent is consumed during peak period, defined as between 3.00pm and 8.00pm. Thus, the electricity consumed per hour during peak period was found to be 308 kWh of electricity and 208 kWh during off-peak period.

The price elasticity of demand is the percentage change in quantity, Q with respect to the percentage change in price, P. The values of elasticity are obtained from table XXX. The elasticity of peak demand is the average of elasticities at 4.00pm and 7.00pm; and the elasticity of off-peak demand is the average of elasticities at midnight and noon.

Peak Demand Estimation

$\varepsilon = -0.568$

$logQ = -0.568logP + C$

$-0.568logP = logQ - C$

$logP = -1.76logQ + C$

$P = AQ^{-1.76}$

$33.7 = A308^{-1.76}$

$P = 8.11 \times 10^{5}Q^{-1.76}$

Off-Peak Demand Estimation

$\varepsilon = -0.4$

$logQ = -0.4logP + C$

$-0.4logP = logQ - C$

$$logP = -2.5logQ + 3.57C$$

$$P = AQ^{-2.5}$$

$$33.7 = A208^{-2.5}$$

$$P = 2.1 \times 10^{7} Q^{-2.5}$$

Appendix B: Consumer Surplus, Deadweight Loss, Household Bill Calculations

In this section, explanations and sample calculations for the consumer surplus, deadweight loss and household bill are presented.

Change in Consumer Surplus (CS)

The change in consumer surplus is found as an integration of the area under the demand curve between the flat tariff and the peak or off-peak tariff.

Peak Model

$\varepsilon = -0.568$

$P = 8.11 \times 10^5 Q^{-1.76}$

$Q = 2271P^{-0.568}$

$$CS = \int_{33.7}^{35.7} 2271P^{-0.568}.\,dP$$

$$= [5256P^{0.432}]_{33.7}^{35.7} = 607\ cents$$

Off-peak Model

$\varepsilon = -0.4$

$P = 2.1 \times 10^7 Q^{-2.5}$

$Q = 849P^{-0.4}$

$$\Delta CS = \int_{28.4}^{33.7} 849P^{-0.4}.\,dP$$

$$= [1415P^{0.6}]_{28.4}^{33.7} = 1139\ cents$$

Deadweight Loss (DWL)

The deadweight loss is represented by the shaded grey area and can be calculated by finding the difference between the change in consumer surplus and the shaded blue area.

DWL = $\Delta CS - Area\ in\ the\ rectangle = 607 - 598 = 9\ cents$

DWL = $\Delta CS - Area\ in\ the\ rectangle = 1139 - 1102 = 37\ cents$

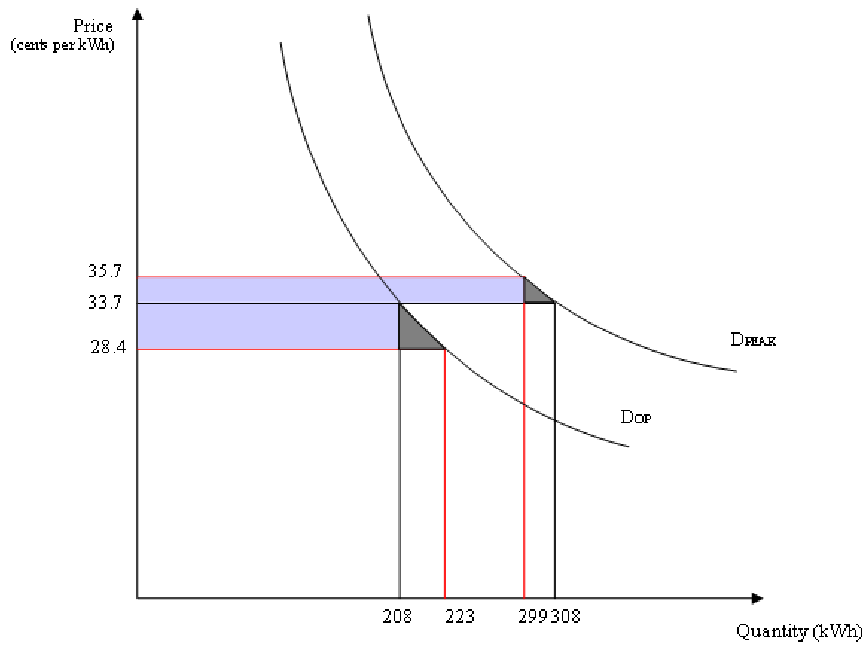

Figure 12 Deadweight Loss and Consumer Surplus

Household Bill

The household bill is calculated by multiplying the peak (off-peak) tariff by the peak (off-peak) consumption and the number of hours that in the peak (off-peak) period.

Appendix C: Cross Price Elasticity of Demand

In this section, explanations and sample calculations for the consumer surplus with non-zero cross price elasticity of demand.

The consumer surplus is the area under the demand curve take quantity multiplied by price. However, the demand curve is a power curve and is not bounded. For the purpose of estimating consumer surplus, the upper bound of price has been assumed to be 500 cents per kWh.

$P = 33.7\ cents\ per\ kWh, Q = 308\ kWh$

$CED = 0.5$

$$CED = \frac{\%Q}{\%P}$$

$$0.5 = \frac{(Q_2 - 308)/308}{-0.157}$$

$Q = 284\ kWh$

The consumer surplus at the equilibrium of 33.7 cents per kWh and 308 kWh is calculated as follows:

$Q = 2272P^{-0.568}$

$$CS = \int_{33.7}^{500} 2272P^{-0.568}$$

$$= 53{,}020\ cents$$

At a CED of 0.5, the fall in off-peak price of 15.7 percent, leads to a decrease in peak consumption to 284 kWh. The demand curve shifts left, thus there will be a new demand curve. $P = 33.7\ cents\ per\ kWh, Q = 284\ kWh$

$P = AQ^{-1.76}$

$33.7 = A284^{-1.76}$

$P = 700{,}600Q^{-1.76}$

Due to the decrease in off-peak price, the new equilibrium is:

$P = 33.7\ cents\ per\ kWh, Q = 274\ kWh$

Consumer Surplus

$Q = 2090P^{-0.568}$

$$CS = \int_{33.7}^{500} 2090P^{-0.568}$$

$$= 48{,}227\ cents$$

The decrease in consumer surplus is 4790 cents.