Seungmoon Choi, Alistair Pellen, Virginie Masson

How does daylight saving time affect electricity demand? An answer using aggregate data from a natural experiment in Western Australia

Energy Economics, 2017; 66:247-260

Final publication at http://dx.doi.org/10.1016/j.eneco.2017.06.018

How Does Daylight Saving Time Affect Electricity Demand? An Answer Using Aggregate Data from a Natural Experiment in Western Australia

Seungmoon Choi[*], Alistair Pellen[†] and Virginie Masson[†]

[*]School of Economics, University of Seoul

[†]School of Economics, University of Adelaide

First Draft: December 2013, This Draft: June, 2017

Abstract

Daylight saving time (DST) affects the lives of more than 1.6 billion people worldwide, with energy saving being the original rationale for its implementation. This study takes advantage of natural experiment data from September 2006 to March 2013 in Western Australia in which DST was observed from December 2006 to March 2009, to estimate the effect of DST on electricity demand. Using the difference-in-differences (DD) approach, we find that DST has little effect on overall electricity demand and electricity generation costs. However, it has a strong redistributional effect by reducing electricity demand substantially in the late afternoon and early evening. This redistributional effect of DST may be of particular interest for policymakers who are interested in controlling high demand and the short term energy market price.

Keywords: Daylight Saving Time, Electricity Demand, Electricity Generation Costs

JEL codes: Q4, Q41, Q48

---

[*]Corresponding author: Seungmoon Choi, School of Economics, University of Seoul, 163 Siripdaero, Dongdaemun-gu, Seoul, South Korea, Email: schoi22@uos.ac.kr. Alistair Pellen, School of Economics, University of Adelaide, SA, Australia, Email: alistair_pellen@hotmail.com. Virginie Masson, School of Economics, University of Adelaide, SA, Australia, Email: virginie.masson@adelaide.edu.au. We are very thankful to the Editor, Richard S. J. Tol and three anonymous reviewers for constructive and helpful comments and suggestions. We also appreciate seminar participants for valuable discussions at the 2015 Korea International Economic Association Annual Meeting, the 2016 Korean Econometric Society Meeting and the 58th National Australian Agricultural and Resource Economics Society Conference in 2014. This work was supported by the 2016 Research Fund of the University of Seoul.

1 Introduction

Energy conservation has often been the major rationale by governments for adopting Daylight Saving Time (DST). DST is the practice of setting clocks forward by one hour, usually from spring to autumn in each year. Variations include setting clocks forward by two hours (Double Daylight Saving Time), or even permanently (year-round Daylight Saving Time). Many countries such as the United States, most European countries, and Australia currently follow DST, which affects an estimated 1.6 billion people worldwide (Kotchen and Grant (2011)).

Despite being observed in many countries for a long time, few studies offer a thorough empirical analysis of the effect of DST on electricity demand, which appears to be due to the unavailability of appropriate data. Most countries have continued to employ DST for a long time since they began to observe it. For some countries, although there was a period when DST was not observed before the current DST, relevant data are not available. Therefore it is difficult to obtain data from both periods of practicing and repealing DST. Furthermore, existing studies make use of limited data sets and present mixed results. More details about the limits of existing studies on the effect of DST on electricity demand are described in the next section. The aim of this paper is to investigate how DST affects electricity demand, using a unique natural experiment data set where DST had been observed for a number of years before it was stopped.

Benjamin Franklin is often credited with the idea of DST; in a letter to a French journal, he lamented the waste of daylight that came about when people slept until after sunrise (Westcott (2010)). However it was not until 1907, when English businessman William Willett campaigned for the introduction of related legislation, that DST started to take its current form (Prerau (2005)). His attempts failed, but during World War I Germany set its clocks forward to conserve energy, and many other countries followed suit until the end of the war (Westcott (2010)). DST was again implemented during World War II only to be dismissed shortly thereafter. It was later widely adopted due to the perception that it could save energy.

We have obtained statewide half-hourly electricity demand data in Western Australia

(WA) from September 2006 until March 2013 that incorporates a natural experiment. From December 3, 2006 to March 29, 2009, WA adopted a form of DST (BOM (2013)) where clocks were set forward by an hour from spring to autumn, and back again for the rest of each year[1]. We will refer to this period as the DST regime and the other periods as the non-DST regime. In our data set, the treatment period is from the last Sunday of October in one year until the day before the last Sunday of March the following year. And the control period corresponds to the rest of each year[2]. The existence of data during and outside the DST regime allows us to identify the effect of DST on electricity demand during the treatment period after controlling for confounding factors such as weather, time trend and seasonalities. To our best knowledge, this is the first empirical study to estimate the overall DST effect on half-hourly electricity demand all through the day for several years using system-wide electricity demand data covering residential, commercial and industrial sectors.

We obtain estimation results on the effect of DST on electricity demand in a difference-in-differences (DD) framework after controlling for other confounding variables. The results show that DST increases electricity demand slightly during the late night and morning (9 pm - 4 am and 7 am - 11 am), while decreasing demand sharply in the late afternoon and early evening (4:30 pm - 8:30 pm). On the other hand, DST does not affect electricity demand during the day, from 11 am till 4:30 pm. The largest decrease in half-hourly demand due to DST is 6.61% from 7 pm - 7:30 pm, and the largest increase is 2.99% from 10 pm - 10:30 pm. Overall, however, DST does not affect electricity demand. The strong redistributional effect of DST on the electricity demand seems to be due to the associated shifts in lighting and weather conditions, combined with unchanged clock time schedules. These results cast doubt on the use of DST as an energy-saving policy but support its use as a way to reduce peak electricity demand.

Electricity demand is found to increase when it gets hot or cold. Because temperature is a key variable among those factors, we used different functions of temperature and proved the impact of DST on electricity demand is robust to various specifications. Wind and

---

[1] DST was observed in Western Australia during the following periods: 3 December 2006 to 25 March 2007, 28 October 2007 to 30 March 2008 and 26 October 2008 to 29 March 2009.

[2] See the diagram in Figure 1 that shows the treatment and control periods and the DST and non-DST regimes in our data period.

precipitation turn out to have an intensifying effect on demand during cold days, but decrease electricity demand during warmer weather. As expected, if the humidity level goes up electricity demand increases more for the time when the temperature is higher. As the solar incentive schemes in WA encouraged people to use solar energy, it is estimated to have decreased electricity demand. The negative effect of school holidays is concentrated in the morning, while the 'day after a public holiday' effect is negative, but only significant from 12-9am.

To compute generation costs we take the Short Term Energy Market (STEM) price as a proxy for the marginal cost of providing electricity. The average STEM price during the treatment period under the non-DST regime multiplied by the estimated change in electricity generation due to DST equals total generation cost. Even though demand tends to be highest in the late afternoon and early evening, we estimate that a decrease in electricity usage during this period would have reduced the overall generation costs by only about 21.1 thousand dollars per treatment period of 154 days[3] and by about 692.9 thousand dollars for the half hour from 7 pm - 7:30 pm alone if DST had been adopted during the treatment period in 2009-2013. This suggests that DST brings about relatively trivial economic benefits.

The reduction in electricity demand during the late afternoon and early evening coincides with the period of high demand and STEM prices. This redistributional effect of DST may be of particular interest for policymakers who are interested in controlling high demand and the STEM price. If the overall goal is to consume less energy or to save generation costs, however, the estimation results show that DST is not the answer.

The effect of DST on energy usage is only one facet of the DST adoption debate. Studies have scrutinized the effects of DST on other aspects of human behavior, including road accident fatalities (Ferguson et al. (1995), Coate and Markowitz (2004), Lahti et al. (2010)), stock returns (Kamstra et al. (2000)), circadian rhythms (Kantermann et al. (2007)) and myocardial infarction (Janszky and Ljung (2008)). Much like the debate on whether DST saves energy, there is currently no broad agreement within the literature on its effects and desirability, thus impeding the construction of sound policies.

---

[3] As discussed below DST in WA began from the last Sunday of October and ended on the last Sunday of March except in 2006 when DST started on December 3. The total number of days for the usual treatment period is 154 or 147 in our data set. We use 154 days because it is the more common period length in our data set.

The next section outlines existing studies on the impact of DST on electricity demand. Section 3 describes our unique electricity demand data set, the data obtained for the control variables and any necessary adjustments to particular data. Section 4 explains our model and the methodology used. Section 5 contains the results and discussion. The effect of DST on generation costs is presented in Section 6. Section 7 concludes. Finally, selected estimation results are presented in the Appendix.

2 Literature Review

Empirical papers on DST can be classified into DST extension, DST-only, and micro-level data studies depending on the characteristics of the data employed. In contrast to these works, our data set includes aggregate electricity demand from both DST and non-DST regimes.

One sort of DST extension is year round DST. The UK introduced a 3 year trial of year round DST in 1968. Although HMSO (1970) reviewed this trial they could not reach any conclusions on whether or not year round DST saved electricity. In most areas of the US, DST had been extended in 1974 and year-round DST was introduced for 15 months. The US Department of Transportation (DOT) empirical study (DOT (1975) and Ebersole et al. (1974)) find an approximate 1% decrease in aggregate electrical load due to DST. The US National Bureau of Standards (Filliben (1976)) evaluated the DOT study but did not support DOT's findings on the grounds of lack of reliability in the original data and in the analysis techniques.

Energy usage patterns have changed dramatically since these studies. According to Bouillon (1983), total energy use in Europe doubled from 1960 to 1983 during which the percentage of energy consumption on lighting reduced from 25% to 10%. Electricity used by U.S households for air-conditioning increased almost 250% between 1978 and 2005 according to EIA (2006). That there are different electricity usage patterns from the 1970s calls for a new investigation of this issue. Another drawback of this work is that they fail to take other factors affecting electricity demand into consideration, which can cause biased estimates.

Other DST extension studies consider the effect of extending DST using years with and without extended DST. Empirical studies using data with varying length of DST periods present contrasting conclusions. Using panel data, Kellogg and Wolff (2008) adopt a difference-in-difference-in-differences (DDD) framework to analyze the DST extension that occurred in Victoria (VIC) and New South Wales (NSW) to accommodate the Sydney Olympics in 2000. Owing to the DST extension, people in VIC and NSW had to get up one hour earlier from 27 August, which was 2 months earlier than the usual DST starting date at the time (29 October). Their findings say that the DST extension actually resulted in an overall energy consumption increase in VIC because the reduction in electricity consumption in the evening was smaller than the increase in the morning. In 2007, the starting date of DST was brought forward from the first Sunday in April to the second Sunday in March and the end date was deferred from the last Sunday in October to the first Sunday in November in the USA. Using daily data from the first four months of 2000 to 2007,[4] Kandel and Sheridan (2007) estimate the effects of DST on electricity demand during the extended DST periods in California. They conclude that the 2007 extension of DST had no significant effect on electricity demand in California. Belzer, Hadley, and Chin (2008) use daily and hourly electricity consumption to investigate the impact of extended DST. They employed electricity consumption data collected from 35 and 29 utilities located across the USA respectively for the spring and the fall in 2006 and 2007. The total electricity savings are estimated to be 0.46 to 0.48 % per each day of DST extension. Using the fact that adoption of DST occurs in a different calendar day each year and the extension of DST by a month in 2007 in Ontario, Canada, Rivers (2016) shows that DST reduces electricity demand in the evening without an offsetting increase in the morning. He finds a reduction in electricity demand of about 1.5% associated with the transition of DST persists for at least 3 weeks following DST adoption.

The energy conserving effect of DST is expected to be maximized in summer. However, the aforementioned DST extension papers evaluate the influence of DST on electricity demand by considering only the extended periods with and without DST instead of the whole DST period. Those extended DST periods are late winter, early spring, or late fall. During these periods, people tend to consume more electricity in the dark and cold mornings if they wake

---

[4] With the exception of the year 2001(energy crisis) and April 2007 (not available) in Kandel and Sheridan (2007).

up one hour earlier due to DST. Thus, restricting data analysis only to the extended DST days can give a misleading answer to the question about whether or not DST saves electricity. This limitation can be overcome by our paper in which we use a unique data set that has observations from both non-DST and DST regimes[5].

A DST-only study uses a data set with no natural experiment. Momani et al. (2009) compare the average daily load in Jordan for several days before and after the onset and removal of DST and show that DST increases the overall generation due to the increase in heating and cooling loads. Mirza and Bergland (2011) use a linear regression model to determine the effect of DST in Sweden and southern Norway. As DST was implemented in 1980, years before the relevant electricity demand data were available, hours from 11am-2pm and 11pm-2am are used as controls in their analysis to obtain a DD estimator. They estimate an overall reduction in electricity consumption of at least 1% in both countries. Another DST-only study from Verdejo et al. (2016) also employs a DD framework to evaluate electricity demand in Chile and finds a marginal reduction when DST is observed. In a DD framework, measuring the DST effect with the difference in electricity consumption during the treatment hours between the treatment and the control periods of each year can be problematic because it compares different days of the year.

As a micro-level data study, Kotchen and Grant (2011) consider the effect of DST on residential electricity demand in northeast Indiana using household-level monthly billing data from more than 200,000 residences between 2004 and 2006. Controls are defined as the parts of the state that either were already observing DST or were in a time zone shift that cancelled out DST. They find that DST actually increases electricity demand by roughly 1%. This study, however, does not estimate the effects of DST on commercial and industrial electricity demand, thus making the conclusions unlikely representative of the overall effect. Moreover, they fail to include weather variables except temperature and household level covariates in the model that can affect electricity consumption such as income and information about household members.

A literature review on the effect of DST on lighting energy use can be found in Aries

---

[5] Because DST in WA was repealed on March 29, 2009, the DST regime amounts to the whole period before March 29, 2009 and the non-DST regime is from March 29, 2009 on in our data set.

and Newsham (2008). In a meta-analysis of the various studies on DST, Havranek, Herman, and Irsova (2016) collected 162 estimates from 44 studies and find that the mean reported estimate indicates modest energy savings, with larger energy savings for countries farther away from the equator, and subtropical regions consuming more energy because of DST.

3 Data

This study uses data on electricity demand, weather, daylight, solar incentive schemes and school and public holidays in WA from September 21, 2006 to March 1, 2013.

3.1 Electricity Demand

There were four separate post-war DST trials in Western Australia (WA) which were all rejected by referendum. DST was mainly opposed by the rural population who were concerned with farming difficulties, exposure to heat and the safety of children, but its popularity was marginal even in the metropolitan regions (WAEC (2010)). The first three trials, in 1974, 1982 and 1991, lasted just one year, while the most recent trial took place from December 3, 2006 to March 29, 2009. More specifically, the clock was set forward from standard time from (Western Australia, Daylight Saving Bill (No.2) 2006):

(a) the hour of 2 a.m. on December 3, 2006 until the hour of 2 a.m. on March 25, 2007 (113 days); and

(b) the hour of 2 a.m. on October 28, 2007 until the hour of 2 a.m. on March 30, 2008 (154 days); and

(c) the hour of 2 a.m. on October 26, 2008 until the hour of 2 a.m. on March 29, 2009 (154 days)[6].

For the length of the data set, the Independent Market Operator (IMO) regulated market activity in the South West Interconnected System (SWIS) and provided half-hourly data on total raw electricity generation. Currently the Australian Energy Market Operator (AEMO) provides this data. The SWIS includes the greater Perth and Bunbury regions, which are

---

[6] The total number of days per treatment period under the non-DST regime in 2009/10 and 2012/13 is 154 days as well while it is 147 days for 2010/11 and 2011/12.

home to approximately 85% of the WA population (ABS (2013)). One limitation of the data is that it does not include electricity demand for some major mining facilities in the north of WA. We were unable to obtain data for these because they are generally privately owned. However, our data set still contains industrial electricity demand within the SWIS. Furthermore, although DST may have affected electricity demand for these mining facilities, it is widely accepted that demand for electricity is substantially more sensitive to clock time changes due to DST in the residential and commercial sectors than in the industrial sector. Besides, WA is isolated from the rest of Australia with respect to electricity and hence net electricity exports are irrelevant. Thus, we anticipate that our data allow us to estimate the effect of DST on the overall electricity demand in WA.

We use half-hourly electricity generation data from the SWIS to compute half-hourly *Electricity Demand*, following the same method used by the IMO (and more recently AEMO) for its annual Electricity Statement of Opportunities report. Electricity generation is measured in megawatt hour (MWh) over a certain time period, while electricity demand is measured in megawatts (MW) at a certain moment in time. Therefore, if electricity demand is constant and equal to 3,000 MW over an hour, then electricity generation in each half hour must be equal to 1,500 MWh. Thus, a good approximation of the electricity demand over a half hour can be found by multiplying the electricity generation value for that half hour by two.

Table 1: Solar incentive schemes in Western Australia (source: Clean Energy Regulator)

Date	Event
June 9, 2009	The Solar Credit Multiplier (SCM) is introduced and is equal to five.
July 1, 2010	The SCM remains at five, and the WA Feed-In Tariff is introduced.
July 1, 2011	The SCM is reduced to three while the Feed-In Tariff remains.
August 1, 2011	The SCM remains at three, but the Feed-In Tariff is removed.
July 1, 2012	The SCM is reduced to two.
January 1, 2013	The SCM is equal to one and is thus effectively removed.

The SWIS data do not include solar photovoltaic (PV) generation. The total amount of small-scale PV capacity was just 21 MW in February 2010, which is less than 1% of electricity demand and has grown, reaching 274 MW in February 2013 (IMO (2013)), largely due to the state and federal solar incentive schemes in place from 2009 to 2012 (IMO (2013)). Hence PV generation was negligible during the DST regime, which is from December 3, 2006 to March 29, 2009. Moreover, the amount of electricity generated by solar panels is dependent on weather and not likely to reach the maximum capacity in general. And there is no direct effect of PV generation on electricity demand when it is dark.

The Solar Credit Multiplier (SCM) was introduced by the Federal Government on June 9, 2009 as part of the Renewable Energy Target, whereby 20% of power is expected to be generated from renewable sources by 2020 (DOE (2013)). It was initially set at five, giving investors in solar energy five times the number of Small-Scale Technology Certificates[7] for which they would otherwise be eligible. As these certificates can be bought and sold, they provide a financial incentive to invest in renewable energy (CER (2013)). The WA government also introduced the Feed-In Tariff scheme on July 1, 2010, which paid investors in small-scale renewable energy systems for any excess energy that they produced and fed into the main grid (IMO (2013)). The scheme was abolished on August 1, 2011, and the SCM was also scaled back gradually until it was effectively removed on January 1, 2013. A summary of the incentive schemes is provided in Table 1.

Although the data could not be adjusted to account for the growth in solar generation, our electricity demand data are expected to show how DST affects electricity demand in WA quite well since our data account for most of the electricity demand of 85% of the WA population. Binary variables for different solar incentive schemes are included in the model to control for the various incentive schemes, as explained in the next section.

3.2 Other Variables

The Bureau of Meteorology (BOM) provided half-hourly data on air temperature, precipitation, relative humidity and wind speed for the Perth Metro weather station, which is the closest station to the Perth central business district.[8]

---

[7] An eligible small-scale PV generation system is entitled to small-scale technology certificates (STCs). The number of STCs per system is determined by its geographical location, installation date, and the amount of electricity in megawatt hours (MWh). These STCs can be sold in the renewable energy certificate market. More details on small-scale technology certificates can be found at http://www.cleanenergyregulator.gov.au/RET/Scheme-participants-and-industry/Agents-and-installers/Small-scale-technology-certificates.

[8] The station is 3.6 kilometres from the central business district.

Temperature is measured to one decimal place in degrees Celsius in half-hourly intervals. Rainfall is recorded since 9am in millimeters (mm), and can easily be converted to *Precipitation* in a given half hour by subtracting the previous half hour's value from the current value (except for the half hour ending 9:30am, where *Precipitation* since 9am is the same as *Precipitation* in that half hour). *Relative Humidity* is measured as an integer percentage. Finally, *Wind Speed* is an integer that captures the average speed in kilometers per hour (km/h) in the ten minutes prior to the observation time. If there is a 'marked discontinuity', the period is shorter; this occurs if there is a sustained change in wind direction of thirty degrees or more accompanied by a wind speed of at least ten knots,[9] or a change in wind speed of at least ten knots that lasts for ten minutes or more.

Although the frequency of observations is usually half-hourly, there are a small number of missing weather data that we replaced by assuming a linear trend between their adjacent values.[10] Also, some additional observations, taken between two normal half-hourly observations or at irregular times, are available; for example, an additional observation might be taken at 11:24pm as well as at 11pm and 11:30pm, or there could be observations at 11pm and 11:24pm but not 11:30pm. Additional observations are usually a result of rapidly changing weather conditions, but cannot be used directly in the data set since the demand data are half-hourly. Therefore, if there is an observation at 11:24pm but not at 11:30pm, then data from 11:24pm is used for the half-hour ending 11:30pm. If there are observations at 11:24pm and 11:30pm, the value at 11:24pm is ignored. On the rare occasion where two observations that are an even number of minutes from the beginning of a half hour (at, say, 11:28pm and 11:32pm) are available, the average of the two values is used. Finally, it should also be noted that the Perth Metro data set contains 101 consecutive half-hourly periods of missing data from 1pm on August 3 to 3:30pm on August 5. We have linearly interpolated these values for a given half hour using the last data point before the period and the first data point after the period for that half hour.[11]

---

[9] One knot is equivalent to the speed of 1.852Km/h.

[10] One temperature observation had clearly been incorrectly recorded, so it was replaced by the linear interpolation procedure just outlined.

[11] The results obtained without taking missing values into account are very similar to those reported in the results section.

Table 2: Summary statistics for September 21, 2006 - March 1, 2013

Variable	Mean	Std Dev	Minimum	Maximum
Electricity Demand (MW)	1951.55	412.72	1172.13	3855.37
Temperature (C)	18.70	6.58	−0.6	43.2
Precipitation (mm)	0.037	0.34	0	36.4
Relative Humidity (%)	63.48	21.26	6	100
Wind Speed (Km/h)	10.44	6.40	0	42

Note: *Electricity Demand* is calculated from electricity generation data obtained from the South West Interconnected System (SWIS) through the Independent Market Operator (IMO) in WA. The data set covers Perth and most other major towns such as Geraldton, Albany, Bunbury and Kalgoorlie. The weather data were obtained from the Perth Metro weather station through the Bureau of Meteorology (BOM).

As stated earlier, we also control for daylight and public and school holidays. *Daylight* was derived from Geoscience Australia's sunrise and sunset times.[12] The information on school holidays was obtained from the Western Australian Department of Education, and the information on *Public Holidays* from the Fair Work Ombudsman and the WA Department of Consumer and Employment Protection.[13]

We perform further adjustments to the data set. We hypothesize that DST's effect on electricity demand (if any) is due to shifts in clock time, and therefore use local clock time instead of solar time to keep track of the observations. However, DST causes irregularities in clock time for the half hours beginning 2am and 2:30am during the spring and autumn transitions, with a 23-hour day at the spring onset and a 25-hour day at the autumn removal. We thus create two observations for the 23-hour day, with data for the 2am and 2:30am missing half hours copied from 1:30am and 3am respectively, and average the relevant values for the 25-hour day. See Kellogg and Wolff (2008) for a similar procedure. This procedure ensures that there are no missing or double observations for the half hours beginning 2am and 2:30am, which is necessary for estimating robust standard errors as detailed in Section 5.1 below. We consider the natural logarithm of *Electricity Demand* as the dependent variable. This approach is widely used in the literature, e.g. Kellogg and Wolff (2008), Mirza and

---

[12] See www.ga.gov.au.

[13] See www.det.wa.edu.au and www.fairwork.gov.au for more details. We used www.fieldbus.org.au/FFevents/PubHol10.htm and www.fieldbus.org.au/FFevents/WApublic.htm to obtain some of the public holiday data. Although these pages no longer appear to exist, https://www.timeanddate.com/holidays/australia/ contains the same data.

Bergland (2011) and Kotchen and Grant (2011).

Summary statistics for the continuous variables used in this study are presented in Table 2. Perth experiences hot summers and mild winters. The average extremum temperatures in Perth are 31.6 and 18.3 degrees Celsius in February, and 18.4 and 7.6 degrees Celsius in July (BOM (2013)). *Temperature* is thus variable enough to cause significant heating and cooling requirements. Also, it is worth noting that *Precipitation* seldom differs from zero, that *Relative Humidity* is usually greater than 50% and that *Wind Speed* tends to be low most of the time while fluctuating significantly at higher values.

4 Model

The treatment period in our data set is the period during which the clock is set forward under the DST regime (from December 3, 2006 to March 29, 2009) and the period from the last Sunday of October until the last Sunday of March (from March 30, 2009 onwards) when there was no clock time change since DST was not observed. The control period refers to the rest of the calendar year unaffected by DST and not included in the treatment period. The DST regime coincides with the period from when WA had adopted DST until DST was repealed, which is from December 3, 2006 till March 29, 2009. The rest of the observations belong to the non-DST regime. We have provided a diagram that displays the treatment and control periods, and the DST and non-DST regimes in the data period in Figure 1.

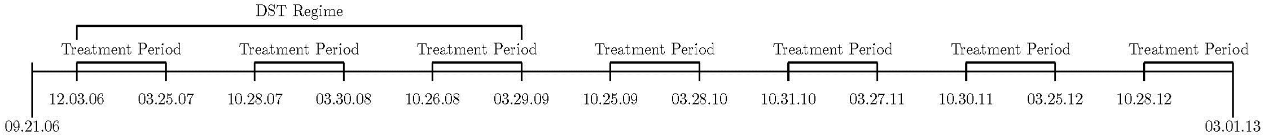
Figures 2 and 3 contrast the average of *Electricity Demand* for each half hour for the control period with the average for the treatment period[14]. It is evident from Figure 2 that there are two peaks, one in the morning around 7am and the other in the early evening about 6pm, during the control period. And a similar electricity usage pattern throughout the day is observed for all years considered. On the other hand, no clear peak like those in Figure 2 is found during the treatment period as can be seen from Figure 3. However, visually inspecting Figure 3, the rate of the decrease in electricity demand slows down at 6pm before it increases again at 7:30pm for the years when DST was not practiced. A similar phenomenon occurs not one hour early but with one hour delay during the treatment period

---

[14] We use data from September 21, 2006 to estimate the models. However, we ignore data for the period from September 21, 2006 to December 3, 2006 when plotting the graphs.

under the DST regime. DST appears to redistribute electricity demand. In Figures 2 and 3, we look only at electricity demand and have not yet considered other factors presented in the previous section and other factors to be discussed below that can affect electricity demand. To isolate how DST changes electricity demand, we need to take those variables into consideration.

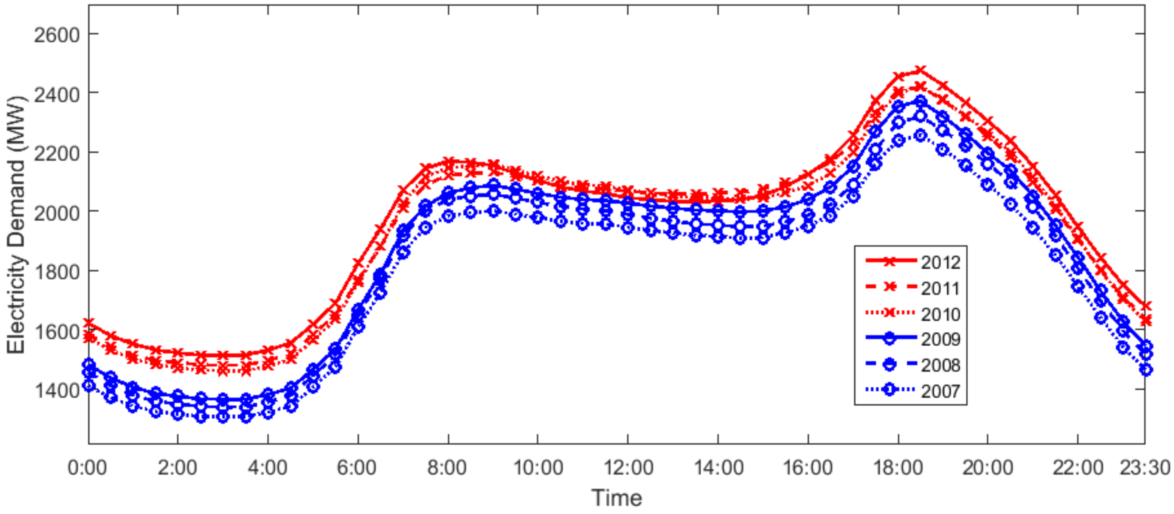
Figure 1: Treatment and Control Periods, and DST and non-DST regime.



Note: We refer to the treatment period as the period during which the clock is set forward under the DST regime (from December 3, 2006 to March 29, 2009) and the period from the last Sunday of October until the last Sunday of March (from March 30, 2009 onwards), as represented in Figure 1. The treatment period thus comprises 7 distinct time periods. The control period refers to the rest of the calendar year unaffected by DST and not included in the treatment period. The DST regime coincides with the period from December 3, 2006 till March 29, 2009. The rest of the observations belong to the non-DST regime.

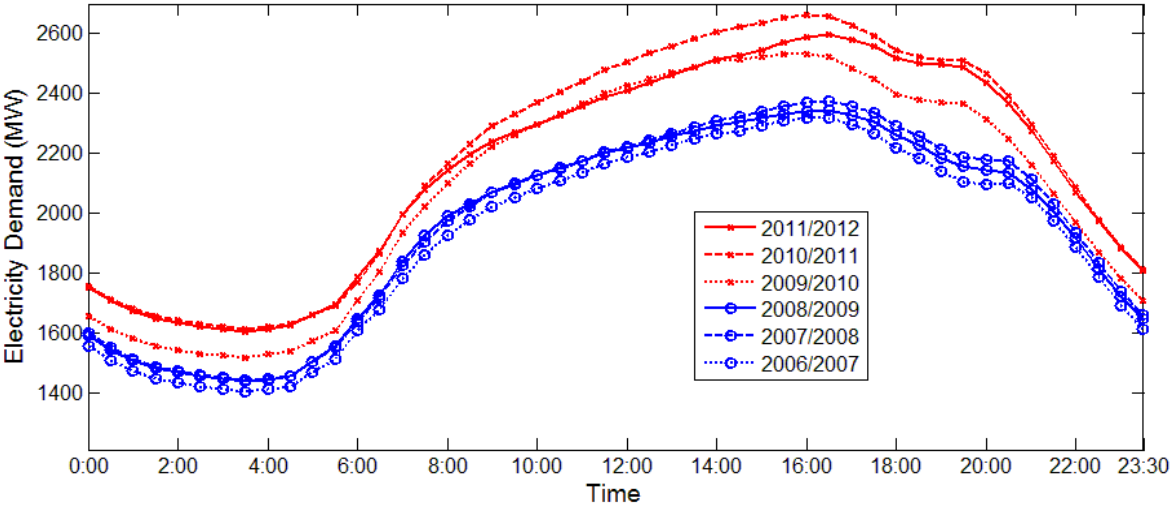
Throughout the literature, variables identified as affecting electricity demand can generally be split into two groups: seasonal variables and weather variables. Seasonal variables include day, week, month, and public holiday binary variables, while weather variables tend to include temperature, relative humidity, precipitation, daylight, cloud cover and wind speed. It is common to hypothesize that the effect of one variable differs depending on the level of another variable. For example, the effect of temperature is assumed to vary from month to month (e.g. Kandel and Sheridan (2007) and Ramanathan et al. (1997)), and depend on humidity (Hyde and Hodnett (1997)), sunlight or precipitation (Kellogg and Wolff (2008)).

Figure 2: Average half-hourly *Electricity Demand* during the control period



Note: Each line in Figure 2 represents the average of *Electricity Demand* for each half hour outside the treatment period in a given year. The blue lines with circles correspond to the years under the DST regime and the red lines with x marks correspond to the years under the non-DST regime. The legend provides further identification.

Figure 3: Average half-hourly *Electricity Demand* during the treatment period



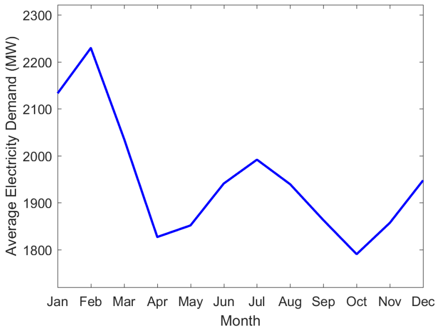
Note: Each line in Figure 3 represents the average of *Electricity Demand* for each half hour during the treatment period, i.e. the period during which the clock is set forward under the DST regime (from December 3, 2006 to March 29, 2009) and the period from the last Sunday of October until the last Sunday of March (from March 30, 2009 onwards) when there was no clock time change since DST was not observed. The blue lines with circles correspond to years under the DST regime, whereas the red lines with x marks correspond to years under the non-DST regime. The legend provides further identification.

The first stage of our analysis is to account for the intraday seasonality that can be observed in Figures 2 and 3 and estimate the effect of DST at different times of the day by running 48 different regressions – one for each half hour of the day. We use a difference-in-differences (DD) approach to identify the effect of DST on electricity demand. The relevant model is shown in equation (1) below.

$$\begin{aligned}\ln(electricity\_demand_{dh}) \;=\;& \beta_0 + \beta_1 DST\_regime_{dh} + \delta_0 treatment_{dh} + \\ & \delta_1 DST\_regime_{dh} \cdot treatment_{dh} \\ & + \gamma' dummies_{dh} + \varphi' environment_{dh} + \omega' interactions_{dh} + \varepsilon_{dh},\end{aligned} \tag{1}$$

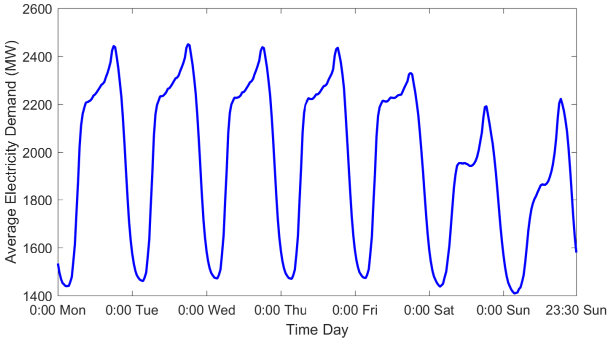
where $\ln(electricity\_demand_{dh})$ is the natural logarithm of *Electricity Demand* in half-hour h on day d. The term ε_{dh} represents an error term. Here DST_regime_{dh} is a binary variable that equals one if the observation took place during the DST regime for a particular half hour h of day d, and zero otherwise. The coefficient of this variable indicates the difference in electricity demand between the DST and non-DST regime periods. The variable $treatment_{dh}$ equals one during a particular half hour h and day d only if the observation occurred during the treatment period, and zero otherwise. The percentage difference in electricity demand between the treatment and control periods equals $100 \cdot \delta_0$. The parameter of interest is the coefficient of the interaction variable $DST\_regime_{dh} \cdot treatment_{dh}$, which equals one only if both DST_regime_{dh} and $treatment_{dh}$ equal one. The estimator $\hat{\delta}_1$ is called the DD estimator, and measures the estimated change in electricity demand due to DST. In other words, $\hat{\delta}_1$ is the difference between DST and non-DST regimes in the average difference of $\ln(electricity\_demand)$ in treatment and control periods after controlling for other confounding factors affecting electricity demand. See, for example Wooldridge (2010) for more about the DD estimator. Assuming that the model is correctly specified, $100 \cdot \hat{\delta}_1$ tells the estimated percentage change in electricity demand in a particular half hour due solely to a shift in clock time and not to the influence of any of the control factors; that is to say, it explains how electricity demand is affected by DST if everything else (such as weather, lighting and seasonality) is held constant.

Figure 4: Intrayear seasonality



Note: Figure 4 displays the average of *Electricity Demand* in each month over the entire sample.

Figure 5: Intraday and Intraweek seasonalities



Note: Figure 5 depicts the average of *Electricity Demand* for each half hour throughout the week over the entire sample.

The column vector $dummies_{dh}$ contains weekly and monthly dummy variables respectively for the intraweek and intrayear seasonalities, annual dummy variables for an overall trend, and binary variables for special occasions such as public and school holidays and for the different solar energy schemes. *Electricity Demand* varies seasonally from month to month, as illustrated by the intrayear pattern shown in Figure 4. Demand is higher in summer and winter than in spring and autumn, thus prompting us to include a binary variable for each month that equals one for observations during that month and zero otherwise. The other sources of seasonality, illustrated in Figure 5, are the intraday and intraweek variations in *Electricity Demand*. It is obvious that *Electricity Demand* is higher during the day especially in the late afternoon and early evening on each day. It is clearly lower although different on Friday, Saturday and Sunday than the other days of the week. To control for this intraweek variation, we introduce a binary variable for each day of the week.

Figures 2 and 3 highlight that *Electricity Demand* tends to increase every year from 2006 to 2011 in the treatment and control period alike. This suggests that an increase in electricity demand from 2009 to 2011, even after controlling for any intrayear pattern, could be due to an annual trend rather than the removal of DST in 2009. This annual trend is reflected in economic growth, population growth and intermittent changes to retail prices. We thus follow Kandel and Metz (2001) and Ramanathan et al. (1998) and include a binary variable for each year to account for this trend.

Other variables such as *Public Holidays* and *School Holidays* affect electricity demand,

and require the inclusion of four associated binary variables. In particular, as commercial demand is a large percentage of electricity demand, the effect of public holidays has strong implications. We separate public holidays into two groups, each represented by a binary variable, as celebration with family and friends is more common for the second group. The first variable is equal to one for Australia Day, Labour Day, Anzac Day, Western Australia Day and the Queen's birthday, and zero otherwise. The second variable is equal to one for New Year's Eve, New Year's Day, Christmas Day, Boxing Day, Good Friday, Easter Sunday and Easter Monday. It is also equal to one for related holiday periods. More precisely, for the Christmas holidays, the model assigns a value of one to any Saturday or Sunday before a Christmas falling on Monday, any day between Boxing Day and New Year's Eve, and any Saturday or Sunday following a New Year's Day falling on Friday. For the Easter holidays, Easter Saturday is assigned a value of one despite not officially being a WA public holiday. For any other day, the second variable is equal to zero. The third binary variable is equal to one if the day is a school holiday and zero otherwise. Finally, because it has been shown that demand is different the day after a public holiday (Ramanathan et al. (1997)), it is necessary to include a fourth binary variable that equals one the day after a public holiday.

Solar incentive schemes are likely to encourage people to use more solar-powered electricity and thus decrease demand for non-solar-powered electricity. To control for this, five separate binary variables are used. Each corresponds to a particular phase of the solar incentive scheme presented in Table 1, as we assume that electricity demand is affected differently across the various phases.

The DST effect cannot be isolated without also considering other influences on electricity demand, including environmental variables such as temperature, humidity, wind speed and daylight. To this end, there is a column vector of variables in the model, $environment_{dh}$, that incorporates these effects. There is widespread agreement in the literature that temperature is the most influential weather variable and that its relation with electricity demand is either V-shaped or U-shaped. Our data also support this. For example, Figure 6 represents the relationship between *Temperature* and *Electricity Demand* for the half hour from 7-7:30pm. The reference line corresponds to the temperature of 18.3 degrees Celsius. The turning points of the temperature-demand relationships in our data range from around 15 degrees in the middle of the night to about 22 degrees in the middle of the day. To model this relationship, Kotchen and Grant (2011), Kellogg and Wolff (2008) and Kandel and Sheridan (2007) use the concept of heating and cooling degrees, as defined by the following equations:

$$Cooling\ Degrees = \max\{0,\ temperature - reference_c\} \tag{2}$$

$$Heating\ Degrees = \max\{0,\ reference_h - temperature\}, \tag{3}$$

where $reference_c$ and $reference_h$ are the reference temperatures for *Cooling Degrees* (CDs) and *Heating Degrees* (HDs), respectively. Equations (2) and (3) ensure that there cannot simultaneously be strictly positive *cooling degree* and *heating degree* values. Following the literature, we consider both reference temperatures to be 18.3 degrees Celsius (65 degrees Fahrenheit).[15] The appropriateness of this assumption for all 48 regressions will be subject to robustness checks, as discussed in Section 5.2. Thus, the $environment_{dh}$ matrix includes the following variables: *Cooling Degrees*, a quadratic in *Cooling Degrees*, *Heating Degrees* and a quadratic in *Heating Degrees.* Although similar to a general quadratic in temperature, this specification allows for asymmetry in the response to heating and cooling degrees.

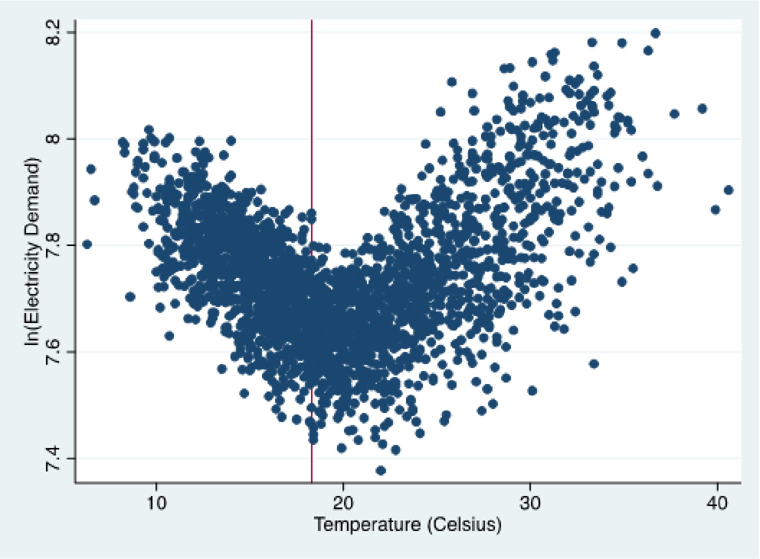
Even if electricity demand is expected to be sensitive to temperature, many studies find that other weather variables have significant effects as well. *Relative humidity* is one such variable, and is included in the $environment_{dh}$ matrix in two ways: first, as a separate variable, and second, as part of an interaction variable with *Temperature* (Hyde and Hodnett (1997)) to account for the greater discomfort created by humidity in extreme temperatures. Similarly, as wind and precipitation generally intensify colder weather and alleviate the effects of hotter weather, we introduce both, *Wind Speed* and *Precipitation,* as interaction variables with *Heating Degrees* and *Cooling Degrees* (Hyde and Hodnett (1997), Kellogg and Wolff (2008)). *Temperature, Relative Humidity, Precipitation* and *Wind Speed* all enter the regression lagged by half an hour, to allow for slightly delayed reactions to changes in conditions (Kellogg and Wolff (2008)). *Daylight* is a binary variable that equals one when a half hour is completely in daylight and zero otherwise; for example, if sunrise is at 5:29am and the half hour starting at 5:30am is being considered, then the daylight variable will equal one for that half hour, but if sunrise is at 5:30am, it will be equal to zero. This variable is

---

[15] As *Temperature* is measured to one decimal place, we adopt a reference temperature of 18.3 degrees Celsius rather than 18.33 as usually assumed in the literature.

relevant only during those half hours in which the amount of daylight varies throughout the year.

Figure 6: The temperature-demand relationship at 7pm



Note: Figure 6 is a scatter plot illustrating the relationship between temperature and ln(*Electricity Demand*) for the half hour beginning 7pm over the entire sample. The reference line corresponds to the temperature of 18.3 degrees Celsius.

Finally, to account for the differing effect of a given temperature across different months, interactions between the *Heating Degrees*, *Cooling Degrees*, *Heating Degrees* quadratic and *Cooling Degrees* quadratic with the month dummies (Kellogg and Wolff (2008)) have been included in the $interactions_{dh}$ matrix. Table 3 contains all variables and interacted terms that have been used in our model with a brief description of each variable.

5 Estimation Results

After presenting and discussing the estimation results of model (1) we provide the outcomes of our robustness check to various specifications of temperature in this section.

Table 3: Summary of variables in model

Variable	Description	Interactions with other variables
$electricity\_demand_{dh}$	The quantity of electricity demanded within the SWIS for a particular half hour h of day d (MW)	N/A
$\ln(electricity\_demand_{dh})$	The natural logarithm of $electricity\_demand_{dh}$	N/A
DST_regime_{dh}	A dummy variable for the observation during the DST regime for a particular half hour h of day d	$treatment_{dh}$
$treatment_{dh}$	A dummy variable for the observation during the treatment period for a particular half hour h and day d	DST_regime_{dh}
$DST\_regime_{dh} \cdot treatment_{dh}$	The interaction of DST_regime_{dh} and $treatment_{dh}$	N/A
$dummies_{dh}$	Dummies for weekly, monthly and annual patterns, public and school holidays, and the solar incentive schemes	CD, HD
Cooling Degrees (CD) for the main model	$CD = \max\{0, temperature - reference_c\}$, where $reference_c = 18.3$ degrees Celsius	*Monthly dummy variables, Precipitation, Wind Speed*
Heating Degrees (HD) for the main model	$HD = \max\{0, reference_h - temperature\}$, where $reference_h = 18.3$ degrees Celsius	*Monthly dummy variables, Precipitation, Wind Speed*
CD for the robustness check	$CD = \max\{0, temperature - reference_c\}$, where $reference_c = 20$ degrees Celsius	*Monthly dummy variables, Precipitation, Wind Speed*
HD for the robustness check	$HD = \max\{0, reference_h - temperature\}$, where $reference_h = 16$ degrees Celsius	*Monthly dummy variables, Precipitation, Wind Speed*
HD for the robustness check	$HD = \max\{0, reference_h - temperature\}$, where $reference_h = 20$ degrees Celsius	*Monthly dummy variables, Precipitation, Wind Speed*
Temperature for the robustness check	The temperature (degrees Celsius)	*Relative Humidity, monthly dummy variables, Precipitation, Wind Speed*
Precipitation	The amount of precipitation (mm)	*CD, HD*
Wind Speed	The average wind speed (km/h) in the ten minutes prior to the observation time	CD, HD
Relative Humidity	An integer percentage that measures relative humidity	*Temperature*
Daylight	A dummy variable that equals one when a given half hour is completely in daylight	N/A

5.1 Results and Discussion

The effect of DST on electricity demand when other factors are held fixed turns out to vary throughout the day. Table 4 shows, for each half hour of the day, 100 times estimates of the DST_regime_{dh} coefficient (β_1), the $treatment_{dh}$ coefficient (δ_0), and the $DST\_regime_{dh} \cdot treatment_{dh}$ coefficient (δ_1) to get percentage changes, with the associated t-values in brackets. Robust standard errors are computed by using a heteroskedasticity and autocorrelation consistent (HAC) estimator suggested by Newey and West (1987) with seven lags. We have used the t statistic to test if the coefficient of an independent variable is zero. An asterisk next to the estimate implies that the parameter is statistically different from zero at the 5% significance level. Overall, DST has a statistically significant effect at the 5% level on electricity demand in 32 of the 48 half hours, with a positive effect in 24 of them. The adjusted R-squared value for the regression of each half-hour is shown in the last column. It ranges from 0.85 to 0.92, which implies that 85% to 92% of the total variations of log-electricity demand are explained by model (1).

As a counterfactual experiment, if we use those estimated percentage changes in electricity demand to calculate changes in electricity demand which could have occurred during the treatment period when DST was not observed in 2009-2012, the largest decrease in electricity demand is about -144 MW. On the other hand, the greatest increase of around 57 MW (or 2.78%) happens during the high-demand 8am period. The fifth column of Table 4 displays the change in electricity demand in MW for each half hour, calculated as the mean of electricity demand for a given half hour during the treatment period under the non-DST regime multiplied by the estimate of the associated change in demand (δ_1). The drops in electricity demand in each of the half hours from 6:30-8pm are all much greater than the highest increase in demand, and coincide with the periods of high electricity demand during the treatment period, as illustrated earlier in Figure 3. Figure 7 plots the estimated changes in *Electricity Demand* owing to DST for each half hour of the day and the corresponding 95% confidence band. If the x-axis is in the 95% confidence band, it implies that the corresponding estimated change is statistically insignificant at the 5% level. The late night and early morning periods, from 12pm-7:30am are characterized by

Table 4: Selected estimation results from the difference-in-differences model

Half hour	β_1	δ_0	δ_1	ΔED (MW)	Adj. R^2
$0:00-0:30$	0.60% (0.83)	−0.04% (−0.07)	2.21%* (3.87)	35.03	0.87
$0:30-1:00$	−0.05% (−0.07)	0.28% (0.44)	2.02%* (3.51)	31.05	0.87
$1:00-1:30$	−0.17% (−0.24)	0.68% (0.95)	1.86%* (3.15)	27.94	0.86
$1:30-2:00$	−0.005% (−0.01)	0.56% (0.79)	1.68%* (2.83)	24.81	0.86
$2:00-2:30$	−0.32% (−0.44)	0.29% (0.40)	1.78%* (2.99)	26.04	0.85
$2:30-3:00$	−0.09% (−0.12)	0.22% (0.28)	1.83%* (3.02)	26.52	0.85
$3:00-3:30$	0.05% (0.07)	0.30% (0.39)	1.71%* (2.86)	24.64	0.85
$3:30-4:00$	0.07% (0.09)	0.22% (0.30)	1.53%* (2.63)	21.92	0.85
$4:00-4:30$	−0.10% (−0.14)	0.21% (0.31)	1.04% (1.80)	14.96	0.85
$4:30-5:00$	0.11% (0.14)	0.00% (0.00)	1.00% (1.75)	14.47	0.85
$5:00-5:30$	0.16% (0.20)	−1.00% (−1.29)	1.99%* (3.49)	29.76	0.85
$5:30-6:00$	0.49% (0.63)	−0.54% (−0.67)	1.49%* (2.03)	23.00	0.86
$6:00-6:30$	0.50% (0.61)	−1.18% (−1.83)	0.84% (1.16)	13.73	0.89
$6:30-7:00$	0.64% (0.72)	−1.65%* (−2.53)	1.18% (1.86)	20.18	0.91
$7:00-7:30$	0.83% (0.88)	−2.31%* (−3.46)	1.69%* (3.46)	30.75	0.91
$7:30-8:00$	1.08% (1.13)	−2.03%* (−3.13)	2.79%* (4.47)	53.06	0.91
$8:00-8:30$	0.84% (0.97)	−1.75%* (−3.14)	2.78%* (4.50)	54.71	0.91
$8:30-9:00$	0.17% (0.21)	−1.37%* (−2.41)	2.38%* (3.93)	47.91	0.90
$9:00-9:30$	0.25% (0.32)	−0.76% (−1.34)	2.04%* (3.45)	41.96	0.90
$9:30-10:00$	0.00% (0.00)	−0.47% (−0.81)	2.00%* (3.41)	41.72	0.90
$10:00-10:30$	−0.12% (−0.16)	0.10% (0.18)	1.79%* (3.04)	37.84	0.90
$10:30-11:00$	0.29% (0.37)	0.16% (0.29)	1.36%* (2.32)	29.09	0.90
$11:00-11:30$	0.44% (0.56)	0.33% (0.51)	0.97% (1.64)	21.00	0.91
$11:30-12:00$	0.53% (0.66)	0.53% (0.80)	0.56% (0.95)	12.28	0.91

Table 4 Continued

Half hour	β_1	δ_0	δ_1	ΔED (MW)	Adj. R^2
12 : 00 − 12 : 30	−0.10% (−0.13)	0.82% (1.08)	0.02% (1.08)	0.44	0.91
12 : 30 − 13 : 00	0.38% (0.42)	0.77% (0.99)	−0.25% (−0.38)	−5.58	0.91
13 : 00 − 13 : 30	0.29% (0.32)	0.60% (0.85)	−0.36% (−0.55)	−8.10	0.92
13 : 30 − 14 : 00	0.38% (0.42)	0.71% (1.00)	−0.44% (−0.69)	−9.99	0.92
14 : 00 − 14 : 30	0.69% (0.75)	0.82% (1.21)	−0.60% (−0.89)	−13.73	0.92
14 : 30 − 15 : 00	0.73% (0.84)	1.14% (1.43)	−0.86% (−1.24)	−19.80	0.92
15 : 00 − 15 : 30	1.21% (1.30)	0.95% (1.19)	−1.00% (−1.44)	−23.17	0.92
15 : 30 − 16 : 00	1.18% (1.30)	0.94% (1.24)	−1.09% (−1.58)	−25.45	0.92
16 : 00 − 16 : 30	1.08% (1.10)	1.17% (1.55)	−1.30% (−1.89)	−30.49	0.91
16 : 30 − 17 : 00	1.31% (1.44)	0.76% (0.99)	−1.37%*(−2.04)	−32.16	0.91
17 : 00 − 17 : 30	1.60% (1.73)	0.29% (0.36)	−1.42%*(−2.06)	−33.07	0.90
17 : 30 − 18 : 00	2.12%*(2.16)	−0.66% (−0.88)	−1.90%*(−2.77)	−43.80	0.89
18 : 00 − 18 : 30	2.11%*(2.23)	−2.11%*(−2.40)	−2.38%*(−3.63)	−53.81	0.89
18 : 30 − 19 : 00	2.30%*(2.34)	−3.66%*(−4.93)	−3.25%*(−4.88)	−72.38	0.89
19 : 00 − 19 : 30	2.50%*(2.54)	−2.26%*(−3.96)	−6.61%*(−5.96)	−144.27	0.89
19 : 30 − 20 : 00	2.36%*(2.43)	0.04% (0.05)	−5.62%*(−6.93)	−121.08	0.89
20 : 00 − 20 : 30	1.38% (1.52)	0.99% (1.12)	−2.85%*(−4.26)	−61.08	0.88
20 : 30 − 21 : 00	1.29% (1.45)	0.16% (0.22)	0.54% (0.85)	11.55	0.88
21 : 00 − 21 : 30	1.49% (1.63)	−0.28% (−0.44)	1.85%*(3.01)	38.55	0.88
21 : 30 − 22 : 00	1.27% (1.40)	−0.19% (−0.30)	2.71%*(4.04)	54.40	0.88
22 : 00 − 22 : 30	1.25% (1.39)	−0.32% (−0.51)	2.99%*(4.90)	57.28	0.88
22 : 30 − 23 : 00	1.05% (1.21)	−0.29% (−0.47)	2.92%*(4.99)	52.96	0.88
23 : 00 − 23 : 30	0.69% (0.85)	−0.32% (−0.55)	2.91%*(5.14)	50.07	0.88
23 : 30 − 0 : 00	0.57% (0.72)	−0.29% (−0.54)	2.68%*(4.69)	44.08	0.87
Overall	0.82% (1.66)	0.31% (0.77)	0.30% (0.91)	5.84	0.92

Note: Table 4 shows selected results from the difference-in-differences model for each half hour. The first column shows the 48 different half hour time intervals. The second column displays the estimated percentage difference in electricity demand between the DST and non-DST regimes. The estimated percentage difference in electricity demand between the control and treatment periods can be found in the third column. The fourth column lists the estimated percentage change in electricity demand (ED) due to the implementation of DST. The fifth column shows the estimated change in demand for each half hour, calculated as the mean of electricity demand during the treatment period under the non-DST regime for a given half hour multiplied by the associated percentage change in demand. All t-values are in parentheses, and * represents statistical significance at the 5% level. Adjusted R^2 for each regression is shown in the last column.

insignificant to moderate increases in electricity demand. A morning peak of 2.79% is then reached at 7:30am, with a moderate increase in electricity demand to follow until 11am. From 11am-4:30pm, DST has an insignificant effect on electricity demand. This insignificant effect of DST on electricity demand during the middle of the day has been assumed to hold without proving it to use as control periods in other existing literature since they do not have any natural experiment data. Our results provide supporting evidence for the assumption made by other researchers. A quite strong electricity-saving effect of DST is observed from 5:30-8:30pm. From 9pm (after sunset) DST once again increases electricity demand moderately.

Because of the shift in clock time, early morning conditions under DST differ especially during those periods in spring before summer starts and in fall before winter begins, with less daylight and lower temperatures, thus resulting in an increase in electricity demand, even after controlling for differences in other factors. Similarly, the early evening decrease in demand is likely to be a result of lighter and warmer conditions in those periods. Furthermore, people are likely to engage in more outdoor activities to enjoy longer and lighter evenings in summer, which will reduce energy use for air-conditioning and lights. After sunset, more people go indoors such as home and restaurants and this seems to be why electricity demand starts to increase from 8:30pm. It is perhaps less clear why DST should increase electricity demand during bedtime hours, but the answer likely lies in the adhesion of scheduled activities to clock time. From 1-5am, residential lighting usage is likely to be very low, especially during the week, so electricity demand would be driven primarily by cooling or heating needs. It is quite reasonable to argue that the decision whether to use cooling or heating is affected by conditions around bedtime. DST has the effect of delaying the onset of lower temperatures in summer and higher temperatures at bedtime are likely to promote an increased use of cooling energy for the rest of the night. In addition, lower temperatures when people wake up in spring and fall under the DST regime could have increased electricity demand for heating. The observed increase in electricity demand from 9-11am would be driven far more by commercial demand than by residential demand, as the workday would start in colder conditions compared with the non-DST scenario in particular at the beginning and end of DST.

As can be seen from Table 4, the DST_regime_{dh} coefficient (β_1) and the $treatment_{dh}$

coefficient (δ_0) are mostly insignificant. This means that there is not much difference in electricity demand between the treatment and control periods and between the DST and non-DST regimes once other confounding factors are controlled for. The estimate of β_1 is only significant and positive from 5:30-8pm, which implies that electricity demand was higher during the DST regime for these half hours, controlling for other factors. The estimate of δ_0 is significant and negative from 6:30-9am and also from 6-7:30pm, indicating a lower electricity demand in the treatment period months during these half hours. This is so even after controlling for all of the month and year specific effects described in Section 4.1.

In order to determine whether DST has an overall effect on electricity demand, we first calculated the weighted average of $\hat{\delta}_1$ such that

$$\sum_{h=1}^{48} \hat{\delta}_{1h} w_h, \tag{4}$$

where $\hat{\delta}_{1h}$ is the estimate of δ_1 and $w_h = AED_h \left/ \sum_{h=1}^{48} AED_h \right.$. And AED_h is average electricity demand during the treatment period under non-DST regime for the h-th half-hour[16]. It turns out to be 0.0032 or 0.32%. Next, using the same weight w_h as in equation (4) the weighted average of changes in electricity demand during the treatment period under the non-DST regime has been computed. That is

$$\sum_{h=1}^{48} \Delta ED_h w_h,$$

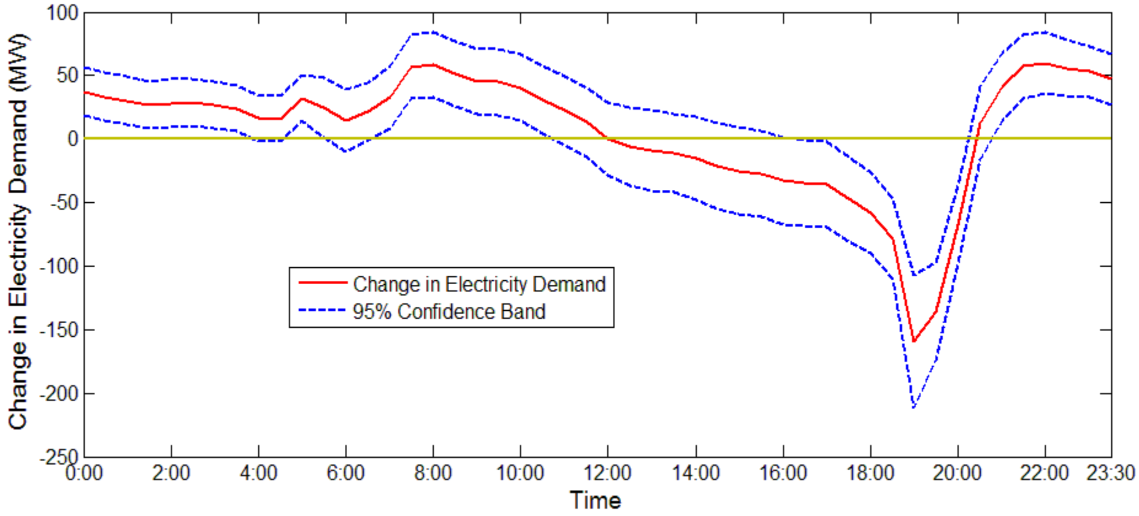
where $\Delta ED_h = \hat{\delta}_{1h} \times AED_h$. It is estimated as about 2MW. These results say that the demand for electricity would have increased slightly if DST had been observed during the treatment period in 2009 through 2012. Finally, the observations from all 48 half hours are combined in a pooled regression model. The model is very similar to the one for the 48 half-hourly regressions. The first main difference is that 47 half-hour dummies are included to control for the intraday effect. The second is that the two key explanatory variables, *Cooling Degrees* and *Heating Degrees*, and their associated quadratic terms are both interacted with each of these half-hour dummies. Heteroskedasticity and autocorrelation robust standard errors proposed by Newey and West (1987) are obtained with 50 lags. The DD estimate of δ_1 for the pooled regression is 0.003, which is consistent with the two results above and

---

[16] Alternatively, $\exp\left(\hat{\delta}_{1h}\right) - 1$ can be used instead of $\hat{\delta}_{1h}$. However, since the absolute values of $\hat{\delta}_{1h}$ are close to zero in all cases, we get similar values.

statistically insignificant at any conventional significance level. That is, DST does not appear to affect overall electricity demand. Considering the results from the pooled regression and separate half-hourly regressions as a whole, we conclude that the intraday redistributional effect of DST on electricity demand is such that the relatively small but frequent increases in electricity demand are offset by the large decreases during the evening.

Figure 7: How DST affects electricity demand throughout the day



Note: Figure 7 is a line graph showing the point estimates of the change in electricity demand during the treatment period under the non-DST regime in MW throughout the day if DST had been observed during this period. The dotted lines are the 95% confidence band.

The response to temperature varies depending on the time of year. Summarizing the estimation results, *Cooling Degrees* when it is hot and *Heating Degrees* when it is cold can adequately capture the relationship between *Electricity Demand* and *Temperature* for all months. Table A.1 in Appendix displays the estimation results of the quadratic functions of *Cooling Degrees* in January (base month for *Cooling Degrees*) and those of *Heating Degrees* in July (base month for *Heating Degrees*) for all half hour intervals. The expected relationship between *Electricity Demand* and *Cooling Degrees* holds quite well in January with a significantly positive coefficient of *Cooling Degrees* in about three quarters of the regressions, and with the coefficient of *Cooling Degrees*-squared also significantly positive in slightly fewer than half of the regressions. Note that for all half hour intervals, at least one of the coefficients of the quadratic function in CD is statistically different from zero at the 5% significance level. Looking at the shape of the estimated quadratic function of *Cooling Degrees* in each half hour, in most cases it is U-shaped and the turning point CDs are negative or small positive numbers (at most 2.17 CDs). In a small number of regressions it is hump-shaped and the turning point CDs are quite big positive numbers. These results imply a positive relationship between *Electricity Demand* and *Cooling Degrees* in January. The *Heating Degrees* coefficient is invariably significantly positive, and the quadratic term has a significantly positive coefficient about half the time. In all half hour intervals the quadratic functions in *Heating Degrees* are U-shaped and the turning point HDs are negative. Thus, *Electricity Demand* is always positively related with *Heating Degrees* in July in a given half hour. We obtained a similar dependence of *Electricity Demand* on *Cooling Degrees* in November, December, February, and March to that of January. And the estimated quadratic functions of *Heating Degrees* in June, August, and September are analogous to those of July. At the end of fall (May) and the beginning of spring (October), *Cooling Degrees* can capture the proportional association between *Electricity Demand* and *Temperature* during the daytime better than *Heating Degrees.* For the rest of the day in these two months, *Electricity Demand* increases as *Heating Degrees* rises. Similarly, in April, *Electricity Demand* goes up as *Heating Degrees* increases during the early morning and when *Cooling Degrees* grows in other parts of the day. When there are no relevant data, e.g., no temperature above 18.3 degrees in July in the middle of the night, coefficients cannot be estimated. The robustness of using 18.3 degrees as a reference is demonstrated later in Section 5.2.

Precipitation and *Wind Speed* have an expected positive effect on *Electricity Demand* when interacted with *Heating Degrees*, and a negative effect when interacted with *Cooling Degrees.* This shows that wind and precipitation have an intensifying effect on demand during cold days, but decrease electricity demand during warmer weather. The estimates for the coefficients of these interaction terms for the 48 half hour intervals are given in Table A.2 in Appendix.

At all times, the coefficient of *Humidity* is negative while that of *Humidity* interacted with *Temperature* is positive. And both of these coefficients are statistically significant in all cases. The positive coefficient of *Humidity*× *Temperature* indicates that if *Humidity* goes up *Electricity Demand* increases more for the time when *Temperature* is higher. This is what we expected to capture using this interaction term. To see the effect of *Humidity* on *Electricity Demand* the average temperature for each half hour is plugged in for *Temperature.* It turns out that for most half hours when *Humidity* increases by 10 percentage points demand for electricity rises up to 2.93% when other factors are held fixed. For some half hours during midnight or early morning the effect of humidity is negative but it is at most -0.67%. The negative estimates could be due to the lower temperatures during these periods. *Daylight* has the expected ceteris paribus effect ranging from -1.7% to -2% on *Electricity Demand* in the morning particularly in spring and fall but appears not to be important during the early evening hours during which more people tend to stay outside in summer. These results are tabulated in Table A.3 in the Appendix.

Table A.4 summarizes how the solar incentive schemes are estimated to have affected *Electricity Demand.* Generally, electricity demand was negatively affected by solar PV generation, with a few exceptions during the first and second regime periods with a positive but small effect. However, those half hour intervals that engendered statistically significant and positive estimates correspond to early morning or evening, and we note that electricity generated by solar panels during the day cannot be stored. As mentioned before the total amount of small-scale PV capacity increased from only 21 MW in February 2010 to 274 MW in February 2013. And more people adopted solar PV generation as time went by, which seems to be why we obtain a higher number of negative coefficients during the day that are statistically significant and practically more significant.

The two different public holiday variables generally have substantially different coefficients, hence justifying the division of public holidays in the model. The negative effect of school holidays is concentrated in the morning, while the 'day after a public holiday' effect is negative, but only significant from 12-9am. To save space, we did not provide all of the estimation results. We direct readers to the appendix for the estimation results for selected coefficients.

5.2 Robustness To Temperature Specifications

Since the relationship between temperature and electricity demand is critical, it is important to determine whether the estimation results are robust to various reasonable temperature specifications. Table 5 shows the results for the DD estimator ($\hat{\delta}_1$) under a number of different nonlinear specifications for temperature. The simplest specification is a quadratic in *Temperature* instead of separate quadratics in *Heating Degrees* and *Cooling Degrees* (Ramanathan et al. (1997)), which models a relatively smooth relationship between *Temperature* and *Electricity Demand*, but does not account well for flat regions[17] in which electricity demand is irresponsive to temperature or for differing effects of hot and cold weather. The quadratic terms are interacted with *month*, *Wind Speed* and *Precipitation.* It can be seen from Table 5 that this specification does not change the estimates substantially at all; the only difference is that the largest decrease in electricity demand is estimated to be -6.98% instead of -6.61%.

If the aforementioned flat regions are of particular importance in controlling for the effect of temperature, the current model specification may not estimate the true treatment effect. We thus use a second approach that requires the adoption of different thresholds for *Cooling Degrees* and *Heating Degrees.* Based on graphical analysis of the temperature-demand relationship throughout the 48 half-hourly periods, a *Cooling Degrees* reference temperature of 20 degrees and a *Heating Degrees* reference temperature of 16 degrees are used. Electricity demand is thus modelled as being irresponsive to temperature, wind speed and precipitation between 16 and 20 degrees Celsius. Again, changes are minor, with the largest decrease now becoming -7.27%. Next, to account for the warm dry weather of Perth, a reference temperature of 20 degrees instead of 18.3 degrees is used with no real effect on the estimates. Finally, to determine whether low temperatures can explain the increase in electricity demand observed earlier during the nighttime hours, a lower reference temperature of 15 degrees is used for the half-hours from 12-6am. The estimates do not change appreciably.[18] The lack of sensitivity of the DD estimates to these different temperature specifications indicates that the main model does not contain unreasonable or strong assumptions with respect to

---

[17] This is also true when we use the same reference temperature for heating degrees and cooling degrees.

[18] The results from this robustness check are not reported in Table 5.

Table 5: Robustness of DD Estimates to Temperature Specifications

Half Hour	Main Model	Temperature Quadratic	Two References	Twenty-Degree Reference
0 : 00 − 0 : 30	2.21%*(3.87)	2.18%*(3.87)	2.11%*(3.64)	2.17%*(3.76)
0 : 30 − 1 : 00	2.02%*(3.51)	1.97%*(3.50)	1.84%*(3.17)	1.92%*(3.33)
1 : 00 − 1 : 30	1.86%*(3.15)	1.83%*(3.19)	1.75%*(2.94)	1.83%*(3.12)
1 : 30 − 2 : 00	1.68%*(2.83)	1.69%*(2.91)	1.63%*(2.73)	1.69%*(2.87)
2 : 00 − 2 : 30	1.78%*(2.99)	1.77%*(3.03)	1.73%*(2.88)	1.80%*(3.04)
2 : 30 − 3 : 00	1.83%*(3.02)	1.83%*(3.10)	1.69%*(2.77)	1.79%*(2.99)
3 : 00 − 3 : 30	1.71%*(2.86)	1.7%*(2.88)	1.56%*(2.59)	1.69%*(2.84)
3 : 30 − 4 : 00	1.53%*(2.63)	1.56%*(2.7)	1.43%*(2.40)	1.51%*(2.59)
4 : 00 − 4 : 30	1.04% (1.80)	1.10% (1.92)	1.00% (1.70)	1.05% (1.81)
4 : 30 − 5 : 00	1.00% (1.75)	1.04%(1.82)	0.96%(1.65)	1.01% (1.76)
5 : 00 − 5 : 30	1.99%*(3.49)	2.06%*(3.62)	1.96%*(3.42)	1.99%*(3.49)
5 : 30 − 6 : 00	1.49%*(2.03)	1.53%*(2.11)	1.47%*(2.01)	1.49%*(2.06)
6 : 00 − 6 : 30	0.84%(1.16)	0.88% (1.22)	0.89% (1.21)	0.86%(1.19)
6 : 30 − 7 : 00	1.18%(1.86)	1.26%*(2.00)	1.13% (1.76)	1.19%(1.87)
7 : 00 − 7 : 30	1.69%*(3.46)	1.70%*(2.63)	1.54%*(2.33)	1.72%*(2.64)
7 : 30 − 8 : 00	2.79%*(4.47)	2.77%*(4.45)	2.55%*(4.04)	2.77%*(4.43)
8 : 00 − 8 : 30	2.78%*(4.5)	2.84%*(4.62)	2.61%*(4.18)	2.78%*(4.51)
8 : 30 − 9 : 00	2.38%*(3.93)	2.43%*(4.00)	2.22%*(3.63)	2.40%*(3.96)
9 : 00 − 9 : 30	2.04%*(3.45)	2.13%*(3.64)	2.00%*(3.41)	2.09%*(3.55)
9 : 30 − 10 : 00	2.00%*(3.41)	2.08%*(3.58)	1.96%*(3.35)	1.96%*(3.96)
10 : 00 − 10 : 30	1.79%*(3.04)	1.84%*(3.15)	1.91%*(3.26)	1.75%*(2.98)
10 : 30 − 11 : 00	1.36%*(2.32)	1.41%*(2.42)	1.41%*(2.37)	1.33%*(2.28)
11 : 00 − 11 : 30	0.97%(1.64)	0.98% (1.66)	0.99%(1.63)	1.00% (1.69)
11 : 30 − 12 : 00	0.56%(0.95)	0.54% (0.91)	0.44%(0.72)	0.57%(0.98)

Table 5 Continued

Half Hour	Main Model	Temperature Quadratic	Two References	Twenty-Degree Reference
12 : 00 − 12 : 30	0.02% (0.08)	0.01% (0.02)	0.00% (0.00)	0.01% (0.02)
12 : 30 − 13 : 00	−0.25% (−0.38)	−0.27% (−0.42)	−0.20% (−0.29)	−0.23% (−0.36)
13 : 00 − 13 : 30	−0.36% (−0.55)	−0.40% (−0.60)	−0.35% (−0.51)	−0.37% (−0.55)
13 : 30 − 14 : 00	−0.44% (−0.69)	−0.47% (−0.74)	−0.45% (−0.67)	−0.45% (−0.71)
14 : 00 − 14 : 30	−0.6% (−0.89)	−0.63% (−0.94)	−0.64% (−0.91)	−0.59% (−0.87)
14 : 30 − 15 : 00	−0.86% (−1.24)	−0.91% (−1.34)	−0.86% (−1.21)	−0.83% (−1.21)
15 : 00 − 15 : 30	−1.00% (−1.44)	−1.05% (−1.53)	−0.97% (−1.35)	−0.96% (−1.39)
15 : 30 − 16 : 00	−1.09% (−1.58)	−1.21% (−1.77)	−1.11% (−1.56)	−1.07% (−1.55)
16 : 00 − 16 : 30	−1.30% (−1.89)	−1.38%*(2.02)	−1.32% (−1.82)	−1.32% (−1.91)
16 : 30 − 17 : 00	−1.37%*(−2.04)	−1.39%*(−2.07)	−1.31% (−1.84)	−1.38%*(−2.05)
17 : 00 − 17 : 30	−1.42%*(−2.06)	−1.50%*(−2.18)	−1.41% (−1.96)	−1.38%*(−2.01)
17 : 30 − 18 : 00	−1.90%*(−2.77)	−1.86%*(−2.71)	−1.96%*(−2.65)	−1.81%*(−2.63)
18 : 00 − 18 : 30	−2.38%*(−3.63)	−2.50%*(−3.76)	−2.42%*(−3.42)	−2.29%*(−3.48)
18 : 30 − 19 : 00	−3.25%*(−4.88)	−3.32%*(−4.95)	−3.34%*(−4.69)	−3.18%*(−4.77)
19 : 00 − 19 : 30	−6.61%*(−5.96)	−6.98%*(−6.29)	−7.27%*(−6.74)	−6.46%*(−6.13)
19 : 30 − 20 : 00	−5.62%*(−6.93)	−5.95%*(−7.31)	−5.76%*(−6.77)	−5.66%*(−6.82)
20 : 00 − 20 : 30	−2.85%*(−4.26)	−3.10%*(−4.59)	−2.96%*(−4.28)	−2.86%*(−4.31)
20 : 30 − 21 : 00	0.54% (0.85)	0.32% (0.51)	0.40% (0.61)	0.45% (0.72)
21 : 00 − 21 : 30	1.85%*(3.01)	1.65%*(2.68)	1.71%*(2.71)	1.75%*(2.86)
21 : 30 − 22 : 00	2.71%*(4.04)	2.54%*(4.11)	2.61%*(4.18)	2.65%*(4.33)
22 : 00 − 22 : 30	2.99%*(4.90)	2.90%*(4.75)	2.89%*(4.71)	2.96%*(4.89)
22 : 30 − 23 : 00	2.92%*(4.99)	2.84%*(4.85)	2.79%*(4.72)	2.88%*(4.95)
23 : 00 − 23 : 30	2.91%*(5.14)	2.82%*(4.97)	2.73%*(4.73)	2.83%*(4.99)
23 : 30 − 0 : 00	2.68%*(4.69)	2.56%*(4.52)	2.58%*(4.46)	2.63%*(4.60)

Note: Table 5 shows selected results of the DD estimator from a number of variations of temperature terms on the main model presented in this paper. The ‘temperature quadratic’ column shows the results from using a quadratic in temperature instead of heating and cooling degrees to specify the relationship between electricity demand and temperature. The ‘two references’ column shows the results from using two references in the heating and cooling degree specification instead of one, with 16 and 20 degrees used as references. The ‘twenty-degree reference’ column shows the results from assuming a reference temperature of 20 degrees Celsius instead of 18.3 degrees Celsius. All t-values are shown in parentheses, and * indicates significance at the 5% level.

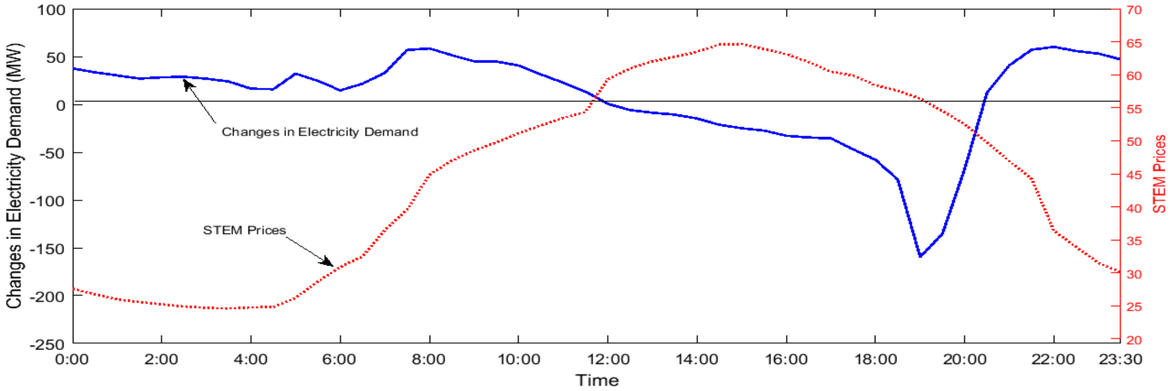
temperature.

6 Other Aspects of Daylight Saving Time

An important economic aspect of DST is the associated change in electricity generation costs. Even if DST negatively affects demand during the early evening, it must still be determined whether the resulting cost savings outweigh the additional costs incurred during other times of the day.

When computing electricity generation costs, we take the Short Term Energy Market (STEM) price as a proxy for the marginal cost of providing electricity. Although most electricity is traded bilaterally in WA, some parties find it necessary to deviate from their arrangements in the short term, and the STEM allows these parties to offer or bid for electricity a day ahead of schedule for each of the 48 half-hourly trading intervals. For each of the intervals, the STEM price is determined in the STEM equilibrium. While prices agreed upon in bilateral agreements may be somewhat static, the STEM price responds dynamically to real conditions that generators and retailers may face (IMO (2012)). This makes STEM price a reasonable approximation of the marginal cost of electricity generation.

Figure 8: Changes in Electricity Demand and STEM Prices



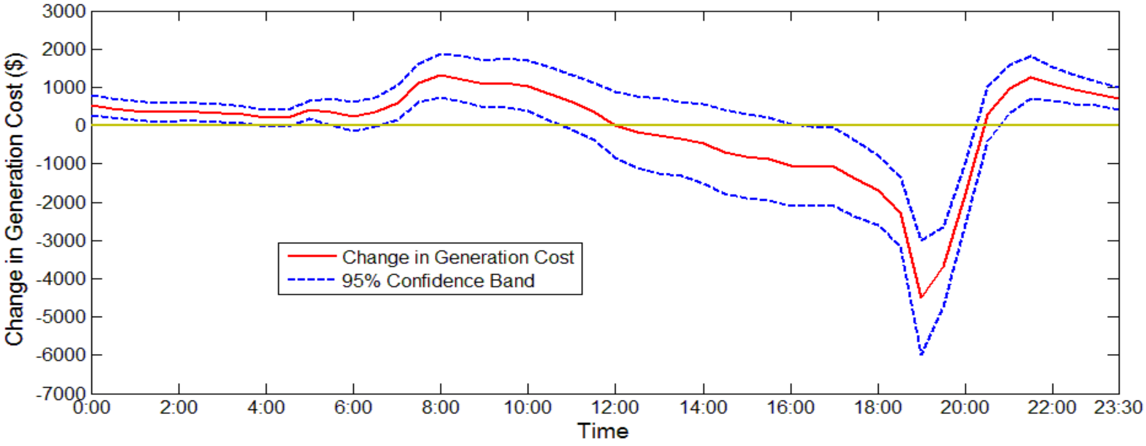
Note: Figure 8 exhibits the change in electricity demand due to DST and the average STEM price during the treatment period under the non-DST regime between 2009-2012 for each half hour.

Because we are interested in how DST affects electricity generation costs we focus on

STEM price data from the treatment period under the non-DST regime between 2009-2012. Figure 8 plots the average of these STEM prices for each half-hour interval and estimates of the changes in electricity demand due to DST from Table 4. Evidently, the peak STEM price at 15:00-15:30 does not align with the maximum electricity savings at 19:00-19:30.

The change in demand for each half hour is converted to generation by dividing it by two, as explained earlier in the Data section. Multiplying the average STEM price in a given half hour during the treatment period under the non-DST regime by the corresponding change in electricity generation due to DST yields changes in electricity generation costs which could have been incurred if WA had adopted DST during 2009-2012. Figure 9 depicts these changes in costs for all half hours and the corresponding 95% confidence band.

Figure 9: How DST would have affected electricity generation costs throughout the day



Note: Figure 9 is a line graph showing the point estimates of the change in electricity generation costs during the treatment period under the non-DST regime in A$ throughout the day if DST had been observed during this period. The dotted lines are the 95% confidence band.

Note that the average STEM prices in the afternoon and early evening when the changes in electricity generation cost due to DST are negative are higher than during the rest of the day. Even so, computing the weighted average of the changes in electricity generation cost over all half hours using the same weight w_h from equation (4) and the number of days in the treatment period (154), the estimated cost savings would have been only around 21.1 thousand dollars per treatment period under the DST regime. The biggest savings for an individual half hour occur from 7-7:30pm, in which generators would have saved about 692.9 thousand dollars per treatment period. But most of these savings are offset by increases in generation costs at other times of the day. This suggests that DST brings about relatively trivial economic benefits compared with WA's gross state product of 256.188 billion dollars in 2013-14.

Whether DST is considered to be an important component of energy policy also depends on the effect of DST on peak demand. DST is estimated to decrease demand substantially during the late afternoon and early evening, when electricity demand is relatively high. As mentioned earlier, controlling peak demand is often a focus in itself: the lower the peak demand, the lower the necessary capacity within the relevant network. There is an increase in electricity demand during the high-demand morning hours, but this does not nullify the early evening gains. As a result of DST, electricity demand decreases sharply in the late afternoon and early evening during which electricity demand and the STEM price are relatively high. This implies that DST can be adopted by policymakers to reduce high demand and the STEM price. On the other hand, we could not find any evidence that DST brings about less energy consumption or generation cost savings.

When DST was first observed in World War I, energy requirements were mostly lighting-based – air-conditioning (especially widespread air-conditioning) and heating by electricity are relatively recent phenomena. This implies that DST is likely to have saved electricity demand in past eras, but the use of electricity for other purposes has since complicated the relationship; indeed, the IMO refers in its Statement of Opportunities reports to the strong growth in air-conditioning installments in WA in this century alone. The effect of DST on overall electricity demand hence evolves over time. It is important to note, however, that the growth in air-conditioning load has slowed, so that the results obtained in this paper are likely to remain relevant for the foreseeable future.

7 Conclusion

This paper takes advantage of recent natural experiment data from September 21, 2006 to March 1, 2013 in Western Australia in which DST was observed from December 2006 to March 2009, when it was abolished at a referendum. Using this unique data set, we analyze the effect of DST on electricity demand for each half-hour interval throughout the day, as well as its overall effect on electricity demand.

A difference-in-differences (DD) approach is adopted to estimate the impact of DST on electricity demand during the treatment period (the last week of October until the last week of March), controlling for variables that may confound the estimate. DST is found to increase electricity demand during the late night and most of the morning, and decrease it in the early evening, with the largest percentage increase and decrease being 2.99% at 10pm and 6.61% at 7pm, respectively. On the other hand, DST does not affect electricity demand during the day, from 11 am till 4:30 pm. Applying the estimated percentage changes to the treatment period when DST was not adopted, we estimate that the largest saving in electricity demand would have been about 144 MW at 7pm, while the largest increase would have been around 58 MW at 8am. DST has an effect on electricity demand, not directly because of changes in conditions, but because of altered conditions in which scheduled activities take place. The overall effect of DST on electricity demand is both statistically and practically insignificant, suggesting that the original aim of implementing DST is no longer being met.

When it comes to other control variables, we find expected relationships between electricity demand and other variables such as temperature, wind, precipitation, humidity, the solar incentive schemes in WA, and holiday variables. Electricity demand is found to increase when it gets hot or cold. Because temperature is well known to be a key variable among independent variables we try different functions of temperature and find the impact of DST on electricity demand is robust to various specifications of temperature. Wind and precipitation turn out to have an intensifying effect on demand during cold days, but decrease electricity demand during warmer weather. If the humidity level goes up electricity demand increases more for the time when the temperature is higher. As the solar incentive schemes in WA encourage people to use solar energy, electricity demand is estimated to decrease.

The negative effect of school holidays is concentrated in the morning, while the 'day after a public holiday' effect is negative, but only significant from 12-9am.

To compute generation costs we take the Short Term Energy Market (STEM) price as a proxy for the marginal cost of providing electricity. Multiplying the average STEM price during the treatment period under the non-DST regime by the estimated change in electricity generation due to DST yields generation cost. Even though demand tends to be highest in the late afternoon and early evening, we estimate that a decrease in electricity usage during this period would have reduced the overall generation costs by only about 21.1 thousand dollars per treatment period of 154 days and by around 692.9 thousand dollars for the half hour from 7 pm - 7:30 pm alone if DST had been adopted during the treatment period in 2009-2013. This suggests that DST brings about relatively trivial overall economic benefits.

As a result of DST, electricity demand has decreased dramatically in the late afternoon and early evening when demand and the STEM price are relatively high. Therefore policy-makers might want to practice DST not to save energy or generation costs but to control high demand and the STEM price.

References

ARIES, M. B., AND G. R. NEWSHAM (2008): "Effect of Daylight Saving Time on Lighting Energy Use: A Literature Review," *Energy Policy*, 36, 1858–1866.

AUSTRALIAN BUREAU OF STATISTICS (ABS) (2013): "Western Australia at a Glance, 2013," accessed on 21 August 2013, www.abs.gov.au/ausstats/abs@.nsf/Lookup/1306.5main+features22013.

BELZER, D., S. HADLEY, AND S.-M. CHIN (2008): "Impact of Extended Daylight Saving Time on National Energy Consumption," U.S. Department of Energy.

BOUILLON, H. (1983): "Mikro- und Makroanalyse der Auswirkungen der Sommerzeit auf den Energie-Leistungsbedarf in den verschiedenen Energieverbrauchssektoren der Bundesrepublik Deutschland, IFR Schriftenreihe 13," Technical University.

BUREAU OF METEOROLOGY (BOM) (2013): "Weather Station Directory," accessed on 1 August 2013, www.bom.gov.au/climate/data/stations.

Clean Energy Regulator (CER) (2013): "Solar Credits," accessed on 21 August 2013, ret.cleanenergyregulator.gov.au/Solar-Panels/Solar-Credits/solar-credits.

Coate, D., and S. Markowitz (2004): "The Effects of Daylight and Daylight Saving Time on US Pedestrian Fatalities and Motor Vehicle Occupant Fatalities," *Accident Analysis and Prevention*, 36(3), 351–357.

Department of the Environment (DOE) (2013): "The Renewable Energy Target (RET) scheme," accessed on 2 January 2014, http://www.environment.gov.au/topics/cleaner-environment/clean-air/renewable-energy-target-scheme.

Ebersole, N., D. Rubin, W. Hannan, E. Darling, L. Frenkel, D. Prerau, and K. Schaeffer (1974): "The Year-Round Daylight Saving Time Study: Interim Report on the Operation and Effects of Year-Round Daylight Saving Time.," US Department of Transportation, Transportation Systems Center, Cambridge, MA, USA.

Energy Information Administration (EIA) (2006): "State Electricity Profiles: Indiana," .

Ferguson, S. A., D. F. Preusser, A. K. Lund, P. L. Zador, and R. G. Ulmer (1995): "Daylight Saving Time and Motor Vehicle Crashes: The Reduction in Pedestrian and Vehicle Occupant Fatalities," *American Journal of Public Health*, 85(1), 92–95.

Filliben, J. (1976): "Review and technical evaluation of the DOT daylight saving time study," US National Bureau of Standards, NBS Internal Report Prepared for the Chairman Subcommittee on Transportation and Commerce, Committee on Interstate and Foreign Commerce, US House of Representatives, KF27.I5589, Washington.

Havranek, T., D. Herman, and Z. Irsova (2016): "Does Daylight Saving Save Energy? A Meta-Analysis," *Available at MPRA: https://mpra.ub.uni-muenchen.de/74518/*.

Her Majestys Stationery Office (HMSO) (1970): "Review of British Standard Time," Command paper Cmnd 4512, London.

Hyde, O., and P. Hodnett (1997): "Modelling the effect of weather in short-term electricity load forecasting," *Mathematical Engineering in Industry*, 6(2), 155–169.

Independent Market Operator (IMO) (2012): “Wholesale Electricity Market Design Summary,” .

Janszky, I., and R. Ljung (2008): “Shifts to and from Daylight Saving Time and Incidence of Myocardial Infarction,” *The New England Journal of Medicine*, 359(18), 1966–1968.

Kamstra, M. J., L. A. Kramer, and M. D. Levi (2000): “Losing sleep at the market: The daylight saving anomaly,” *American Economic Review*, 90(4), 1005–1011.

Kandel, A., and M. Sheridan (2007): “The Effect of Early Daylight Saving Time on California Electricity Consumption: A Statistical Analysis,” .

Kantermann, T., M. Juda, M. Merrow, and T. Roenneburg (2007): “The human circadian clock’s seasonal adjustment is disrupted by daylight saving time,” *Current Biology*, 17(22), 1996–2000.

Kellogg, R., and H. Wolff (2008): “Daylight time and energy: Evidence from an Australian experiment,” *Journal of Environmental Economics and Management*, 56, 207–220.

Kotchen, M. J., and L. E. Grant (2011): “Does daylight saving time save energy? Evidence from a natural experiment in Indiana,” *Review of Economics and Statistics*, 93(4), 1172–1185.

Lahti, T., E. Nysten, J. Haukka, P. Sulander, and T. Partonen (2010): “Daylight Saving Transitions and Road Traffic Accidents,” *Journal of Environmental and Public Health*, 2010.

Mirza, F. M., and O. Bergland (2011): “The impact of daylight saving time on electricity consumption: Evidence from Southern Norway and Sweden,” *Energy Policy*, 39, 3558–3571.

Momani, M. A., A. B. Yatim, and M. A. Mohd (2009): “The impact of the daylight saving time on electricity consumption - A case study from Jordan,” *Energy Policy*, 37(5), 2042–2051.

Prerau, D. (2005): *Saving the Daylight: Why We Put the Clocks Forward*. Granta Books.

Ramanathan, R., R. Engle, C. W. J. Granger, F. Vahid-Araghi, and C. Brace (1997): “Short-run forecasts of electricity loads and peaks,” *International Journal of Forecasting*, 13, 161–174.

RIVERS, N. (2016): "Does Daylight Savings Time Save Energy? Evidence from Ontario," *Available at SSRN: https://ssrn.com/abstract=2772048*.

U. S. DEPARTMENT OF TRANSPORTATION (DOT) (1975): "The Daylight Saving Time Study: A Report to Congress from the Secretary," .

VERDEJO, H., A. C. B., D. ECHIBURU, W. ESCUDERO, AND E. FUCKS (2016): "Impact of daylight saving time on the Chilean residential consumption," *Energy Policy*, 88, 456–464.

WESTCOTT, M. (2010): "Daylight Saving in Queensland: Daylight Saving for South East Queensland Referendum Bill 2010 (Qld)," .

WESTERN AUSTRALIAN ELECTORAL COMMISSION (WAEC) (2010): "2009 Western Australian Referendum on Daylight Saving: Report," .

WOOLDRIDGE, J. M. (2010): *Econometric Analysis of Cross Section and Panel Data*. The MIT Press, 2nd Edition.

Appendix

The below tables summarize further selected results for each half-hourly regression from the main DD specification used in the paper; the 'half hour' column identifies the relevant regression.

Table A.1: Estimation Results of Cooling Degrees and Heating Degrees

Half Hour	Cooling Degrees (CD)	CD^2	Heating Degrees (HD)	HD^2
0 : 00 − 0 : 30	0.022*(5.20)	0.0006 (1.50)	0.021*(5.17)	0.0005*(2.39)
0 : 30 − 1 : 00	0.023*(4.79)	0.0003 (0.81)	0.018*(4.32)	0.0005*(2.42)
1 : 00 − 1 : 30	0.023*(5.17)	0.0004 (0.97)	0.017*(4.27)	0.0005*(2.40)
1 : 30 − 2 : 00	0.024*(5.06)	0.0002 (0.58)	0.016*(4.07)	0.0004*(2.19)
2 : 00 − 2 : 30	0.025*(5.09)	0.0002 (0.35)	0.016*(3.83)	0.0004 (1.85)
2 : 30 − 3 : 00	0.025*(5.53)	0.0000 (0.08)	0.015*(3.75)	0.0004 (1.92)
3 : 00 − 3 : 30	0.024*(5.22)	0.0001 (0.30)	0.014*(3.36)	0.0004 (1.86)
3 : 30 − 4 : 00	0.024*(5.19)	0.0000 (0.10)	0.013*(3.17)	0.0004*(2.01)
4 : 00 − 4 : 30	0.022*(4.96)	−0.0001 (−0.31)	0.012*(2.90)	0.0004*(2.41)
4 : 30 − 5 : 00	0.026*(5.47)	−0.0002 (−0.58)	0.0088*(2.20)	0.0004*(2.28)
5 : 00 − 5 : 30	0.026*(4.45)	−0.0005 (−1.04)	0.010*(2.72)	0.0004*(2.25)
5 : 30 − 6 : 00	0.027*(4.22)	−0.0007 (−1.19)	0.0097*(2.29)	0.0004 (1.79)
6 : 00 − 6 : 30	0.031*(4.35)	−0.0009 (−1.45)	0.0092*(1.96)	0.0004 (1.86)
6 : 30 − 7 : 00	0.025*(4.37)	−0.0004 (−0.84)	0.013*(3.17)	0.0004 (1.85)
7 : 00 − 7 : 30	0.018*(3.52)	0.0002 (0.43)	0.014*(3.09)	0.0004*(2.02)
7 : 30 − 8 : 00	0.015*(3.24)	0.0004 (1.09)	0.016*(4.00)	0.0004*(2.09)
8 : 00 − 8 : 30	0.013*(2.74)	0.0005 (1.58)	0.021*(4.31)	0.0003 (1.31)
8 : 30 − 9 : 00	0.0088 (1.93)	0.0008*(2.59)	0.017*(3.25)	0.0008*(2.64)
9 : 00 − 9 : 30	0.0053 (1.27)	0.001*(3.85)	0.014*(2.25)	0.0014*(3.46)
9 : 30 − 10 : 00	0.0025 (0.59)	0.001*(4.37)	0.013 (1.64)	0.0019*(2.68)
10 : 00 − 10 : 30	−0.002 (−0.49)	0.0012*(5.64)	0.015 (1.75)	0.0021*(2.48)
10 : 30 − 11 : 00	−0.0034 (−0.82)	0.0012*(5.97)	0.022*(3.11)	0.0015 (1.67)
11 : 00 − 11 : 30	−0.0035 (−0.79)	0.0012*(5.11)	0.027*(4.38)	0.0008 (0.89)
11 : 30 − 12 : 00	−0.0052 (−1.14)	0.0012*(6.25)	0.024*(3.39)	0.0014 (1.23)

Table A.1 Continued

Half Hour	Cooling Degrees (CD)	CD^2	Heating Degrees (HD)	HD^2
12 : 00 − 12 : 30	0.0015 (0.30)	0.0009* (4.29)	0.027* (5.91)	0.0008 (1.21)
12 : 30 − 13 : 00	0.0053 (1.01)	0.0007* (3.17)	0.022* (5.24)	0.0013* (2.20)
13 : 00 − 13 : 30	0.0010 (1.20)	0.0009* (4.61)	0.021* (4.17)	0.0016* (2.18)
13 : 30 − 14 : 00	0.0014 (0.33)	0.0009* (5.29)	0.019* (4.19)	0.0021* (2.92)
14 : 00 − 14 : 30	0.0072 (1.67)	0.0007* (3.80)	0.020* (3.77)	0.0019* (2.64)
14 : 30 − 15 : 00	0.0052 (1.22)	0.0007* (4.10)	0.013 (1.94)	0.0041* (3.20)
15 : 00 − 15 : 30	0.0094* (2.25)	0.0005* (3.18)	0.021* (2.78)	0.0029* (2.41)
15 : 30 − 16 : 00	0.013* (3.05)	0.0004* (2.19)	0.020* (2.77)	0.0035* (2.58)
16 : 00 − 16 : 30	0.012* (2.68)	0.0005* (2.60)	0.024* (3.26)	0.0031* (2.29)
16 : 30 − 17 : 00	0.013* (2.95)	0.0004* (2.12)	0.029* (4.4)	0.0023 (1.76)
17 : 00 − 17 : 30	0.015* (2.89)	0.0004 (1.61)	0.022* (3.11)	0.0034* (3.17)
17 : 30 − 18 : 00	0.017* (3.47)	0.0003 (1.51)	0.034* (5.21)	0.0014 (1.73)
18 : 00 − 18 : 30	0.016* (3.23)	0.0004 (1.73)	0.035* (4.83)	0.0012 (1.45)
18 : 30 − 19 : 00	0.016* (2.87)	0.0004 (1.39)	0.043* (6.14)	0.0002 (0.34)
19 : 00 − 19 : 30	0.020* (3.33)	0.0003 (0.95)	0.039* (4.99)	0.0006 (0.86)
19 : 30 − 20 : 00	0.021* (3.56)	0.0003 (0.87)	0.042* (5.13)	0.0002 (0.34)
20 : 00 − 20 : 30	0.024* (4.79)	0.0002 (0.72)	0.037* (4.92)	0.0005 (0.86)
20 : 30 − 21 : 00	0.024* (4.48)	0.0003 (0.69)	0.033* (5.06)	0.0008 (1.60)
21 : 00 − 21 : 30	0.025* (4.60)	0.0003 (0.81)	0.033* (6.23)	0.0007 (1.80)
21 : 30 − 22 : 00	0.025* (6.51)	0.0004 (1.47)	0.033* (6.02)	0.0005 (1.44)
22 : 00 − 22 : 30	0.025* (7.67)	0.0006* (2.30)	0.030* (6.13)	0.0005 (1.58)
22 : 30 − 23 : 00	0.027* (8.50)	0.0004 (1.75)	0.026* (5.61)	0.0005 (1.94)
23 : 00 − 23 : 30	0.024* (6.43)	0.0006* (1.96)	0.027* (5.76)	0.0003 (1.19)
23 : 30 − 0 : 00	0.022* (5.60)	0.0006 (1.78)	0.025* (5.49)	0.0004 (1.71)
Overall	0.018* (6.86)	0.0003 (1.31)	0.014* (5.37)	0.001* (6.04)

The 'Cooling Degrees (CD)' and 'CD^2' columns show the estimated coefficients of the cooling degree and cooling degree squared variables and their t-values in parentheses for all half hour intervals in January, the base month for *Cooling Degrees.* The 'Heating Degrees (HD)' and 'HD^2' columns show the estimated coefficients of the heating degree and heating degree squared variables and their t-values in parentheses for all half hour intervals in July, the base month for *Heating Degrees.* An asterisk, * next to the estimate indicates significance at the 5% level.

Table A.2: Estimation Results of CD × Wind Speed, HD × Wind Speed, HD × Precipitation, and CD × Precipitation

Half Hour	CD × Wind Speed (WS)	HD × WS	HD × Precipitation	CD × Precipitation
0 : 00 − 0 : 30	−0.0006*(−6.26)	0.0001 (1.90)	0.0001 (0.12)	−0.0079 (−1.80)
0 : 30 − 1 : 00	−0.0005*(−5.49)	0.0001 (1.43)	−0.001 (−1.09)	0.0039 (1.05)
1 : 00 − 1 : 30	−0.0006*(−5.26)	0.0000 (0.66)	−0.0008 (−0.88)	−0.0006 (−0.45)
1 : 30 − 2 : 00	−0.0005*(−5.11)	0.0000 (−0.51)	0.0002 (0.42)	0.0002 (0.17)
2 : 00 − 2 : 30	−0.0005*(−4.20)	0.0000 (−0.84)	0.001 (1.34)	0.0009 (0.29)
2 : 30 − 3 : 00	−0.0005*(−3.71)	0.0000 (−0.75)	0.0002 (0.42)	−0.0012 (−0.66)
3 : 00 − 3 : 30	−0.0005*(−3.67)	0.0000 (−0.32)	0.0003 (0.51)	−0.0091 (−1.04)
3 : 30 − 4 : 00	−0.0005*(−3.19)	0.0000 (−1.09)	0.0005 (1.05)	−0.012 (−0.65)
4 : 00 − 4 : 30	−0.0003 (1.96)	−0.0001 (1.96)	0.0012*(2.01)	−0.059*(−2.20)
4 : 30 − 5 : 00	−0.0005*(−2.78)	0.0000 (0.43)	0.0004 (1.14)	0.0033 (0.65)
5 : 00 − 5 : 30	−0.0003 (−1.77)	0.0000 (−0.53)	−0.0002 (−0.81)	−0.0014 (−0.11)
5 : 30 − 6 : 00	−0.0003 (−1.71)	0.0000 (0.32)	0.0004 (0.97)	−0.0069*(−2.24)
6 : 00 − 6 : 30	−0.0005*(−2.76)	0.0000 (1.22)	0.0000 (0.06)	−0.0033*(−2.00)
6 : 30 − 7 : 00	−0.0004*(−2.11)	0.0000 (0.36)	0.0017 (1.57)	−0.0023 (−0.69)
7 : 00 − 7 : 30	−0.0002 (−1.47)	0.0001 (1.45)	0.0023*(2.23)	−0.0009 (−0.25)
7 : 30 − 8 : 00	−0.0001 (−0.76)	0.0001 (1.95)	0.0006 (1.52)	0.0007 (0.12)
8 : 00 − 8 : 30	0.0000 (−0.14)	0.0002*(3.57)	0.0012*(2.40)	0.018 (0.88)
8 : 30 − 9 : 00	0.0000 (−0.47)	0.0002*(2.86)	0.0009 (1.16)	0.0069*(5.37)
9 : 00 − 9 : 30	−0.0001 (−0.79)	0.0002*(3.02)	0.0028*(3.44)	0.0054*(2.18)
9 : 30 − 10 : 00	0.0000 (−0.34)	0.0001 (1.55)	0.0038*(6.28)	0.0059*(7.06)
10 : 00 − 10 : 30	0.0000 (0.50)	0.0002*(2.24)	0.0026*(3.15)	0.018*(2.02)
10 : 30 − 11 : 00	0.0001*(2.24)	0.0003*(2.69)	0.002*(2.21)	0.0028 (0.32)
11 : 00 − 11 : 30	0.0002*(4.07)	0.0003*(2.71)	0.0011 (1.46)	0.011*(5.29)
11 : 30 − 12 : 00	0.0002*(4.46)	0.0003*(2.87)	0.0016*(2.14)	0.004 (1.58)

Table A.2 Continued

Half Hour	CD × Wind Speed (WS)	HD × WS	HD × Precipitation	CD × Precipitation
12 : 00 − 12 : 30	0.0002*(4.05)	0.0002*(2.54)	0.001 (1.26)	−0.0085 (−0.88)
12 : 30 − 13 : 00	0.0002*(4.70)	0.0003*(2.53)	0.0003 (0.32)	0.0052 (0.76)
13 : 00 − 13 : 30	0.0002*(4.73)	0.0003*(3.13)	−0.0001 (−0.06)	0.0041 (0.56)
13 : 30 − 14 : 00	0.0002*(6.25)	0.0003*(2.22)	0.0032*(2.26)	0.0064 (0.61)
14 : 00 − 14 : 30	0.0003*(6.07)	0.0003*(2.49)	0.002 (1.36)	0.0101 (0.69)
14 : 30 − 15 : 00	0.0003*(6.14)	0.0004*(2.83)	0.0012 (1.84)	0.0108 (1.78)
15 : 00 − 15 : 30	0.0003*(5.63)	0.0003*(2.26)	0.0022*(2.29)	0.0022*(4.22)
15 : 30 − 16 : 00	0.0003*(6.31)	0.0001 (1.07)	0.0025*(2.83)	0.0095*(2.23)
16 : 00 − 16 : 30	0.0003*(5.76)	0.0002 (1.20)	0.0016 (1.18)	0.0079 (1.33)
16 : 30 − 17 : 00	0.0003*(5.48)	0.0001 (0.97)	0.0018 (1.80)	0.0008 (0.80)
17 : 00 − 17 : 30	0.0003*(4.41)	0.0001 (1.38)	0.0057*(3.14)	−0.0045*(−2.71)
17 : 30 − 18 : 00	0.0002*(3.21)	0.0003*(2.77)	0.002*(2.00)	−0.0043 (−1.44)
18 : 00 − 18 : 30	0.0002*(2.36)	0.0003*(4.09)	0.0013 (0.83)	−0.0063 (−0.92)
18 : 30 − 19 : 00	0.0001 (1.39)	0.0004*(6.12)	0.0007 (1.16)	0.0064*(2.39)
19 : 00 − 19 : 30	0.0000 (0.30)	0.0005*(7.62)	−0.0002 (−0.46)	0.0002 (0.32)
19 : 30 − 20 : 00	−0.0001 (−0.91)	0.0005*(7.48)	0.0001 (0.09)	−0.0028 (−1.53)
20 : 00 − 20 : 30	−0.0003*(−3.25)	0.0005*(7.11)	−0.0016 (−1.71)	0.0028 (0.35)
20 : 30 − 21 : 00	−0.0004*(−4.78)	0.0004*(6.14)	−0.0004(−0.76)	0.0121*(6.08)
21 : 00 − 21 : 30	−0.0004*(−5.74)	0.0004*(6.30)	0.0000 (−0.01)	−0.0073*(−3.57)
21 : 30 − 22 : 00	−0.0005*(−5.77)	0.0004*(6.29)	−0.0004 (−0.47)	−0.0133*(−2.27)
22 : 00 − 22 : 30	−0.0006*(−7.12)	0.0003*(5.07)	0.0002 (0.30)	−0.0021 (−0.63)
22 : 30 − 23 : 00	−0.0007*(−7.64)	0.0003*(5.18)	−0.0003 (−0.42)	−0.0179*(−3.61)
23 : 00 − 23 : 30	−0.0006*(−7.01)	0.0002*(3.97)	−0.0006 (−1.33)	−0.0159*(−3.83)
23 : 30 − 0 : 00	−0.0006*(−5.92)	0.0001*(3.06)	0.0007 (0.78)	−0.0093*(−2.85)
Overall	0.0001*(2.60)	0.0000 (−1.39)	0.001*(3.69)	0.0007 (0.61)

The 'CD × Wind Speed' and 'HD × Wind Speed' columns show the estimated coefficients, respectively, of the interaction between wind speed and cooling degrees, and that between wind speed and heating degrees with their t-values in parentheses. 'HD × Precipitation' and 'CD × Precipitation' columns show the estimated coefficients, respectively, of the interaction between precipitation and heating degrees, and that between precipitation and cooling degrees with their t-values in parentheses. An asterisk, * next to the estimate indicates significance at the 5% level.

Table A.3: Estimation Results of Humidity, Humidity × Temperature, and Daylight

Half Hour	Relative Humidity	Humidity × Temperature	Daylight
0 : 00 – 0 : 30	−0.0033*(−10.82)	0.0002*(12.48)	–
0 : 30 – 1 : 00	−0.0029*(−9.34)	0.0002*(10.53)	–
1 : 00 – 1 : 30	−0.0027*(−8.47)	0.0002*(9.75)	–
1 : 30 – 2 : 00	−0.0026*(−8.38)	0.0002*(9.45)	–
2 : 00 – 2 : 30	−0.0024*(−7.35)	0.0002*(8.32)	–
2 : 30 – 3 : 00	−0.0022*(−6.72)	0.0002*(7.70)	–
3 : 00 – 3 : 30	−0.0021*(−6.51)	0.0001*(7.32)	–
3 : 30 – 4 : 00	−0.002*(−6.54)	0.0001*(7.27)	–
4 : 00 – 4 : 30	−0.0021*(−6.45)	0.0001*(7.16)	–
4 : 30 – 5 : 00	−0.0014*(−4.72)	0.0001*(5.51)	–
5 : 00 – 5 : 30	−0.0016*(−4.93)	0.0001*(5.65)	–
5 : 30 – 6 : 00	−0.0013*(−4.43)	0.0001*(5.26)	−0.019*(−2.84)
6 : 00 – 6 : 30	−0.0012*(−3.86)	0.0001*(4.53)	−0.017*(−2.75)
6 : 30 – 7 : 00	−0.0016*(−4.64)	0.0001*(5.25)	−0.017*(−2.75)
7 : 00 – 7 : 30	−0.0017*(−4.36)	0.0001*(5.08)	−0.020*(−3.96)
7 : 30 – 8 : 00	−0.0019*(−5.22)	0.0001*(6.12)	–
8 : 00 – 8 : 30	−0.0021*(−6.30)	0.0001*(7.45)	–
8 : 30 – 9 : 00	−0.0023*(−7.33)	0.0002*(9.13)	–
9 : 00 – 9 : 30	−0.0029*(−8.35)	0.0002*(10.13)	–
9 : 30 – 10 : 00	−0.0035*(−10.01)	0.0002*(12.10)	–
10 : 00 – 10 : 30	−0.0038*(−10.21)	0.0003*(12.79)	–
10 : 30 – 11 : 00	−0.0041*(−10.53)	0.0003*(13.61)	–
11 : 00 – 11 : 30	−0.0044*(−10.39)	0.0003*(13.50)	–
11 : 30 – 12 : 00	−0.0045*(−10.73)	0.0003*(14.14)	–

Table A.3 Continued

Half Hour	Relative Humidity	Humidity × Temperature	Daylight
12 : 00 − 12 : 30	−0.0042*(−9.60)	0.0003*(13.20)	−
12 : 30 − 13 : 00	−0.0042*(−9.98)	0.0003*(13.65)	−
13 : 00 − 13 : 30	−0.0044*(−9.30)	0.0003*(12.72)	−
13 : 30 − 14 : 00	−0.0046*(−9.46)	0.0003*(12.63)	−
14 : 00 − 14 : 30	−0.0045*(−9.22)	0.0003*(12.35)	−
14 : 30 − 15 : 00	−0.0046*(−9.37)	0.0003*(12.57)	−
15 : 00 − 15 : 30	−0.0048*(−9.81)	0.0003*(12.82)	−
15 : 30 − 16 : 00	−0.0047*(−9.21)	0.0003*(12.42)	−
16 : 00 − 16 : 30	−0.0045*(−8.46)	0.0003*(11.66)	−
16 : 30 − 17 : 00	−0.0046*(−9.46)	0.0003*(12.79)	−
17 : 00 − 17 : 30	−0.0048*(−10.65)	0.0003*(14.08)	−0.023*(−3.52)
17 : 30 − 18 : 00	−0.0048*(−10.80)	0.0003*(13.87)	−0.016 (−1.81)
18 : 00 − 18 : 30	−0.0053*(−13.08)	0.0003*(15.93)	−0.0017 (−0.21)
18 : 30 − 19 : 00	−0.0055*(−14.03)	0.0003*(16.35)	−0.0092 (−1.23)
19 : 00 − 19 : 30	−0.0054*(−13.72)	0.0003*(16.00)	0.013 (1.30)
19 : 30 − 20 : 00	−0.0053*(−13.30)	0.0003*(15.32)	−0.0031 (−0.34)
20 : 00 − 20 : 30	−0.005*(−12.11)	0.0003*(14.08)	−
20 : 30 − 21 : 00	−0.0048*(−12.42)	0.0003*(14.56)	−
21 : 00 − 21 : 30	−0.0046* (−11.84)	0.0003*(14.10)	−
21 : 30 − 22 : 00	−0.0041*(−10.71)	0.0003*(12.96)	−
22 : 00 − 22 : 30	−0.0039*(−10.49)	0.0003*(12.37)	−
22 : 30 − 23 : 00	−0.0035*(−10.65)	0.0002*(12.61)	−
23 : 00 − 23 : 30	−0.0035*(−10.78)	0.0002*(12.94)	−
23 : 30 − 0 : 00	−0.0035*(−10.64)	0.0002*(12.33)	−
Overall	−0.0039*(−18.94)	0.0003*(22.96)	−0.0482*(−34.55)

The ‘Relative Humidity’ column displays the estimated coefficient of relative humidity, while the ‘Humidity × Temperature’ column displays the estimated coefficient of the interaction between humidity and temperature. ‘Daylight’ shows the estimated coefficient of daylight, and is available only for those half hours in which the presence of daylight depends on the time of year. For each case, the t-value is in parentheses next to the estimate. An asterisk, * next to the estimate indicates significance at the 5% level.

Table A.4: Estimation Results of Solar Regimes

Half Hour	Solar Regime (SR) 2009/10	SR 2010/11	SR 2011	SR 2011/12	SR 2012
0 : 00 − 0 : 30	0.015*(2.34)	0.019 (1.51)	0.014 (0.73)	−0.016 (−1.02)	−0.055*(−2.74)
0 : 30 − 1 : 00	0.0098 (1.33)	0.017 (1.37)	0.010 (0.52)	−0.020 (−1.26)	−0.058*(−2.91)
1 : 00 − 1 : 30	0.0097 (1.34)	0.020 (1.55)	0.013 (0.70)	−0.018 (−1.13)	−0.054*(−2.68)
1 : 30 − 2 : 00	0.0084 (1.15)	0.021 (1.62)	0.017 (0.91)	−0.017 (−1.07)	−0.051*(−2.53)
2 : 00 − 2 : 30	0.0082 (1.16)	0.021 (1.71)	0.018 (0.98)	−0.017 (−1.07)	−0.051*(−2.49)
2 : 30 − 3 : 00	0.0098 (1.36)	0.023 (1.85)	0.022 (1.16)	−0.013 (−0.81)	−0.048*(−2.33)
3 : 00 − 3 : 30	0.011 (1.50)	0.024 (1.91)	0.024 (1.26)	−0.011 (−0.70)	−0.046*(−2.23)
3 : 30 − 4 : 00	0.012 (1.75)	0.026*(2.10)	0.027 (1.43)	−0.0075 (−0.47)	−0.038 (−1.91)
4 : 00 − 4 : 30	0.011 (1.56)	0.024 (1.91)	0.025 (1.31)	−0.008 (−0.50)	−0.038 (−1.88)
4 : 30 − 5 : 00	0.0093 (1.34)	0.022 (1.78)	0.025 (1.36)	−0.0095 (−0.60)	−0.041*(−2.04)
5 : 00 − 5 : 30	0.0083 (1.17)	0.012 (0.99)	0.0069 (0.36)	−0.024 (−1.54)	−0.063*(−3.10)
5 : 30 − 6 : 00	0.014 (1.94)	0.023 (1.87)	0.029 (1.38)	−0.0034 (−0.21)	−0.034 (−1.62)
6 : 00 − 6 : 30	0.017*(2.24)	0.020 (1.64)	0.032 (1.49)	0.0059 (0.36)	−0.023 (−1.07)
6 : 30 − 7 : 00	0.019*(2.29)	0.013 (0.98)	0.020 (0.90)	−0.0089 (−0.51)	−0.050*(−2.22)
7 : 00 − 7 : 30	0.022*(2.59)	0.014 (1.06)	0.016 (0.73)	−0.0097 (−0.57)	−0.057*(−2.56)
7 : 30 − 8 : 00	0.025*(2.81)	0.022 (1.69)	0.027 (1.16)	0.0016 (1.09)	−0.041 (−1.80)
8 : 00 − 8 : 30	0.025*(3.17)	0.018 (1.41)	0.022 (1.01)	−0.0071 (−0.42)	−0.050*(−2.27)
8 : 30 − 9 : 00	0.022*(3.08)	0.010 (0.88)	0.0059 (0.27)	−0.021 (−1.31)	−0.073*(−3.39)
9 : 00 − 9 : 30	0.020*(2.96)	0.0057 (0.51)	−0.0054 (−0.26)	−0.033*(−2.14)	−0.09*(−4.34)
9 : 30 − 10 : 00	0.012 (1.89)	−0.0038 (−0.33)	−0.022 (−1.11)	−0.048*(−3.13)	−0.11*(−6.30)
10 : 00 − 10 : 30	0.0062 (0.97)	−0.013 (−1.14)	−0.034 (−1.83)	−0.063*(−4.12)	−0.13*(−6.22)
10 : 30 − 11 : 00	0.0049 (0.76)	−0.012 (−1.08)	−0.036*(−2.11)	−0.062*(−4.06)	−0.13*(−6.17)
11 : 00 − 11 : 30	0.0033 (0.50)	−0.014 (−1.28)	−0.041*(−2.25)	−0.068*(−4.41)	−0.13*(−6.56)
11 : 30 − 12 : 00	0.0038 (0.57)	−0.014 (−1.19)	−0.044*(−2.55)	−0.070*(−4.52)	−0.14*(−6.74)

Table A.4 Continued

Half Hour	Solar Regime (SR) 2009/10	SR 2010/11	SR 2011	SR 2011/12	SR 2012
12 : 00 − 12 : 30	−0.0013 (−0.20)	−0.017 (−1.47)	−0.050*(−2.85)	−0.076*(−4.88)	−0.15*(−6.79)
12 : 30 − 13 : 00	0.0018 (0.25)	−0.014 (−1.18)	−0.046*(−2.47)	−0.071*(−4.3)	−0.14*(−6.27)
13 : 00 − 13 : 30	−0.0003 (−0.04)	−0.017 (−1.34)	−0.047*(−2.39)	−0.073*(−4.31)	−0.14*(−6.20)
13 : 30 − 14 : 00	−0.0021 (−0.28)	−0.017 (−1.41)	−0.049*(−2.53)	−0.078*(−4.73)	−0.15*(−6.58)
14 : 00 − 14 : 30	−0.0013 (−0.17)	−0.017 (−1.31)	−0.046*(−2.23)	−0.075*(−4.33)	−0.14*(−6.08)
14 : 30 − 15 : 00	0.0012 (0.16)	−0.014 (−1.13)	−0.036 (−1.84)	−0.067*(−3.88)	−0.13*(−5.58)
15 : 00 − 15 : 30	0.0042 (0.53)	−0.0088 (−0.68)	−0.027 (−1.34)	−0.058*(−3.35)	−0.12*(−5.04)
15 : 30 − 16 : 00	0.0048 (0.61)	−0.0075 (−0.59)	−0.026 (−1.3)	−0.060*(−3.48)	−0.12*(−5.09)
16 : 00 − 16 : 30	0.0034 (0.43)	−0.0099 (−0.76)	−0.03 (−1.48)	−0.060*(−3.48)	−0.12*(−5.05)
16 : 30 − 17 : 00	0.0051 (0.68)	−0.010 (−0.83)	−0.030 (−1.41)	−0.056*(−3.27)	−0.11*(−4.73)
17 : 00 − 17 : 30	0.013 (1.63)	0.0000 (0.00)	−0.011 (−0.56)	−0.033 (−1.87)	−0.082*(−3.41)
17 : 30 − 18 : 00	0.014 (1.73)	0.0029 (0.22)	−0.0095 (−0.41)	−0.027 (−1.49)	−0.071*(−2.94)
18 : 00 − 18 : 30	0.014 (1.91)	0.0044 (0.34)	−0.0055 (−0.26)	−0.021 (−1.16)	−0.061*(−2.56)
18 : 30 − 19 : 00	0.015*(2.01)	0.0053 (0.43)	−0.0019 (−0.09)	−0.017 (−0.97)	−0.055*(−2.41)
19 : 00 − 19 : 30	0.017*(2.10)	0.011 (0.81)	0.0036 (0.17)	−0.0098 (−0.55)	−0.048*(−2.05)
19 : 30 − 20 : 00	0.017*(1.96)	0.0098 (0.73)	0.0011 (0.05)	−0.0097 (−0.55)	−0.051*(−2.17)
20 : 00 − 20 : 30	0.014 (1.53)	0.0068 (0.46)	−0.0067 (−0.29)	−0.015 (−0.77)	−0.057*(−2.28)
20 : 30 − 21 : 00	0.019*(2.07)	0.010 (0.68)	−0.0019 (−0.08)	−0.012 (−0.64)	−0.055*(−2.25)
21 : 00 − 21 : 30	0.023*(2.39)	0.013 (0.86)	−0.008 (−0.35)	−0.010 (−0.55)	−0.052*(−2.17)
21 : 30 − 22 : 00	0.022*(2.30)	0.011 (0.76)	−0.0059 (−0.27)	−0.014 (−0.74)	−0.056*(−2.39)
22 : 00 − 22 : 30	0.019*(2.03)	0.0059 (0.41)	−0.010 (−0.47)	−0.024 (−1.29)	−0.069*(−2.94)
22 : 30 − 23 : 00	0.021*(2.39)	0.01 (0.72)	−0.0024 (−0.11)	−0.02 (−1.14)	−0.066*(−2.96)
23 : 00 − 23 : 30	0.018*(2.26)	0.011 (0.8)	0.0017 (0.08)	−0.021 (−1.24)	−0.066*(−3.11)
23 : 30 − 0 : 00	0.015 (1.93)	0.013 (1.01)	0.0063 (0.33)	−0.023 (−1.37)	−0.064*(−3.08)
Overall	0.012*(2.90)	0.0051 (0.76)	−0.0082 (−0.76)	−0.031*(−3.56)	−0.077*(−6.80)

The ‘Solar Regime (SR) 2009/10,’ ‘Solar Regime (SR) 2010/11,’ ‘SR 2011,’ and ‘SR 2011/12’ columns show the estimated coefficients of the dummy variables of the specified solar regimes and their *t*-values in parentheses. An asterisk, * next to the estimate indicates significance at the 5% level.