Location matters: daylight saving time and electricity use

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Daylight saving time and electricity use

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Abstract

The primary rationale for daylight saving time (DST) has long been energy savings. Whether it achieves this goal, however, remains a subject of debate. Recent studies, examining only one location at a time, have shown DST to increase, decrease or leave overall energy use unchanged. Rather than concluding the effect is ambiguous, this paper is the first to test for heterogeneous regional effects based on differences in (natural) sun times and (societal) waking hours. Using a rich hourly data set and quasi-experimental methods applied across Canadian provinces, this paper rationalizes the differing results, finding region-specific effects consistent with differences in sun times and waking hours. DST increases electricity use in regions with late sunrises and early waking hours.

JEL Classification: C54, Q4, Q48

Keywords: Daylight saving time; electricity demand; regional effects

THE PRIMARY RATIONALE FOR DAYLIGHT SAVING TIME (DST) has long been energy savings. Whether or not DST saves energy, however, remains a subject of debate. In terms of electricity use, the extra sunlight in the evening hours should reduce demand for lighting. This, however, may be offset by incremental demand in the now-darker morning hours. Ultimately, it is an empirical question. Recent studies using modern econometric techniques run the gamut of findings, showing DST to decrease, increase or leave electricity use unchanged.[1]

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[1] See Table 1 for a summary of recent research findings.

These mixed results are not necessarily a sign the effect of DST on electricity use is unclear. It is plausible and reasonable to expect DST to have different effects in different regions. The intuition is straightforward, though to the best of my knowledge unexplored in the literature: in regions where households typically awaken early relative to sunrise, shifting clocks forward one hour is more likely to shift people from otherwise sunlit waking hours to darkness, imposing a higher morning energy cost. Existing papers have not empirically examined this effect because they study one location at a time. This paper is the first to empirically examine how the effect of DST on electricity use can differ across regions based on differences in sun times and waking hours. In doing so, this paper reconciles the different results in the literature and, importantly, changes the way we think about the link between DST and energy savings to a regional perspective.

To motivate this hypothesis, Figure 1 plots recent results from the literature along with each study region's time of sunrise during the spring transition. The figure is not meant to be definitive, but there is some evidence of a positive relationship between the effect of DST and time of sunrise. Confounding this relationship, however, are differences in estimation methodology allowing for inference over different date ranges; significant latitudinal variation in study locations changing the importance of DST; and cultural or institutional differences in waking hours (Havranek, Herman and Irsova, 2016).

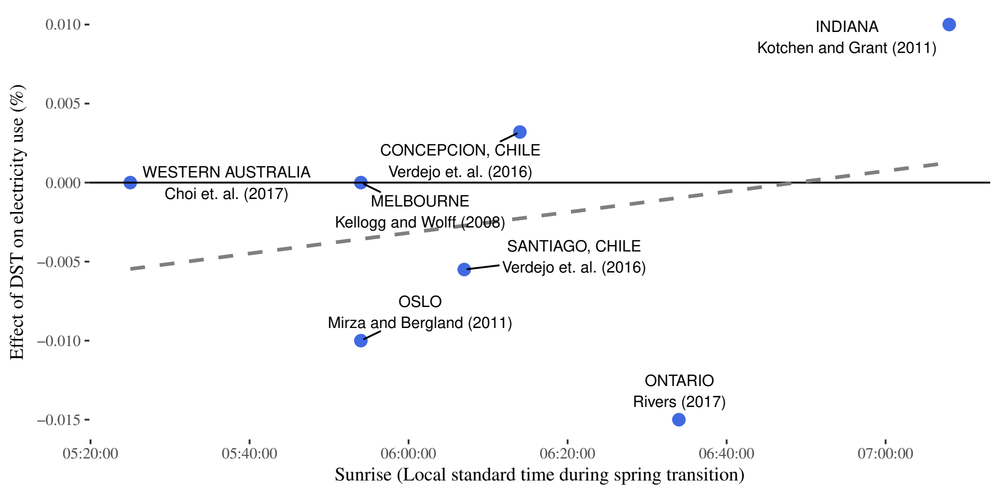


Figure 1: Empirical results from other studies

To avoid these confounding factors, I estimate the causal effect of DST on electricity use across Canada, whose electricity system offers some advantages for this study. Canada's geographic breadth provides large longitudinal variation, covering four and a half time zones, while the bulk of its population lies within a reasonably small latitudinal bandwidth. This both controls for aggregate differences in sunlight due to latitude, but offers substantial variation in sunrise times across longitudes. Also, as compared to U.S. states, Canadian provinces are each predominantly served by a single utility, with each province largely falling within a single time zone. This makes the analysis clean and straightforward. Finally, performing all the analysis with a single estimation strategy avoids differences due solely to methodology.

The fundamental empirical challenge to estimating the causal effect of DST on electricity use is in proper identification of the counterfactual – what would electricity use be in the absence of a DST transition? To estimate this effect, I follow Rivers (2017) and Smith (2016) in exploiting the variation in DST's annual start and end dates. The regression analysis essentially compares electricity usage on days that differ only on whether they fall under DST or not, after controlling for observable factors that include weather, time and date fixed effects. The variation in start and end dates comes both from a policy change in 2007 that extended the DST period, as well as annual fluctuation arising from DST starting on, currently, the 2nd Sunday in March which falls on a different date each year. It is important to note that this allows for inference only over the roughly 7 week time range of variation in start and end dates, not the entirety of the DST period.

To supplement the fixed effects approach, I also perform a difference-in-differences analysis using the province of Saskatchewan, which does not observe DST, versus its nearby provinces. Similar estimates add confidence to the fixed effects results while also offering a glimpse as to he persistence of the DST effect on a subset of Canadian provinces.

My results are consistent with the aforementioned intuition regarding sun times and waking hours. The effect of DST on electricity demand ranges from -1.3% in British Columbia and -1% in Ontario, where people tend to rise late and the sun rises early, to +1.5% in Alberta and Manitoba, where people tend to rise early and the sun rises late. A simple regression across all provinces finds 10 additional minutes of morning light is associated with DST reducing electricity use by approximately 0.2 to 0.8%. This finding rationalizes the different results in the literature, emphasizing the role regional sun times and waking hours play in whether or not DST saves electricity.

Evidence as to the effect of DST on energy use is relevant to current policy debates.[2] This paper can help inform policymakers to make evidence-based decisions on whether to implement, maintain or abolish DST. It highlights the importance of considering regional effects in assessing the effect of DST on energy use. It is, however, just one aspect to consider. Other potential costs and benefits to consider include, but are not limited to, effects on natural gas use for heating,

[2] As of time of writing (2017), nearly half of the U.S. states have motions in their legislature to consider the abolishment of DST, most of which seeking inter-state regional coordination with the change. In Canada, the Alberta government is considering legislation to abolish DST and shift to either year-round Central or Pacific standard time.

traffic safety and health.[3] Also, considering DST policy only at a local level risks losing the major economic benefits of broader regional coordination of time systems.

1 Background

Every spring and fall, clocks across much of North America, Europe and a few other parts of the world are shifted forward and back one hour. This practice is closely followed by another semi-annual ritual: debate over the merits and demerits of Daylight Saving Time (DST).

The original intention of DST in advancing clocks one hour was to allow for lifestyles following clock time to receive one extra hour of sunlight after standard working hours, at the sacrifice of some early morning sun. Opponents argue that making the transition twice a year is costly. Farmers and those following a more agrarian lifestyle argue their activities are governed by natural sunlight, not clock time, and thus DST causes them to become out of sync with delivery drivers, stores, etc. Proponents argue the extra sunlight after working hours has value in areas of retail, sports, and general wellbeing. But the main argument for DST has typically been energy savings.

The link to energy savings dates back to World War I, when DST began as a method of conserving energy during war time. It was first adopted by the German and Austro-Hungarian empires, but the practice quickly spread to other European countries and across the Atlantic to the United States and Canada (Bartlett, 2001). The practice waned in the ensuing years, increasing again during the Second World War, and falling thereafter. The emphasis on energy conservation as a primary goal was reinforced when DST returned in the 1970s, becoming widely adopted as a result of the 1970s energy crisis. In 2007, the US (and with Canada matching) extended daylight saving time by an extra month as part of the US Energy Policy Act. The spring transition advanced from early April to mid-March and the fall transition was pushed back from late October to November.

Despite this focus on energy savings, however, the effect of DST on energy use remains a subject of dispute. Table 1 summarizes the literature on DST and energy use. The majority of studies relate to electricity use and find DST reduces demand. More recent studies, however, using modern empirical techniques, encompass the spectrum of results: DST is found to increase, decrease and have no aggregate effect on electricity use. This paper adds to that discord, but also examines a possible explanation to reconcile different findings in different regions.

[3] Smith (2016), for example, finds that fatal vehicle crashes in the US increase by roughly 6% in the week immediately following spring transition due changing sleep patterns. Wolff and Makino (2017) find that additional recreation activity due to more afternoon sunlight increases caloric burn by 10%.

Table 1: Summary of studies on DST and electricity demand

Study	Location	Method	Finding
HMSO (1970)	UK	Before/after analysis	No conclusive evidence; ↑ 2.5% in morning, ↓ 3% in evening
US DOT (1974)	US	Before/after analysis	↓ 1% (US National Bureau of Standards reviewed the study and did not support the finding)
Bouillon (1983)	Germany	Simulation model	↓ 1.8%
Hillman and Parker (1988)	UK	Model	Predicts ↓ 9% residential lighting, ↓ 4% commercial lighting
Littlefair (1990)	UK	Model	Predicts 5% ↓ in lighting demand
Rock (1997)	US	Simulation model	Predicts slight ↑
Ramos et al. (1998)	Mexico	Theoretical	↓ 0.65 – 1.10%
Reincke and van der Broek (1999)	EU	Simulation model	↓ 0–0.5% (depending on country)
Fischer (2000)	Germany	Case study	Overall effect neutral
Small (2001)	New Zealand	Before/after analysis	↓ 2%
CEC (2001)	California	Regression model over various transitions	No overall effect
Kellogg and Wolff (2008)	Australia	Quasi-experimental (Olympics)	No overall effect (intraday shift)
Mirza and Bergland (2011)	Norway	Difference-in-differences	↓ 1%
Kotchen and Grant (2011)	Indiana	Quasi-experimental (County level changes)	↑ 1%
Verdejo et al. (2016)	Chile	Intra-day difference-in-differences	Near-zero, but heterogeneous across country
Hancevic and Margulis (2016)	Argentina	Difference-in-differences with DST abolishment	↑ 0.5%
Choi, Pellen and Masson (2017)	Western Australia	DST extension	Little overall effect
Rivers (2017)	Ontario	Quasi-experimental (Transition variation)	↓ 1.5%

2 Conceptual Framework

The intuition behind heterogeneous regional effects draws on the original premise of DST—to shift ambient light one hour later to reduce lighting requirements during otherwise dark evening waking hours at the cost of less light in morning waking hours. The relative benefits and costs of this shift will differ by region depending on a region's typical sun times (natural factors) and waking hours (societal factors), and more importantly: how they overlap. In regions with late sunrises and early waking hours, it is more likely that the one hour time shift to DST will darken otherwise sunlit waking hours.

The concept is presented graphically in Figure 2. Panel 2a illustrates the time shift that occurs during the spring transition to DST. With local prevailing time along the horizontal axis, sunrise that previously occurred at 6:30am local time shifts forward to occur at 7:30am local time.

Panel 2b illustrates how the shift affects sunlit waking hours. In this chart, waking hours stay fixed as it is assumed that waking hours are governed by local clock time, whereas sun times "shift" one hour forward in terms of clock time. The dark dotted region in the morning represents incremental darkness during waking hours as a result of DST. The light chevroned region in the evening represents incremental light during waking hours as a result of DST. In this example, additional evening light is offset one-for-one by more morning darkness during waking hours, with potentially no net effect on electricity demand.

Panel 2c shows how a region's waking hours may change this neutral result. A *late* lifestyle receives the full benefit of increased evening sunlight, but the additional morning darkness is of little cost to them as the shift occurs largely during non-waking hours. Conversely, Panel 2d shows that an *early* lifestyle has the opposite effect—they receive the full cost of additional morning darkness but little benefit from additional evening light. Thus one would expect a region with a preponderance of late lifestyles to benefit more from DST (in terms of electricity savings) than one made up largely of early lifestyles.

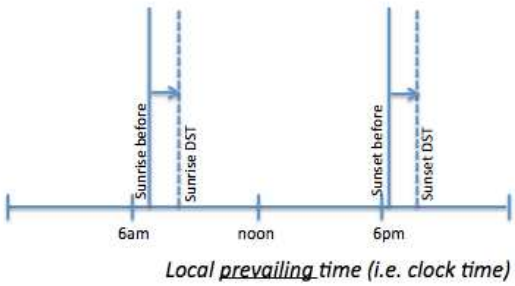
Sun times act similarly, but in opposite direction, to waking hours. Later sunrise and sunset times have the equivalent effect as early waking hours (Panel 2e). They shift the period of overlapping daylight and waking hours to the right, i.e. towards the evening. A region with late sun times would experience a greater cost of morning darkness, and potentially less evening benefit, as compared to a region where the sun rises and sets earlier.

It is worth noting that lighting demand is but one component of electricity demand. To the extent regions differ in terms of their industrial share of demand or use of electricity as a primary heating source, the relative importance of DST-affected lighting demand will also differ. This is discussed in more detail in Section IV.

3 Empirics

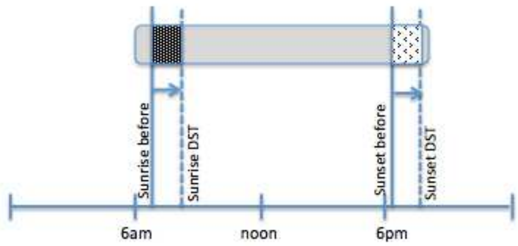
This section estimates the effect of DST on electricity use for each Canadian province. In Section IV, these estimates are used to examine the broader question regarding the relationship between the DST effect and regional sun times and waking hours.

The essential empirical problem in estimating the effect of DST on electricity use is the construction of the counterfactual – i.e. what would electricity use be under the same conditions, for the same hour, if the DST transition had not occurred? To identify this effect, I take a fixed effects



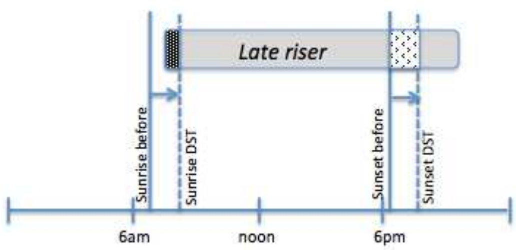
(a) Time Shift

Clocks shift forward 1 hour. Sunrise that occurred at 7am Standard time now occurs at 8am Daylight Saving time.



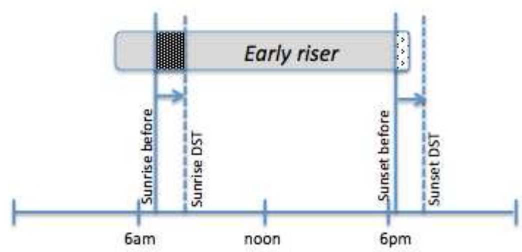
(b) Sunlight and waking hours

Light during waking hours is affected. Dark dotted area is incremental dark (morning). Light chevron area is incremental light (evening).



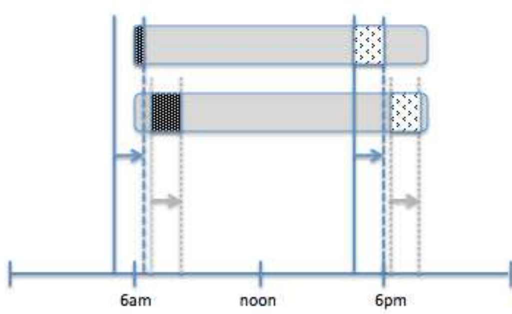
(c) Late risers

"Late" lifestyle gets full evening benefit, little morning cost.



(d) Early risers

"Early" lifestyle gets little evening benefit, but full morning cost.



(e) sun times

Sunrise and sunset times matter too. Late sun times are equivalent to early working hours. Full cost of incremental morning darkness.

Figure 2: INTUITION BEHIND HETEROGENEOUS REGIONAL EFFECTS OF DST

approach exploiting the quasi-random variation in annual start dates of DST. The regression analysis compares electricity demand on the same day (or hour) of the year that differ across years only by whether or not DST is being observed, after controlling for observable factors of demand such as temperature, hour of the day, day of the week, holidays and year trends.

3.1 Data

The empirical estimation requires extremely granular data on both electricity demand and relevant controls. For this analysis, I collect hourly electricity demand for all the Canadian provinces dating from 2001 through 2015.[4] In total there are 1,008,000 hourly observations. The data are summarized in Table A.1 in the Appendix.

For each observation, I create time- and date-based dummy variables. Specifically, dummy variables are created for (i) hour of day; (ii) day of week; (iii) day and/or hour of year (depending on the model specification); (iv) statutory holidays; (v) year; and (vi) DST (i.e. whether the date-time period falls under DST or not).

Weather data come from Environment Canada's historical data website.[5] The key variable is temperature by hour for the major population centres of each province. The hourly data cover the same period as the electricity data (2001–2015) and are summarized in Table A.2 in the Appendix.

There are two ways in which temperature data can be used as controls. The first is to use heating and cooling degrees – a standard unit in electricity analysis – which captures the difference between the actual temperature and what is considered neutral (18°C).[6] Typically, heating and cooling degrees and their respective squares (to account for nonlinear effects) are included as controls. An alternative, non-parametric approach, is to bin the temperature variable into 2°C increments to flexibly control for temperature in the regression analysis.[7] I use both in the analysis and find no significant difference in the estimates for the DST effect, although the more flexible temperature bins increase precision slightly.

3.2 Methodology

I follow Rivers (2017) and Smith (2016) in taking a fixed effects approach to estimating the causal effect of DST on electricity demand. This method exploits the variation in start and end dates of

[4]Data were available from 2001–2015 for AB, SK, MB, ON and NB. For the other provinces (BC, PE, NS, NL and QC), data were available only from 2007 onwards.

[5]Data available at: http://climate.weather.gc.ca/historical_data/search_historic_data_e.html, accessed Jan 3, 2017.

[6]To be clear, $heatingdegrees = \max(18 - Temp, 0)$; $coolingdegrees = \max(Temp - 18, 0)$.

[7]I also tried 1°C bins. There were no significant differences in the estimated effect of DST on electricity use between the two specifications. 2°C bins were preferred as some 1°C bins had few observations leading to less precision.

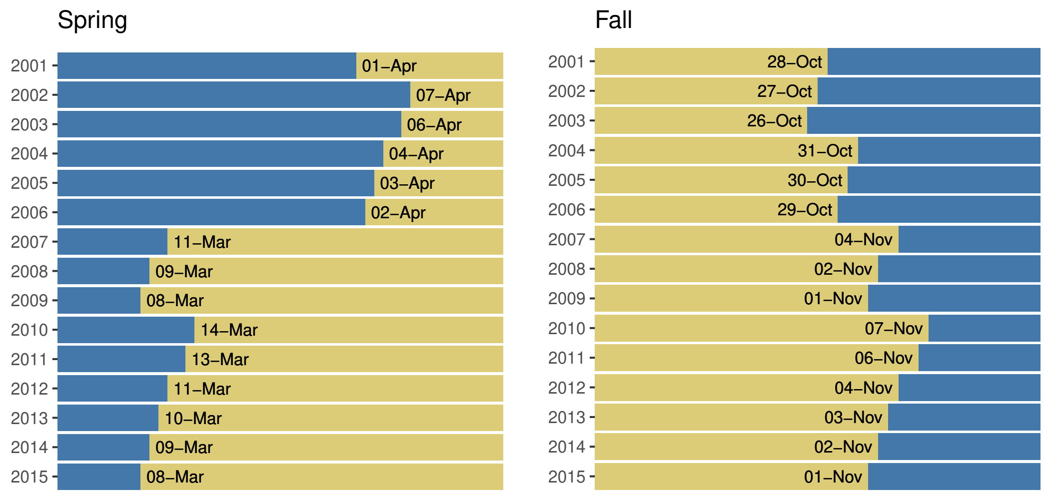


Figure 3: Transition dates to Daylight Saving Time

Note: The darker region is in Standard time, while the lighter region falls under DST. The overall range of transition dates over the 15 year period is roughly 5 weeks in the spring and 2 weeks in the fall.

DST from year to year (shown in Figure 3). Essentially, it allows me to compare electricity demand in hours of the year that are on DST in some years but remain on Standard time in others, having controlled for other observable factors.

The regression equation is given by Equation 1:

$$\ln Demand_{ydh} = \beta_0 + \beta_1 DST_{ydh} + \gamma W_{ydh} + \theta D_{ydh} + \epsilon_{ydh} \tag{1}$$

The dependent variable is the natural logarithm of hourly electricity demand for each year-day-hour (ydh) observation over the 15 years of the dataset. The variable DST_{ydh} is a dummy variable that represents whether an hour falls within DST ($DST_{ydh} = 1$) or not ($DST_{ydh} = 0$). W_{ydh} are the temperature controls given by either heating and cooling degrees and their squares or temperature bins depending on specification, and D_{ydh} represent the time and date dummy variables (i.e. hour-of-day, day-of-week, day- or hour-of-year, year and statutory holidays).

The coefficient of interest is β_1. This represents the expected difference in demand (in logs) between hours that are on DST versus not; in effect, the percentage change in demand as a result of DST. The identifying assumption is that once controlling for observables, fixed effects and DST, the expected residual in electricity demand is zero, i.e. $E[\epsilon_{ydh}|DST_{ydh}, W_{ydh}, D_{ydh} = 0]$. Given the high dimensionality of the controls, this seems a reasonable assumption. Under these conditions, and given the exogenous assignment of annual DST transition dates, the causal interpretation of β_1 is the effect of DST on electricity demand.

Standard errors are clustered at the year-month level. This allows for correlation of errors within the year-month bandwidth. This is a reasonable assumption, given non-demand related conditions that may be distinct from month to month. For example, Alberta's regulated retail power rate is set monthly. The rate can vary not only due to monthly demand differences, but also supply conditions, creating correlation of errors within a year-month cluster.[8]

3.3 Results

Table 2 lists the estimated effect of DST on electricity use for each province under various model specifications. All specifications include dummy variables for hour-of-day, day-of-week, holidays, and year. Model 1 includes day-of-year fixed effects and no weather controls. The lack of weather controls incorrectly attributes temperature-driven changes in demand to DST. The direction of this omitted variable bias depends on both the covariance of temperature controls and DST, as well as the covariance of temperature controls and demand. Thinking about heating and cooling degrees, we expect the covariance between temperature controls and demand to be positive – more extreme temperatures are correlated with greater demand, all else equal. The relationship between temperature controls and DST, however, is region-specific, depending on the prevalence of extreme temperature in the winter vs summer.

Model 2 includes weather controls and precision is improved in nearly all provinces. The omitted variable bias is also corrected. Looking at Alberta, as an example, we see the estimated effect of DST has increased. This makes sense, as the covariance between the temperature controls and the DST dummy is negative in Alberta while the covariance between temperature and demand is positive, thus the sign of the omitted variable bias from excluding weather controls is negative.[9]

Models 3 and 4 replace day-of-year fixed effects with more granular hour-of-year fixed effects, with the latter using more flexible weather controls. Precision improves slightly in the latter specification.

Referring to the preferred specification of Model 4, the largest negative effects (a decrease in electricity use due to DST) are seen in BC (-0.013) and Ontario (-0.010). The largest positive effect (an increase in electricity use due to DST) are found in Alberta (0.015) and Manitoba (0.016). With respect to the control variables, weekdays tend to increase demand by approximately 5% relative

[8] As an alternative method to account for auto-correlation, I repeated the analysis using Newey-West standard errors, with lags set at 72 hours based on Andrews (1991). The Newey-West standard errors were smaller, and thus I chose to use the more conservative (larger) clustered standard errors.

[9] The negative covariance between temperature and DST may not be intuitive at first. The intuition is gleamed when considered degree days. There are more degree days in winter in Alberta (for heating) than there are in summer (for cooling). Hence the correlation between this temperature variable and DST is negative.

Table 2: FIXED EFFECTS ESTIMATES

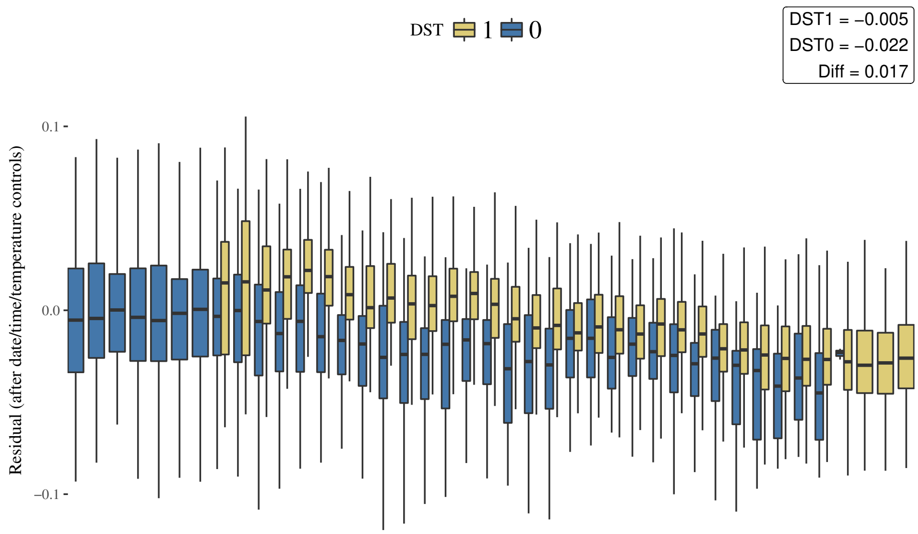
DEPENDENT VARIABLE = ln DEMAND ESTIMATED COEFFICIENT = DST (BY PROVINCE)	Model 1	Model 2	Model 3	Model 4
BC	-0.0110	-0.0160	-0.0145	-0.0127
	(0.0181)	(0.0104)	(0.0114)	(0.0110)
AB	0.0095	0.0143	0.0143	0.0154
	(0.0045)	(0.0047)	(0.0048)	(0.0048)
MB	-0.0052	0.0093	0.0108	0.0156
	(0.0146)	(0.0073)	(0.0075)	(0.0066)
ON	-0.0116	-0.0109	-0.0107	-0.0100
	(0.0084)	(0.0055)	(0.0056)	(0.0053)
QC	0.0159	0.0028	0.0048	0.0016
	(0.0198)	(0.0106)	(0.0110)	(0.0103)
NB	0.0134	0.0117	0.0126	0.0128
	(0.0134)	(0.0074)	(0.0076)	(0.0074)
PE	-0.0036	-0.0060	-0.0024	-0.0022
	(0.0167)	(0.0158)	(0.0163)	(0.0166)
NS	-0.0106	-0.0088	-0.0060	-0.0069
	(0.0175)	(0.0167)	(0.0180)	(0.0188)
NL	0.0017	-0.0100	-0.0053	-0.0017
	(0.0223)	(0.0114)	(0.0122)	(0.0122)
Weather controls:				
Heating/cooling degrees	-	X	X	-
Temperature bins	-	-	-	X
Fixed effects:				
Day of year	X	X	-	-
Hour of year	-	-	X	X

Note: Each cell in the table represents the coefficient on DST for the respective model specification, run separately for each provincial dataset. Standard errors (shown in parentheses) are clustered at the month-year level.

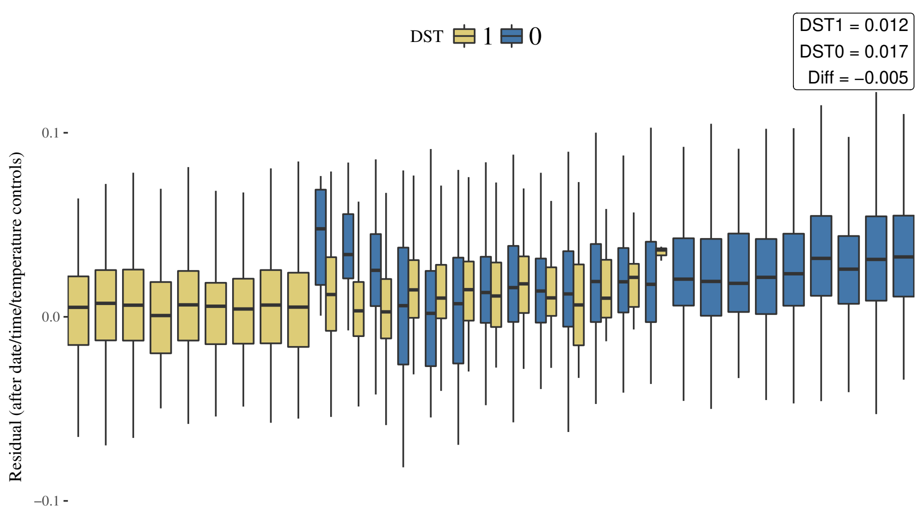
to weekends, while statutory holidays bring that number down by 4% (making holiday demand roughly 1% higher than weekend demand). The coefficients on year dummies generally increase by year, reflecting an upward annual trend in overall demand.

The fixed effects approach is shown visually in Figure 4, which plots the residuals of a regression of demand (in logs) on time, date and temperature controls, excluding the day-of-year or hour-of-year fixed effects.[10] The residuals are calculated separately for days falling under DST vs not. The plots overlap on days when DST is observed in some years and not in others.

[10]The regression equation to create the residuals for this figure is $\ln Demand_{ydh} = \beta_0 + \gamma W_{ydh} + Hour_h + Weekday_d + Year_y + Holiday_{yd} + \epsilon_{ydh}$, run separately for observations under DST vs not. For simplicity, the residuals are plotted for one province, Alberta. Similar plots for all provinces are provided in the Appendix.



(a) Spring



(b) Fall

Figure 4: The effect of DST on demand (Alberta)

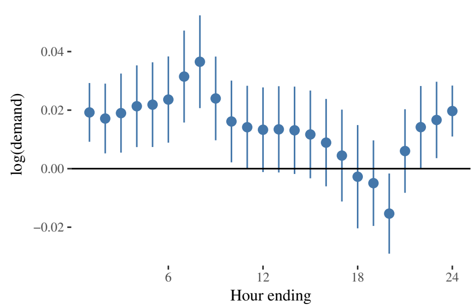
Note: Each filled rectangle (box) represents the range of 25th to 75th percentile of residuals for each respective day, with horizontal lines representing the median. The boxes are shown separately for days that fall under DST (DST=1, shown in yellow) and not under DST (DST=0, shown in blue). Whiskers extend 1.5 times the inter-quartile range (25th to 75th).

The increase in electricity use in Alberta can be clearly seen in the Spring period. On the days of overlap, electricity demand residuals are noticeably higher in years that fall under DST (shown in yellow) versus the same days not under DST (shown in blue). In the fall transition, however, other than an initial response, there appears to be no significant effect across the full period.

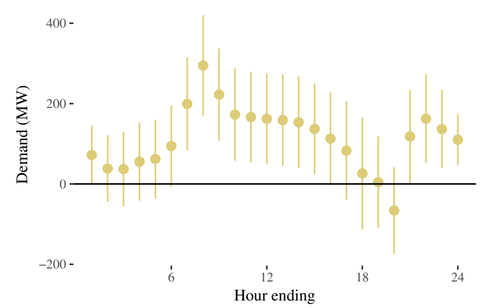
The above estimates are average results across entire days. To understand how it is possible that DST increases or decreases overall electricity usage, it is informative to see how it affects individual hours. To do so, I repeat the fixed effect regression (using Model 4 in logs and levels) for the two provinces with large differences in average results – Alberta and British Columbia – this time interacting *DST* with 24 hourly dummies. The hourly coefficients are shown in Figure 5.

In both provinces we see a clear reduction in electricity use in the evening hours, noticeably around 8pm when hours are "lit" by the DST shift. However, in the case of Alberta, this decrease is more than offset by a significant increase in the morning hours. In B.C. there is also an increase in morning electricity use, but it is substantially less than Alberta's. As we will explore in Section IV, this is consistent wtih differences between the provinces in terms of sunrise and waking times. In Alberta, people tend to rise earlier while the sun rises later than B.C.

ALBERTA

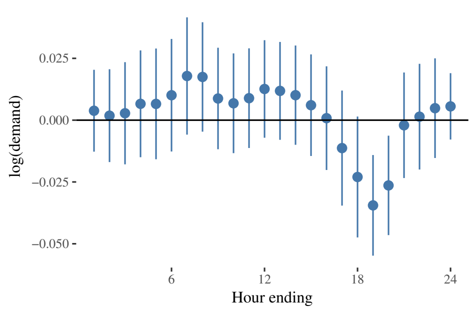


(a) Logs

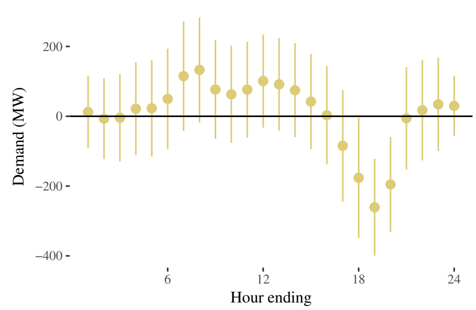


(b) Levels

BRITISH COLUMBIA



(c) Logs



(d) Levels

Figure 5: Hourly estimates of effect of DST on electricity use

Note: The figures on the left represent the estimated effect of DST on the log of electricity use, approximating percentage changes, for each hour of the day. The figures on the right represent changes in the levels in megawatts by hour. Error bars represent 95% confidence interval, clustered by year-month.

One puzzle from the Alberta picture is the increase in electricity demand in not only the most affected hours, but across other hours of the day. The levels picture presents a more intuitive "near-zero" effect during the overnight hours. The difference between levels and logs is that the percentage charts are percentage by hour, thus not visually reflecting the much smaller average demand during the overnight hours. On a percentage basis the overnight increase appears significant, but this is not the case in terms of megawatts.

3.4 Robustness

As an alternative approach to estimating the effect of DST on electricity use, I employ a *difference-in-differences* technique using the province of Saskatchewan, which does not observe DST, as a counterfactual. Since annual growth trends and temperature sensitivities differ across provinces, I employ the difference-in-differences regression including province-specific date, time and weather controls. The regression equation is:

$$\ln Demand_{tp} = \beta_0 + \beta_1 DST_t + \beta_2 Treated_p + \beta_3 DST_t \times Treated_p + \gamma_p W_{tp} + \theta_p D_{tp} + \epsilon_{tp} \quad (2)$$

where p indicates the respective province and *Treated* indicates the province that observes DST (i.e. Saskatchewan receives $Treated = 0$). The coefficient of interest, β_3, represents the difference in expected (log) demand in a time period that is on DST vs one that is not, in a province that is treated vs one that is not – the so-called *difference-in-differences* estimate. The weather (W_{tp}) and date/time (D_{tp}) controls are interacted with the province dummies and thus estimated separately.[11] Figure A.1 in the Appendix plots the very different responsiveness to temperature across provinces, highlighting the importance of separately controlling for weather.

Table 3 lists the results of the difference-in-differences estimates for the two provinces to the East and West of Saskatchewan. The estimates are similar to the fixed effects estimates. BC and ON show a negative effect of DST on electricity use, whereas AB shows a positive effect. MB differs in finding a result not statistically different than zero.

Overall, these difference-in-differences results provide a level of confidence to the fixed effects estimates. Additionally, they give a sense as to the persistence of the effect. While the fixed effects approach is only able to identify the effect over the roughly 7 weeks where the DST transition differs across years, the difference-in-differences approach allows for inference over the entirety of the period.

[11] The datetime controls includes *HourofDay*, *DayofWeek*, *Holiday*, *Year* and *Month*. The weather controls use 2°C bins.

Table 3: DIFFERENCE-IN-DIFFERENCES ESTIMATES

DEPENDENT VARIABLE = ln DEMAND				
	BC	AB	MB	ON
DST×Treated	-0.0176	0.0109	0.0005	-0.0136
	(0.0013)	(0.0007)	(0.0011)	(0.0010)

Note: Each cell in the table represents the regression results for the coefficient on DST×Treated, run separately for each provincial dataset merged with Saskatchewan. Robust standard errors are shown in parentheses.

4 Heterogeneous Regional Effects

The results above echo the varied findings in the literature: the effect of DST on electricity use is not universally positive or negative. Returning to the conceptual framework introduced in Section II, I examine whether the estimated effect of DST is location-specific in a predictable manner. In particular, I examine the correlation between the effect of DST on electricity use and a region's sun times and waking hours.

4.1 Data

We begin with sun times alone. While lacking the information of waking hours, sunrise has objectivity as its advantage. The data is not subject to issues related to survey data. Canada also provides significant variation in sunrise times, both within and across time zones, due to its broad longitudinal variation. Figure 6 illustrates the spatial variation in sunrise times during the spring transition. For the analysis, I calculate a mean sunrise time for each province using their population-weighted centroid coordinates.

For waking hours, I use data from the General Social Survey, a Statistics Canada resource that collects time-use information from a random sample of 25,000 Canadians across all 10 provinces. Respondents are asked to complete a diary of daily activities, including wakeup times. This is the ideal metric for this study, however, there is significant bunching of respondents at the round value of 7:00 am, raising data quality concerns.

As an alternative to wake-up times, I also use the mean time people leave for their commute in each province.[12] Commute time data has higher inter-provincial variance than wakeup time data and appears to be less prone to bunching at round numbers.

[12]Source: Statistics Canada NHS Data table 99-012-X2011031.

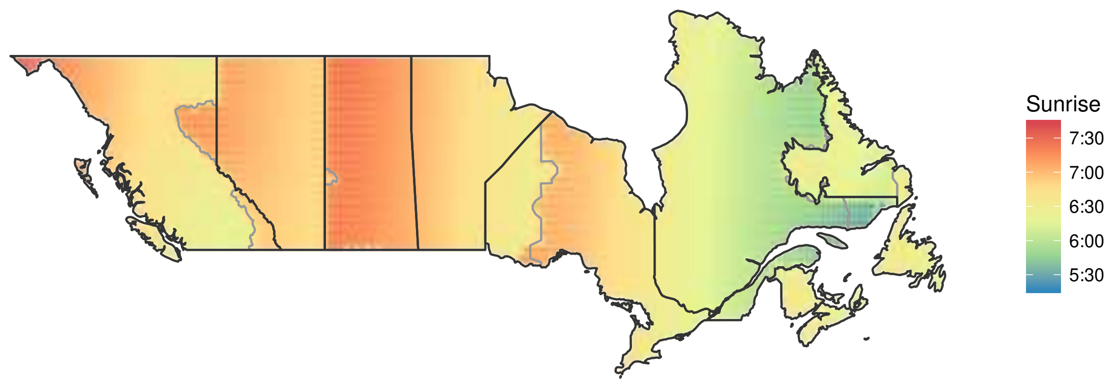


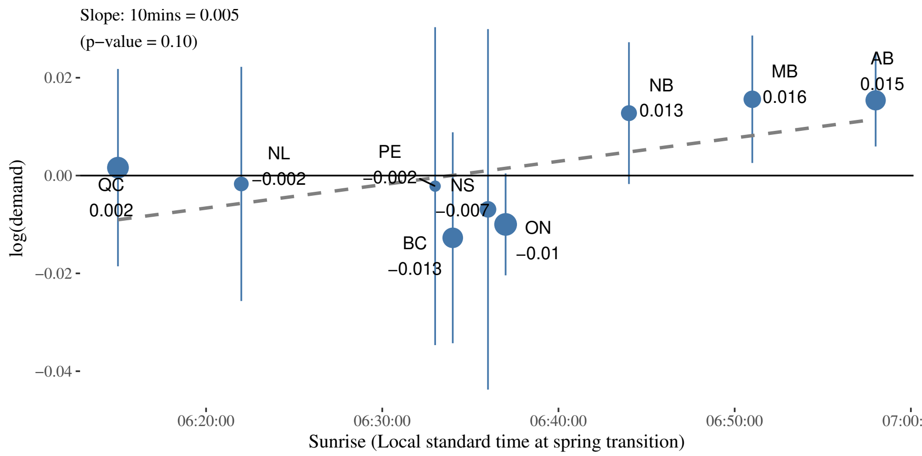
Figure 6: Sunrise times across Canada during the spring transition
Note: Picture represent sun times during the spring transition (March 10th). As this is close to spring equinox, there is very little north-south variation in sun rise times; instead, the variation in east-west sun rise times is evident. Data from geonames.org.

For both wake-up and commute times, I calculate the number of minutes between sunrise and their respective values. These serve as metrics to represent the likelihood of sunlit waking hours being darkened by the DST transition. For example, Alberta has only 93 minutes between the time of sunrise and the mean time leaving for work. After the transition, this is shortened to 33 minutes, leaving many Albertans darkened by the time shift. Whereas, in Ontario, the pre-transition time difference is 134 minutes, shortened to 74 after the transition. This means less Ontarians are likely to be darkened by DST, and thus less electricity increase during the morning hours.

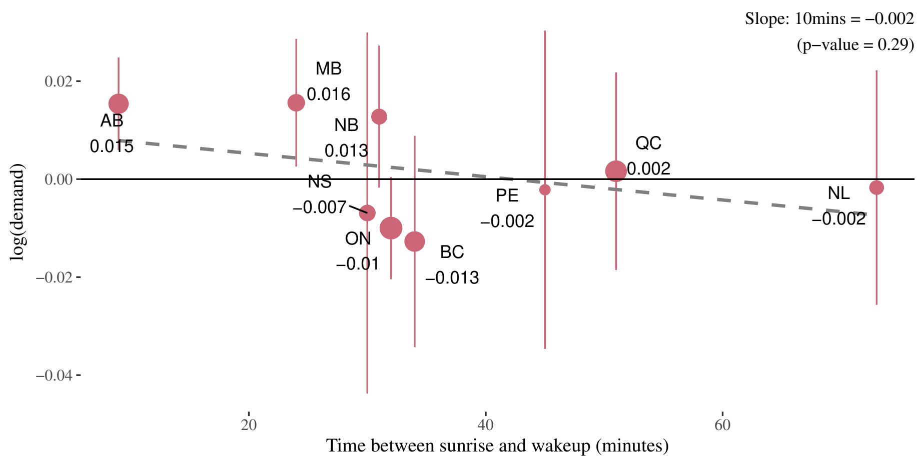
4.2 Results

Figure 7 presents the results showing the relationship between the effect of DST on electricity use and the three time metrics fitted by a simple OLS trend line. Point estimate markers are scaled by the population size of each province to place less emphasis on sparsely populated provinces with potentially greater idiosyncratic demand factors. Error bars indicate the 95% confidence interval. For all three metrics, the relationship between regional morning light and the DST effect is consistent with the conceptual framework.

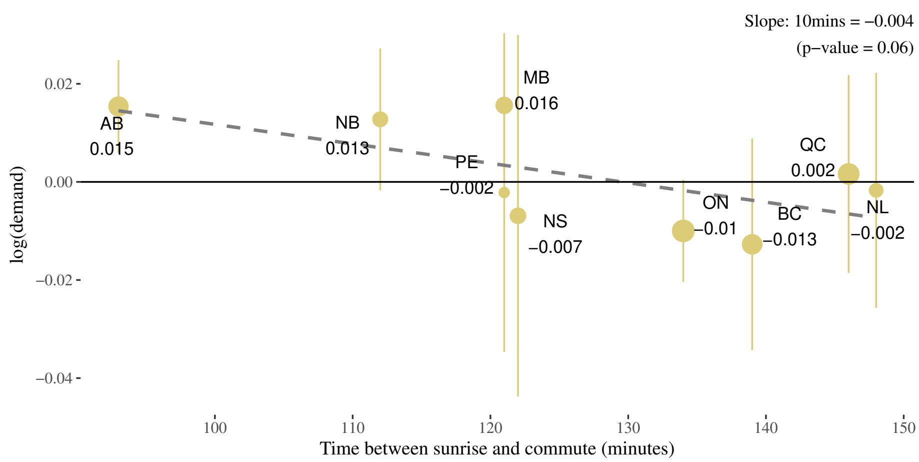
Panel 7a illustrates the relationship between the effect of DST on electricity use versus a region's mean sunrise time. The slope of the trend line indicates that every 10 minutes of later sunrise is associated with an increase in electricity use of 0.5% when observing DST (p-value = 0.10).



(a) Sunrise



(b) Wakeup



(c) Commute

Figure 7: Effect of DST versus morning sun light

Note: Point estimate marker sizes are weighted by 2016 census population data by province. Error bars represent 95% confidence interval.

Panel 7b plots the relationship between the DST effect and the number of minutes between sunrise and wakeup. Less morning light prior to waking is associated with an increase in electricity use as a result of DST, consistent with the conceptual framework. In this case, 10 less minutes between sunrise and wakeup is associated with a 0.2% increase in the effect of DST on electricity use. In this example using wakeup times, the p-value (0.29) suggests the slope is not significantly different than zero.

Panel 7c uses the time between sunrise and commute. This shares a similar downward sloping pattern, however, the magnitude is both greater and more statistically significant. Ten less minutes between sunrise and wakeup is associated with a 0.4% increase in the effect of DST on electricity (p-value = 0.06).

Alberta is at the extreme end of all three metrics, with late sunrises combined with early wake-ups and commutes combining to very little morning sunlight minutes. Correspondingly, Alberta also has the largest positive effect on electricity demand from DST. Newfoundland and Labrador (NL) also extend the horizontal axis in Panel 7b due to a significantly later wake-up times; the difference is less pronounced when considering commute times.

Of these results, only the relationship between the DST effect and time between sunrise and commute can reject the null hypotheses of no relationship with greater than 90% confidence. This emphasizes the difficulty in obtaining significant power to estimate the relationship. It also highlights other potential confounders involved in the relationship, including differences in industrial shares of electricity demand as well as shares of electricity demand for heating. In fact, Quebec stands out among Canadian provinces in terms of its share of households using electricity as their primary heat source (82% vs 41% Canadian average; see Appendix). In this case, the conceptual framework based on shifts in lighting demand will be masked by heating demand, less affected by morning light shifts. Removing Quebec both increases the slope (to 0.8%) and improves the p-value (to 0.03) in Panel 7c.

5 Conclusion

My results emphasize the need to consider local factors when estimating the effect of DST on electricity use. The effect of DST on electricity demand is region-specific; regions with late sunrises and early waking hours face a higher cost of additional morning darkness.

The effect of DST on electricity use across Canada ranges from -1 to -1.3% in Ontario and British Columbia to +1.5% in Alberta and Manitoba. This is consistent with their relative differences in sunrise and wake-up times. I estimate that for every 10 minutes of less morning sunlight in a region, DST increases electricity demand by 0.2 to 0.5%. This increases to as much as 0.8% when excluding the province of Quebec, whose electricity demand is more dependent on heating than lighting.

Just how big are these effects? In terms of welfare implications, we can calculate the estimated increase in consumer and social costs arising from this increased electricity demand. Taking the extreme example of Alberta, with the latest sunrises and earliest waking hours, I find DST increases electricity use by roughly 1.5% during the period of transition. The consumer cost of this additional demand is roughly $12 million per annum, based on inference over the 7 week range of transition dates and a supply cost of $65 per MWh. The social cost, based on the average GHG intensity of Alberta's electric system (0.8 tonnes-CO_2 per MWh) and a $42 social cost of carbon, adds an additional $7 million per year. Thus the total cost of additional electricity demand due to DST is roughly $19 million per year. If we extend this to the entirety of the DST period based on the difference-in-differences estimates, the annual amount rises to roughly $90 million. To be sure, this is still not a large number in a province with a GDP of $280 billion (2014), however, any positive cost adds to the question of the necessity of DST.

Another way to view this increase is in relation to other efforts being made to conserve energy. For example, while the province of Alberta is currently considering abolishing DST, they are also handing out free LED bulbs to improve energy efficiency. For perspective, if all Albertan residents switch their lightbulbs to energy-efficient LED, the result would be a reduction of electricity demand in the province of 1.6% [13] In other words, DST negates not all, but roughly one-eighth to three-fifths, of the energy benefits from a full switch to LED lightbulbs.[14] While the province of Alberta considers energy efficiency programs to conserve energy (including LED subsidies and giveaways), in this case a simpler—and likely less costly option—may be at hand.

In conclusion, the lesson from this paper is that policymakers considering whether to keep, implement or abolish DST need to consider local factors; the answer as to how DST affects electricity use appears to be region specific in a predictable manner. Of course, electricity savings are but one dimension for policy makers to consider. The economic benefit of regional coordination from aligned time systems is another important consideration in setting DST policy, as are effects

[13]This estimate is calculated based on an 18% residential share of total demand × 10% share for lighting demand × 90% energy savings from LEDs as compared to incandescent bulbs.

[14]The effect is 1/8 despite a similar percentage reduction since the LED savings occur year-round, whereas the effect of DST can only be inferred over the 7 week period of transition dates. If we allow for the DST effect to persist across the entire DST period, the effect is 3/5th of the LED savings.

on health and safety. For many of these, just as we have found for electricity savings, one should not assume estimated effects in other regions to apply universally – understanding local effects is critical.

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A Appendix

A.1 Summary Tables

Table A.1: Summary Statistics of Hourly Electricity Demand (MW/h)

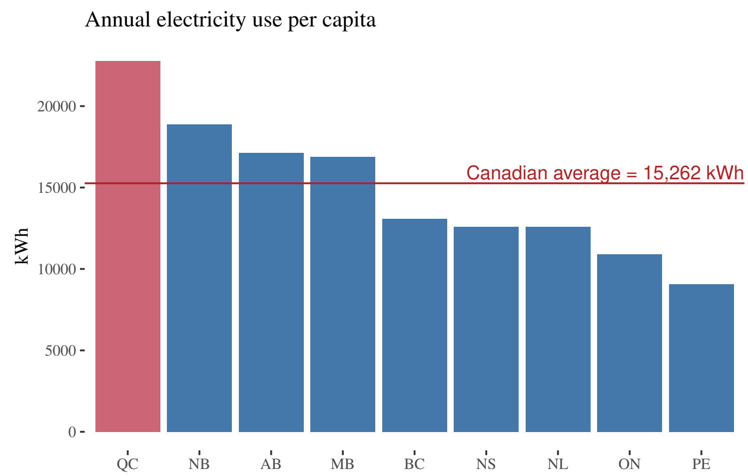
		DST=0			DST=1		
		Mean	Min	Max	Mean	Min	Max
BC	2007-15	7935	4852	10986	6399	4026	9477
Alberta	2001-15	8248	5216	11229	7771	5030	10520
Saskatchewan	2001-15	2615	1377	3682	2319	1234	4654
Manitoba	2001-15	2966	1825	4366	2174	1337	3881
Ontario	2001-15	17570	10811	24979	16196	10539	27005
Quebec	2007-15	26159	14877	39266	18590	12535	34047
New Brunswick	2001-15	1965	973	3326	1388	729	2623
PEI	2007-15	161	87	265	141	76	226
Nova Scotia	2007-15	1523	730	2192	1223	675	1991
NFLD & Labrador	2007-15	980	338	1523	646	243	1498

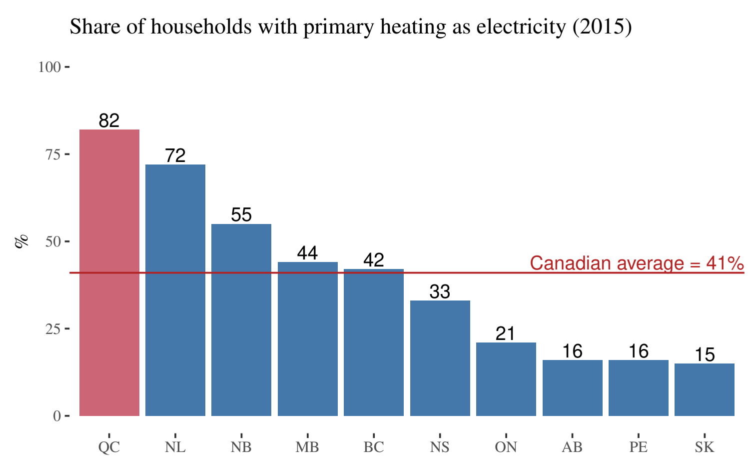
Table A.2: SUMMARY STATISTICS OF WEATHER DATA

	DST=0			DST=1		
	Mean	Min	Max	Mean	Min	Max
BC						
Temperature	4.8	–13.6	15.8	13.5	–5.0	33.9
Heating Degree Hours	13.2	2.2	31.6	4.9	0	23.0
Cooling Degree Hours	≈ 0	≈ 0		0.5	0	15.9
ALBERTA						
Temperature	–4.7	–33.9	25.2	10.6	–25.8	34.0
Heating Degree Hours	22.7	0	51.9	8.1	0	43.8
Cooling Degree Hours	≈ 0	0	7.2	0.7	0	16.0
SASKATCHEWAN						
Temperature	–10.8	–44.9	16.6	11.1	–36.1	37.9
Heating Degree Hours	28.8	0	62.9	8.0	0	54.1
Cooling Degree Hours	0	0	0	1.1	0	19.9
MANITOBA						
Temperature	–10.8	–40.7	18.3	12.4	–26.5	37.0
Heating Degree Hours	28.8	0	58.7	6.9	0	44.5
Cooling Degree Hours	≈ 0	0	0.3	1.3	0	19.0
ONTARIO						
Temperature	–1.2	–25.4	20.6	15.5	–16.9	37.5
Heating Degree Hours	19.2	0	43.4	4.5	0	34.9
Cooling Degree Hours	≈ 0	0	2.6	2.0	0	19.5
QUEBEC						
Temperature	–4.5	–27.5	19.2	14.2	–16.7	35.2
Heating Degree Hours	22.5	0	45.5	5.5	0	34.7
Cooling Degree Hours	≈ 0	0	1.2	1.6	0	17.2
NEW BRUNSWICK						
Temperature	–3.8	–30.4	19.5	12.2	–17.9	34.7
Heating Degree Hours	21.8	0	48.4	6.8	0	35.9
Cooling Degree Hours	≈ 0	0	1.5	1.0	0	16.7
PEI						
Temperature	–2.9	–25.6	18.0	11.5	–16.5	32.4
Heating Degree Hours	20.9	0	43.6	7.3	0	34.5
Cooling Degree Hours	≈ 0	0	≈ 0	0.8	0	14.4
NOVA SCOTIA						
Temperature	–1.9	–23.3	18.3	11.8	–13.9	33.9
Heating Degree Hours	19.9	0	41.3	7.0	0	31.9
Cooling Degree Hours	≈ 0	0	0.3	0.7	0	15.9
NFLD & LABRADOR						
Temperature	–1.2	–18.2	17.9	9.2	–16.0	30.4
Heating Degree Hours	19.2	0.1	36.2	9.2	0	34.0
Cooling Degree Hours	≈ 0	0	≈ 0	0.4	0	12.4

A.2 Quebec as outlier in electricity use and heating share

The province of Quebec is a relative outlier both in terms of electricity use per capita, as well as electricity's share of primary heating. Since the conceptual framework is based on shifts in morning light inducing more lighting demand, the emphasis on heating in Quebec's electricity demand.



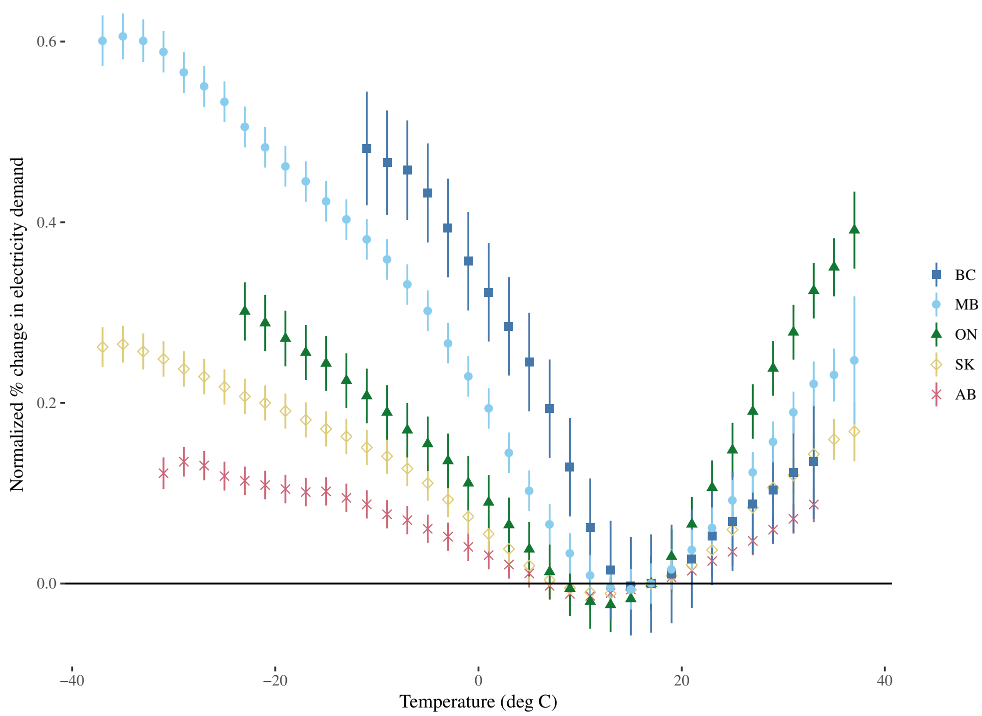


Source: Statistics Canada Table 153−0145 (Households and the Environment Survey)

A.3 Temperature sensitivity of electricity demand

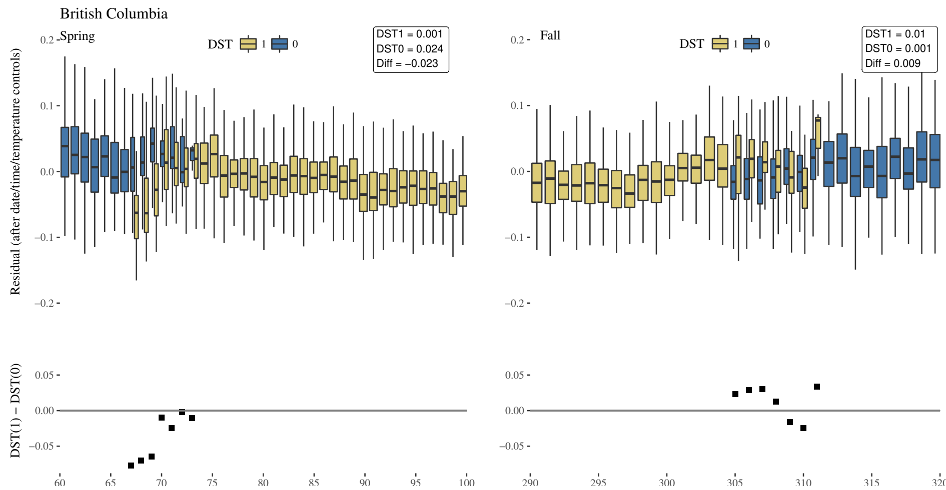
The sensitivity of each province's electricity demand to temperature can vary significantly. In the below figure, we see the effect of temperature on electricity demand as compared to a "neutral" 18°hour. In the extreme cold, Manitoba's (MB) electricity demand increases by 60% relative to a 18°hour. Whereas, Alberta's (AB) only increase approximately 15%. This reflects both the greater use of electric heating in MB (vs AB), as well as AB's greater proportion of industrial demand in their total demand. During heat events, we see Ontario's (ON) greater sensitivity, likely on account of ON having a larger share of households with air conditioning as compared to the other provinces.

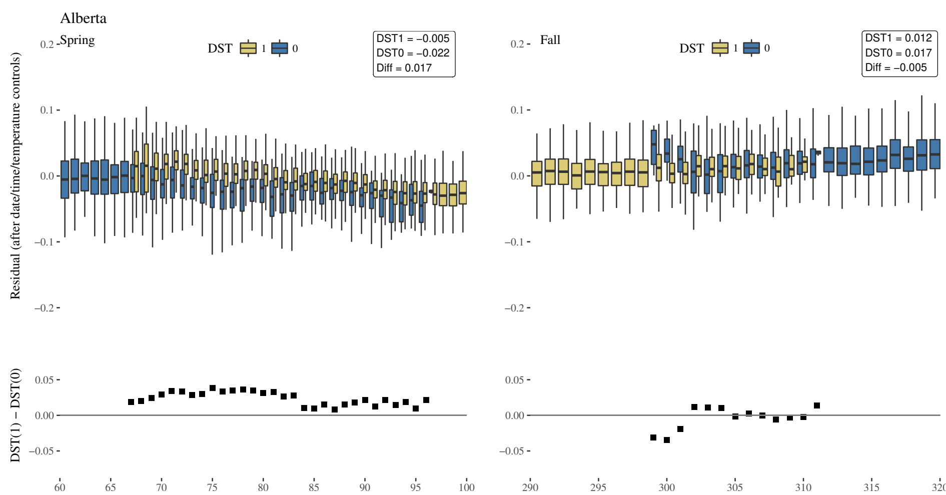
Figure A.1: Temperature sensitivity of electricity demand by province

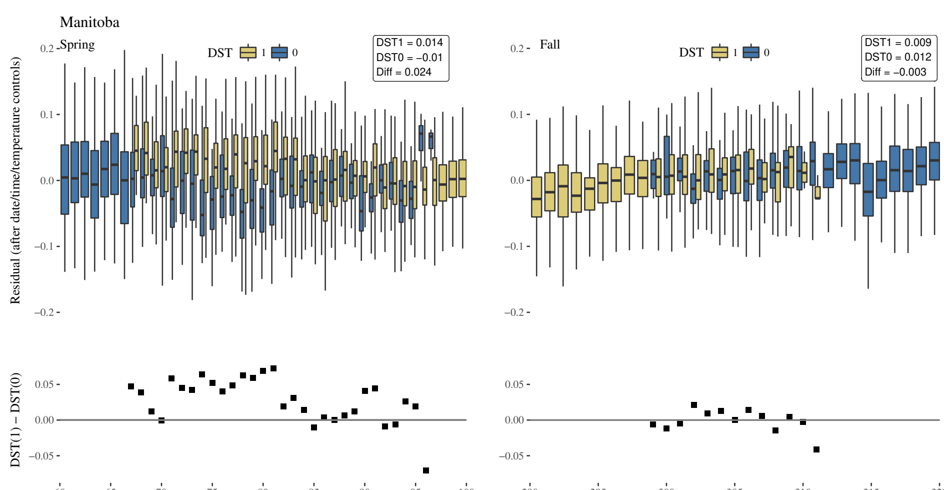


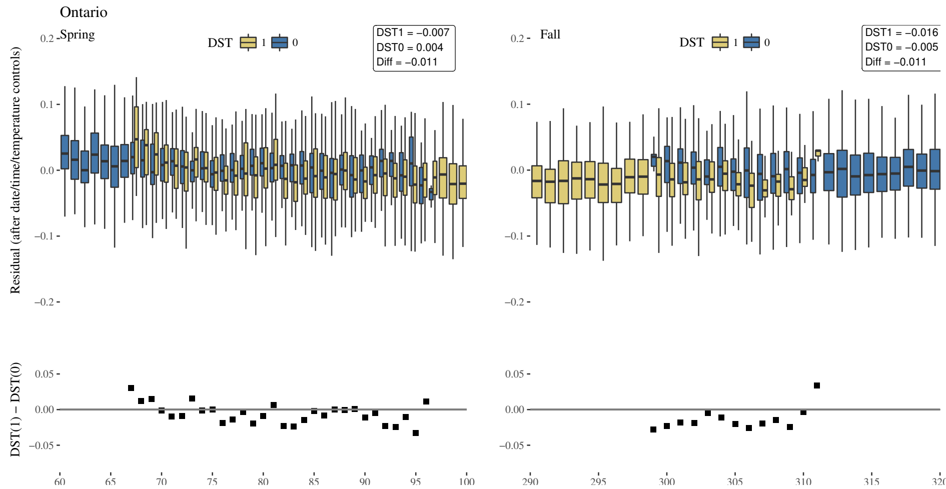
Note: Shown above are estimates from a regression of (log) demand on 2°temperature bins, including hourly, weekday, holiday and year controls. The difference between the respective coefficient and the "neutral" temperature bin of 16-18°C is plotted along with the 95% confidence interval.

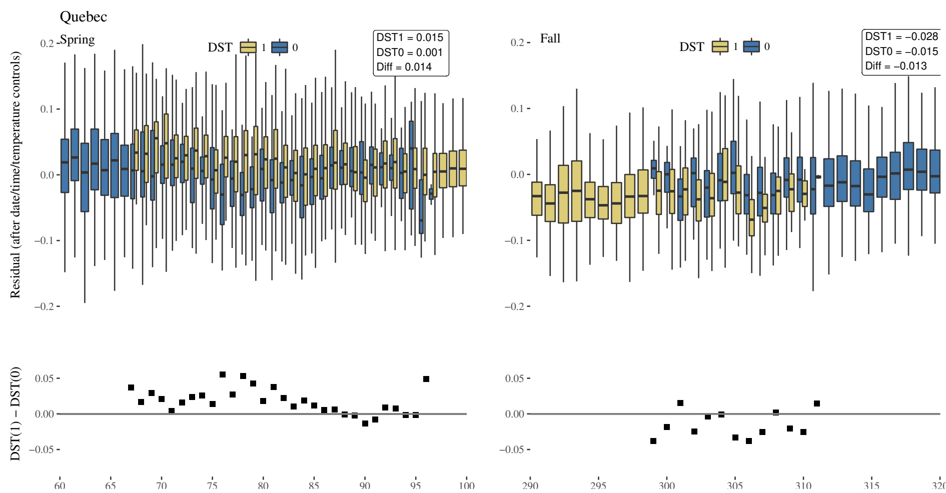
A.4 Seasonal fixed effects plots

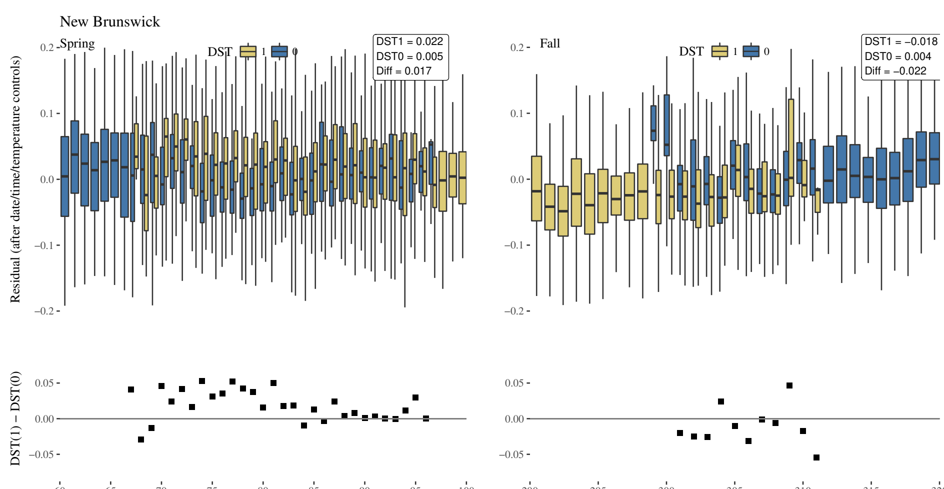


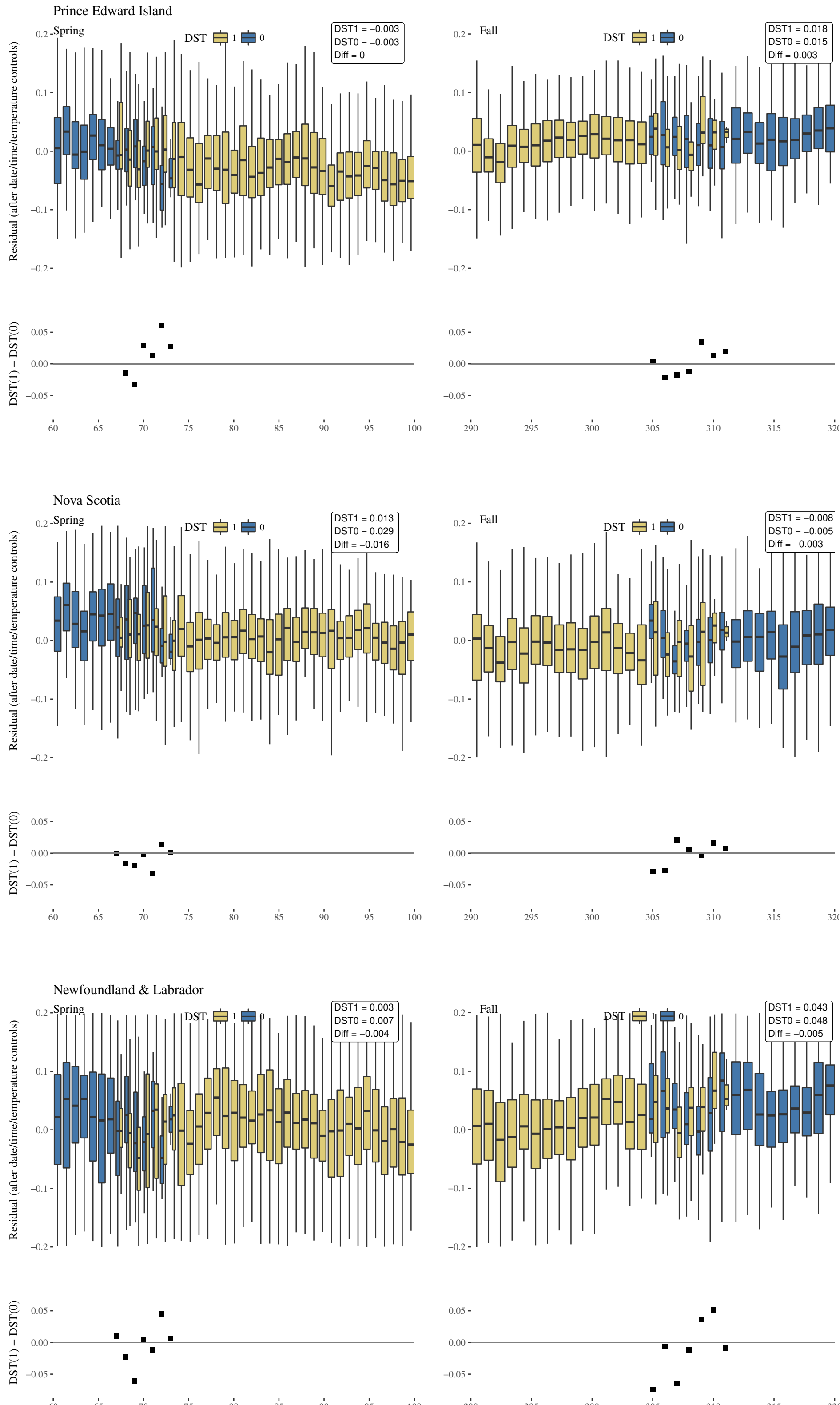





Ontario
Spring
Fall
DST 1 0
DST1 = −0.007
DST0 = 0.004
Diff = −0.011
DST1 = −0.016
DST0 = −0.005
Diff = −0.011
Residual (after date/time/temperature controls)
DST(1) − DST(0)


Quebec
Spring
Fall
DST 1 0
DST1 = 0.015
DST0 = 0.001
Diff = 0.014
DST1 = −0.028
DST0 = −0.015
Diff = −0.013
Residual (after date/time/temperature controls)
DST(1) − DST(0)


New Brunswick
Spring
Fall
DST 1 0
DST1 = 0.022
DST0 = 0.005
Diff = 0.017
DST1 = −0.018
DST0 = 0.004
Diff = −0.022
Residual (after date/time/temperature controls)
DST(1) − DST(0)


Prince Edward Island
Spring
DST 1 0
DST1 = −0.003
DST0 = −0.003
Diff = 0
Fall
DST 1 0
DST1 = 0.018
DST0 = 0.015
Diff = 0.003
Nova Scotia
Spring
DST 1 0
DST1 = 0.013
DST0 = 0.029
Diff = −0.016
Fall
DST 1 0
DST1 = −0.008
DST0 = −0.005
Diff = −0.003
Newfoundland & Labrador
Spring
DST 1 0
DST1 = 0.003
DST0 = 0.007
Diff = −0.004
Fall
DST 1 0
DST1 = 0.043
DST0 = 0.048
Diff = −0.005
Residual (after date/time/temperature controls)
DST(1) − DST(0)