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Behavioral responses to Daylight Savings Time

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ABSTRACT

Daylight Savings Time (DST) is promoted as a tool to conserve energy. However, ex post reduced form estimates of the effects of DST find no evidence of energy savings and find some evidence of a small increase in energy use. This paper investigates this disconnect using detailed individual time use data to look at the behavioral effects of DST. We study how individuals change their time use in response to the abrupt shift in daylight associated with DST. We leverage two natural experiments to identify the effect of DST on behavior. First, we study periods around the annual shift in daylight induced by moving into and out of DST. Second, we compare activities by time interval before and after the change in DST start dates that occurred in 2007. We find cautious evidence that individuals are shifting potentially energy intensive activities earlier in the day, which is consistent with earlier findings of increased energy usage.

1. Introduction

Implementing or extending DST programs are a kind of behavioral “nudge” to reduce energy use. Recent changes to Daylight Savings Time (DST) were promoted in this way, by promising a reduction in the demand for electric lighting (Aries and Newsham, 2007). Prior research has focused on changes in energy consumption due to DST, but results vary in an interesting way. Prospective studies find that DST reduces overall electricity use between 0.5 and 3.5 percent (Ebersole et al., 1974), whereas retrospective studies find no reduction or perhaps even a small increase in energy use (Kellogg and Wolff, 2008; Kotchen and Grant, 2011). This paper sheds light on the disconnect by investigating how individuals adjust their behavior in response to DST using detailed time-diary data.

Ex-ante research into the effects of DST and DST extensions is largely simulation based. It uses observed behavior absent DST to estimate and extrapolate energy savings under a DST regime. These studies typically use simple behavioral assumptions to simulate changes in lighting usage under DST and then extrapolate the resulting effect of these changes on total energy usage. Predictions vary widely, with most finding that DST results in energy savings, and in some instances savings as large as 9 percent.[1] In more recent work, the California Energy Commission (Kandel and Mills, 2001) used data from the then-current DST system to forecast energy use under a program that would have extended DST year-round. The study predicted that such a change would result in a 0.6 percent reduction in electricity consumption, as well as an overall reduction in electricity prices.

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[1] A detailed summary of this literature can be found in Aries and Newsham (2007).

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In contrast, more recent work uses changes in DST policies and quasi-experiments to ex-post causally identify impacts of DST. The Department of Energy (Belzer et al., 2008) used regression models of daily and hourly electricity consumption from a sample of utilities located across the United States to assess the effects of the 2007 DST extension. Researchers used a difference-in-difference approach that compared data from 2006 (before the extension) to data from 2007 (after the extension) and controlled for variables other than DST that might affect energy consumption, including heating and cooling degree days, day of week, and holiday status. They found that total electricity savings induced by Extended Daylight Saving Time (EDST) were about half a percent for each day of the extension. Savings occurred in the late afternoon and evening with small increases in usage during the early mornings. Results also suggested that the energy savings were not consistent across geographical regions; energy savings were smaller in southern states, possibly due to greater air conditioning use in warmer afternoons and evenings. Kellogg and Wolff (2008) use data from a quasi-experiment in Australia when DST was extended to accommodate the 2000 Olympic games. The extension was not implemented in all states, which allowed a difference-in-difference model comparing panel data on half-hourly electricity consumption from a state that experienced the extension with a state that did not. Kellogg and Wolff find that the DST extension failed to reduce energy consumption, and although the estimates are not statistically significant, point estimates suggest an overall increase in usage. Most recently, Kotchen and Grant (2011) exploit a natural experiment that occurred in Indiana after the Energy Policy Act of 2005, to provide empirical estimates of DST effects on electricity consumption. Prior to the 2005 law, the majority of Indiana counties did not observe DST. This allows the authors to compare households' electricity demand before and after 2007 to estimate the effects of DST. Their results show that DST actually increased residential electricity demand in Indiana by about 1 percent per year.

While recent studies find either no change or increased energy use as a result of DST, they do not explore the changes in *individual* behavior that may drive changes in energy use. Exploring this gap is the main contribution of this paper. We use the American Time Use Survey (ATUS) to estimate behavioral responses to DST. Specifically, we study how individuals shift the amount of time during the day they spend sleeping, awake at home, and awake away from home. Put differently, we test the extent to which the time of sunrise and sunset affects daily behavior versus the extent to which individual behavior simply follows the clock. By determining the underlying behavioral responses to DST, this paper tests assumptions made in the previous simulation models that may have led to overly optimistic estimates of energy savings. Because the ATUS is a nationally representative data set that contains information on all activities of respondents, we can systematically study behavioral responses on a national scale and draw conclusions about individuals' reactions to time shifts – both shifting time forward by an hour in the spring, and shifting it back again in the fall.

We find that DST has the largest impact in the spring, causing individuals to get up earlier in the morning, and to spend most of the additional time awake in their homes. We also find some evidence that individuals spend less time at home in the evenings. Results suggest that individuals are performing household chores and activities in the morning that results in additional time for other activities in the evening. This shift towards morning chores did not factor into prior simulation studies and provides important insight into the discrepancies between predicted energy savings and realized savings. Additionally, the results provide insights into other important impacts associated with DST – thought to be associated with sleep deprivation – that may have larger ramifications, e.g vehicle safety (Coren, 1996, 1998), workplace safety (Barnes and Wagner, 2009), and stock market returns (Kamstra et al., 2000).

We continue in Section 2 with background information on DST programs. Section 3 describes the data used in this analysis, and Section 4 discusses the econometric models used to estimate the effects of DST on behavior. Results are presented in Section 5, and the final section offers some concluding remarks.

2. Background

DST was first introduced in the United States on March 19, 1918 with the Standard Time Act. This legislation mimicked policies that were already being used in several European countries to conserve fuel during the first world war. The practice however was unpopular and the national law was abolished shortly after the war. In the time between World Wars I and II, the choice to participate in DST was left to local governments, and adoption varied across cities and states. In 1942 President Franklin Roosevelt reintroduced DST, but extended the time change to cover the entire year calling it "War Time". Again, following the war in 1945, DST returned to being a local policy and remained that way until 1966.

In the early 1960s, varying DST policies across cities and states elicited complaints. DST differed not only over space but also over time with different jurisdiction observing different beginning and ending dates. These differences caused particular issues for the transportation industry. Conducting business across state boarders was difficult and lobbying began for a national law regulating DST. This resulted in the Uniform Time Act of 1966, which mandated that clocks be advanced one hour beginning at 2:00 a.m. on the last Sunday in April and turned back one hour at 2:00 a.m. on the last Sunday in October. States, however, were allowed to exempt themselves from DST as long as the entire state did so. Additionally, states located in two different time zones were allowed to exempt one time zone without exempting the other. For example, at that time both Michigan and Indiana had some counties that observed DST, and others that did not.

The Department of Transportation (DOT) is responsible for enforcing and evaluating DST. This has included, among other responsibilities, evaluating proposals to extend DST. It was through this evaluation process that Congress decided to change the effective dates of DST in 1986 with the goal of reducing energy use. Beginning in 1987, DST began on the first Sunday in April and remained in effect until the last Sunday in October. Then, after another review process by the DOT, Congress passed the Energy Policy Act of 2005, which extended DST for an additional four weeks, again with the stated intent of reducing energy usage. As of 2007, DST starts on the second Sunday of March and ends on the first Sunday of November.

Today, all states and territories except Arizona, Hawaii, American Samoa, Puerto Rico, and the Virgin Islands observe DST, but the policy remains controversial. Several states have recently discussed legislation to either observe Standard Time (ST) year-round or DST year-round. In its 2011 session, the Colorado legislature voted on bills for both moves. Nevada has similarly debated both legislation moving to yearlong DST and legislation moving to yearlong ST. Meanwhile, Florida, Montana, and Alaska have all discussed moving to yearlong ST and thereby abolishing DST.

3. Simulation approach

Ex-ante simulation models and ex-post evaluation studies have come to different conclusions as to the effectiveness of DST. The ex-post studies have used well understood evaluation methods, largely differences-in-differences. However, it will behoove us to briefly review the methods used to project the energy effects of DST. We focus on the California Energy Commission (CEC) model, also estimated by both Kellogg and Wolff (2008) and Kotchen and Grant (2011), as a case in point.

The simulation approach regresses energy use in hour h on day d on minutes of daylight, and a set of other control variables,

$$q_{dh} = a_h + b_h \text{Controls}_d + c_h \text{Weather}_{dh} + d_h.\text{Daylight}_{dh} + \mathbf{u}_{dh}. \tag{1}$$

This generates a set of coefficients and a residual for each hour. The CEC model then lags the daylight and weather variables by one hour and adds back the residuals to generate predicted energy use for the period after the DST transition,

$$\hat{q}^{sim}_{dh} = \hat{a}_h + \hat{b}_h \text{Controls}_d + \hat{c}_h \text{Weather}_{dh-1} + \hat{d}_h \text{Light}_{dh-1} + \hat{\mathbf{u}}_{dh}. \tag{2}$$

The key assumption is that DST does not change behavior beyond changes in light and weather; unobservables are added back in. Kellogg and Wolff (2008) put it succinctly, “the simulation will be inaccurate if people awaken later in winter than they do in spring under extended DST.” We now investigate whether this is in fact the case.

4. Data

To study behavioral change in response to the DST time change, we combine data on daily activities, daylight savings status, surface weather conditions and sunrise and sunset times. First, we use the American Time Use Survey (ATUS), a nationally representative, federally administered survey on time use in the United States. The survey collects information on all activities performed by respondents during a designated 24-h period. It was first administered in 2003 and is ongoing. It is administered throughout the year, allowing us to collect responses over the entire period, 2003–2011 (BLS, 2011). Because each respondent provides detailed information on his/her activities during the designated 24-h period, we are able to determine how much time each person spent in various activities for various periods of the day, which may be affected by DST and may in turn impact energy demand.

Note that a nontrivial number of the ATUS responses are missing detailed information on the respondent’s geographic location, which is necessary in order to match the responses to appropriate weather, daylight, and DST regime information. To obtain these data we use information from the Current Population Survey (CPS), in which the respondents are included. In particular, we use data from the CPS for the corresponding year and match ATUS respondents to their final CPS interviews. These interviews occurred 2–5 months prior to the ATUS survey and contained more complete geographic information including the respondent’s core based statistical area (CBSA). After matching the two data sets and dropping all responses for which a valid CBSA could not be identified (roughly 30% of the total number of respondents to the ATUS or 39,219 individuals), we are left with 88,477 responses spanning 9 years.

To determine which respondents were on DST when completing the ATUS, we use information on the start and end dates for DST by state for the period 2003–2011. DST was extended beginning in 2007, so our data contains information on 4 years prior to the policy change and 5 years after. For our primary analysis we retain only those individuals interviewed on a weekday in the week before or the week after the spring or fall DST transition. Note that the amount of time that individuals spend in different activities varies considerably between weekdays and weekends, and DST may have differing effects. As a result, we focus on weekdays only. We will subsequently explore whether findings are robust to alternative weekday windows.

In addition to sunrise and sunset times, surface weather conditions are likely to influence the amount of time respondents spend sleeping, at home, and away from home. To control for these effects, we use historical daily surface weather data for the United States from 2003 to 2011 from the National Climatic Data Center’s (NCDC) Climate Data Online database. The data contain daily measures of mean temperature, mean wind speed, maximum temperature, minimum temperature, and total precipitation (rain and/or melted snow) for over 2000 stations in the U.S. We use latitude and longitude coordinates to determine which station was located closest (measured as the crow flies) to the center of each CBSA, allowing the data for those stations to be merged with the ATUS. Finally, for each set of CBSA coordinates we used PyEphem[2] to compute sunrise

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[2] http://rhodesmill.org/pyephem/index.html.

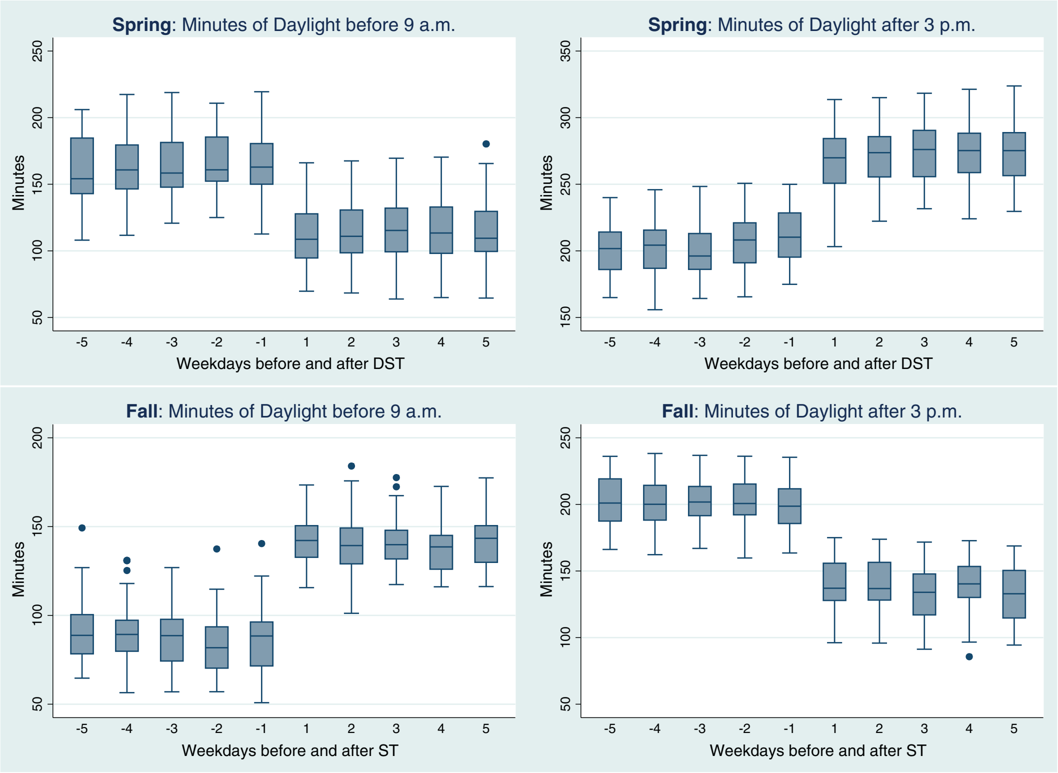

Fig. 1. Effects of DST: spring and fall.

and sunset times. Fig. 1 presents minutes of sunlight both before 9 a.m. and after 3 p.m. for the weekdays before and after the DST transition for each of the individuals in our sample.

Finally, while not strictly necessary given the empirical design, we include a series of covariates that might explain time use in an effort to improve precision. We include information on employment status, gender, marital status, education, and demographic structure of the household, with a particular emphasis on the number and age of children in the respondent's household. Sample means and standard deviations for the week before and week after both the spring and the fall DST transition are reported in Table 1. Differences between samples before and after the DST transition are well within what one might expect given sampling variability. This is expected given the design of the ATUS, where the diary date is plausibly exogenous to the individual and should be uncorrelated with a switch onto or off of DST.

We create three, mutually exclusive variables that capture time spent in: sleep, activities at home, and activities away from home. Aggregating activities into these three broad categories allows for a transparent analysis of how changes in time use may affect residential energy consumption. For example, if individuals sleep less in the morning when DST is in effect, they will likely begin using lighting and heating earlier. Thus energy demand in the morning may rise. This effect would be further supported if individuals also spent more time in home-based activities in the morning. Essentially all ATUS activities were divided into one of the three categories.[3]

DST affects the amount of daylight in the morning and evening. As a result, we focus on how time use varies during these periods. Sunrise occurs between 5 a.m. and 8 a.m. in the U.S., and sunset occurs between 3 p.m. and 8 p.m. For all ATUS respondents, we measure time spent in each of the three activities between the hours of 5 a.m. and 9 a.m., and 3 p.m. and 8 p.m. Further, we consider time use in the late evenings that maybe affected by time use earlier in the day. In short we consider time use in five periods: 5–9 a.m., 3–5 p.m., 5–8 p.m., 8–10 p.m., and 10 p.m.–12 a.m. We plot how time use changes over the DST, transition. For each weekday in the week before and after the spring/fall transition we plot minutes spent at home and away from home in the mornings and late afternoons/evenings in Figs. 2–11.

Table 2 reports the mean and standard deviation (in parentheses) for the minutes per day each ATUS respondent spent engaged in the previously described activities during each of the time periods of interest. We summarize time use separately for weekdays occurring the week before and weekdays occurring the week after the DST transition, both in the fall and in the spring. We also report the average difference (*Diff*), and the p-value of the t-test of equality of means (p). A couple of features bear noting. The largest difference is in time spent sleeping during the morning in the week after DST in the spring.

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[3] Details of this classification are available from the authors upon request.

Table 1
Summary statistics.

	Spring				Fall			
	Week before DST		Week after DST		Week before ST		Week after ST	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Monday	0.20	0.40	0.19	0.39	0.18	0.38	0.18	0.38
Tuesday	0.19	0.39	0.17	0.38	0.19	0.39	0.18	0.39
Wednesday	0.19	0.39	0.17	0.37	0.18	0.39	0.17	0.37
Thursday	0.17	0.37	0.18	0.39	0.18	0.38	0.16	0.36
Friday	0.16	0.37	0.18	0.39	0.18	0.38	0.19	0.39
2003	0.15	0.36	0.15	0.36	0.18	0.38	0.17	0.37
2004	0.08	0.28	0.09	0.29	0.11	0.32	0.10	0.30
2005	0.11	0.32	0.11	0.31	0.10	0.30	0.11	0.32
2006	0.10	0.30	0.11	0.31	0.10	0.31	0.09	0.29
2007	0.10	0.29	0.10	0.29	0.10	0.30	0.10	0.30
2008	0.09	0.29	0.11	0.31	0.07	0.25	0.09	0.28
2009	0.12	0.32	0.10	0.31	0.10	0.30	0.10	0.30
2010	0.11	0.32	0.12	0.33	0.10	0.31	0.11	0.31
2011	0.13	0.34	0.11	0.31	0.13	0.33	0.13	0.33
EST	0.50	0.50	0.50	0.50	0.50	0.50	0.49	0.50
CST	0.26	0.44	0.28	0.45	0.27	0.45	0.27	0.44
MST	0.06	0.24	0.06	0.23	0.07	0.26	0.07	0.25
PST	0.17	0.38	0.16	0.37	0.15	0.36	0.17	0.38
Age	45.95	17.73	46.20	17.01	46.41	17.50	46.62	17.49
Employed	0.63	0.48	0.63	0.48	0.61	0.49	0.62	0.49
Retired	0.15	0.36	0.15	0.36	0.17	0.37	0.16	0.37
Married	0.50	0.50	0.52	0.50	0.52	0.50	0.53	0.50
Elderly	0.17	0.37	0.16	0.37	0.18	0.38	0.18	0.38
Advance Degree	0.12	0.32	0.12	0.32	0.12	0.32	0.13	0.33
Kids Under 13	0.31	0.46	0.31	0.46	0.31	0.46	0.30	0.46
Number of Kids	0.89	1.14	0.94	1.19	0.87	1.15	0.91	1.19
Age of Youngest Child	3.63	5.31	3.57	5.24	3.60	5.31	3.55	5.22
Temperature	47.66	13.02	53.17	11.58	57.00	10.92	53.75	11.20
Precipitation	0.07	0.21	0.08	0.21	0.09	0.28	0.07	0.23
Observations	1881		2068		1984		2049	

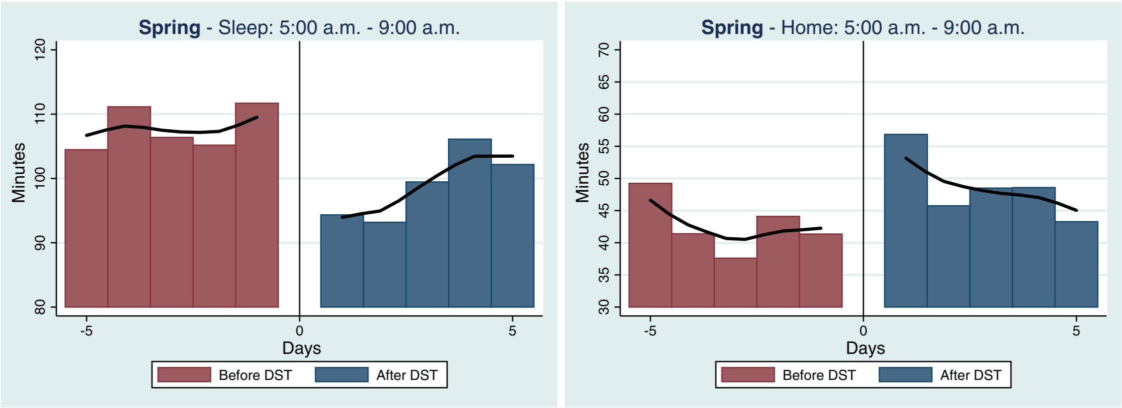
The estimated difference of −7.46 min is markedly larger than the next largest difference. Individuals also spend 4.62 more minutes at home after the DST transition in the spring. The effects of the fall DST to ST transition are typically smaller and less statistically significant. Individuals spend less time at home and more time away from home on DST in the fall, though this difference is not significant at conventional levels. At first glance, it seems that the largest effects of DST are felt in the morning. Because time diary dates are randomly assigned to individuals, the mean differences reported in Table 2 can be interpreted as average treatment effects.

5. Empirical approach

To investigate how individuals change their behavior in response to DST, we focus on activities that directly affect residential energy demand. DST changes the amount of sunlight in the morning and the evening, and at the margin is most likely to affect activities performed at those times. DST takes effect in the U.S. on a precise day and time each year. As a result, estimating the effect of the time change lends itself naturally to a regression discontinuity (RD) design. Sunrise and sunset times change continuously by 0–3 min per day, meaning that days just before the sharp, 1-h shift are otherwise similar. See Fig. 1 for a graphical representation of sunrise and sunset time around the DST shifts for individuals in our sample. The weather also tends to be similar for days on either side of the DST transition. The identifying assumption in this case is that in the absence of DST, the activity variables (sleep, home, and away) vary smoothly over time. This means that, for example, to the extent that time spent sleeping in the morning changes, it does so smoothly with the date. As a result any discrete changes in the variable can be attributed to DST.

In an effort to consistently estimate the treatment effect we estimate a parametric RD model, following Lee and Lemieux (2010). Given a DST date, and an ATUS interview date, Z, we can construct a running variable, z, that measures the time in days before and after the DST transition ($z = Z - \text{DSTdate}$). We define D to be a dummy variable that takes on a value of one on DST and zero on ST. A straightforward way of estimating the treatment effect is to run a pooled regression over the cutoff, and include an interaction term between D and the running variable z, thereby allowing the effect of the running variable to vary on either side of the discontinuity.

Figs. 2–10 suggest that either linear or quadratic functional forms in the running variable offer a reasonable approximation on either side of the discontinuity. We estimate a linear specification in the forcing variable z, which minimizes


(a)Sleep

(b)Home

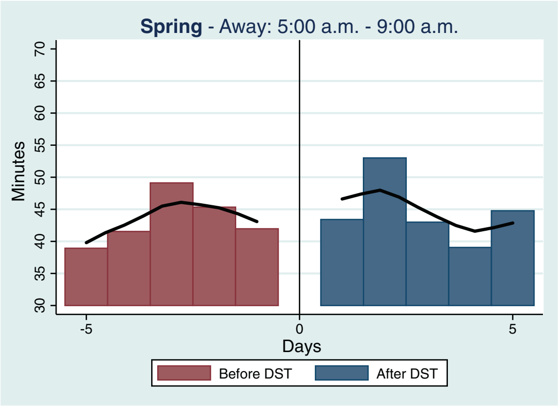
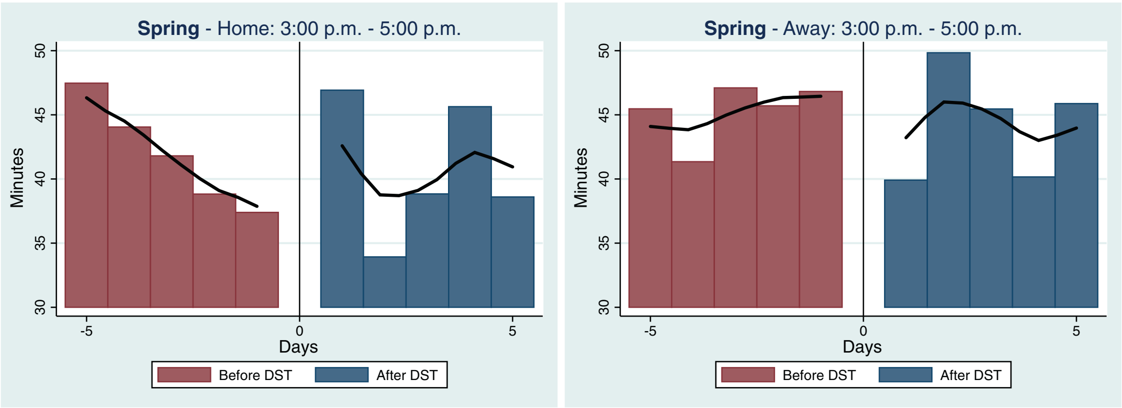

(c)Away

Fig. 2. Spring: 5 a.m. to 9 a.m.


(a)Home

(b)Away

Fig. 3. Spring: 3 p.m. to 5 p.m.

both Akaike's Information criterion and the Schwatz's Information criterion.[4] The resulting linear estimating equations are:

$$Y_i = \alpha_i + \tau \cdot D_i + \beta_1 \cdot z_i + \beta_3 \cdot D_i \cdot z_i + \gamma \cdot X_i + e_i, \tag{3}$$

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[4] Additional functional forms are discussed in the robustness section.

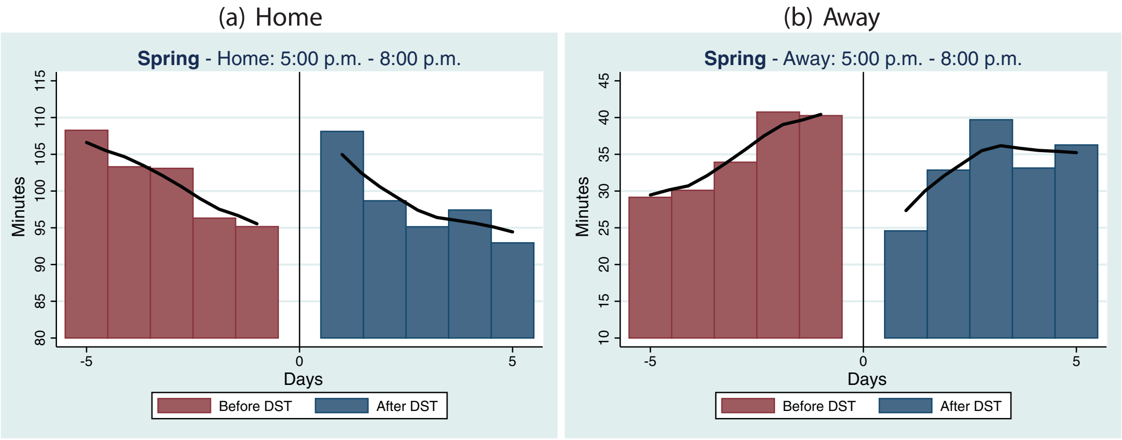
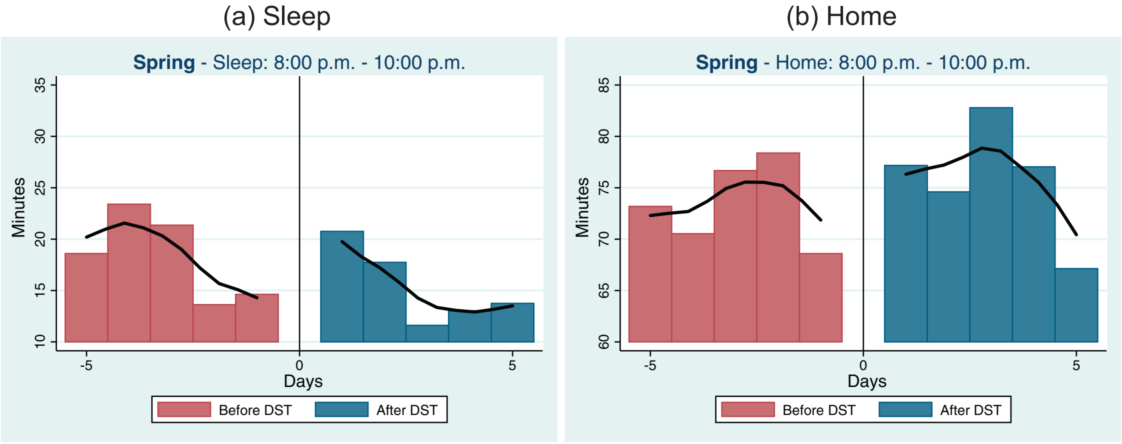

(a) Home (b) Away

Fig. 4. Spring: 5 p.m. to 8 p.m.


(a) Sleep (b) Home

(c) Away

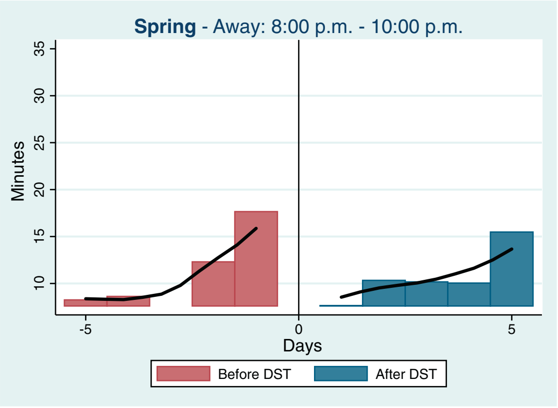
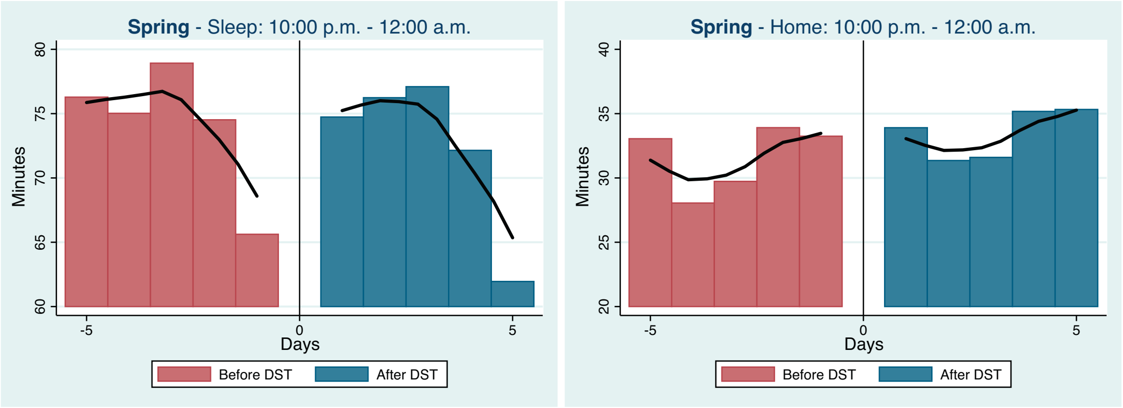


Fig. 5. Spring: 8 p.m. to 10 p.m.

where Y_i represents the minutes that ATUS respondent i spent in a given activity (sleep, home, away) in a given time period, and X_i includes demographic, household, and weather covariates such as age, employment status, presence of young children, and maximum temperature/precipitation. These covariates are included in the regressions to increase the precision of the RD estimator and to capture variation in activity patterns. For example, morning sleep patterns likely vary by age and


(a) Sleep (b) Home

(c) Away

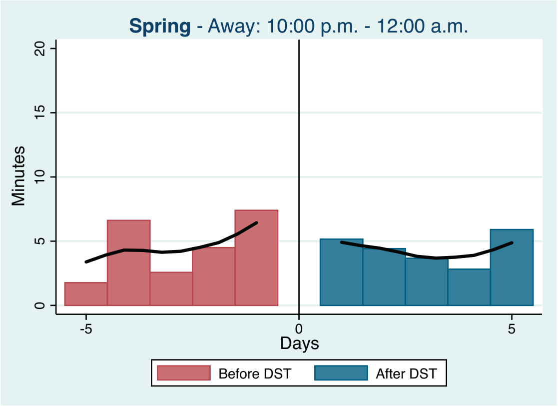


Fig. 6. Spring: 10 p.m. to 12 a.m.

employment status.[5] Some specifications also include year and month dummies to control for the 2006 policy changes that extended DST by three weeks in the spring and one week in the fall. The coefficient of interest in Eq. (3) is τ, which we will refer to as the RD coefficient.

We estimate the RD equations over a range of 5 days (excluding weekends) on either side of the DST transition. This is slightly smaller than the optimal bandwidth for a sharp design suggested by Imbens and Kalyanaraman (2009), but has the advantage of balancing the sample to contain the same set of weekdays on either side of the discontinuity.[6] One important caveat is that, given a single week before and after the DST transition, we cannot control for differences between individual days of the week, which may confound a day-of-week effect with a treatment effect.[7] We attempt to isolate these effects in Section 6. Finally, we also estimate a nonparametric local linear regression – including only day-of-week covariates – to check for robustness to the functional form assumption above. We estimate a model using a triangular kernel, where the optimal bandwidth is chosen according to Imbens and Kalyanaraman (2009).

Based on the findings of DST simulation models, we would expect to see little behavioral change by individuals. In other words, if people operate completely “off of the clock” with little regard to daylight, then we would expect that time use would not change when under DST. We do not find evidence consistent with this hypothesis. Our results show that on average the switch to DST in the spring (Table 4) causes individuals to *reduce* the time they spend sleeping in the morning and *increase* the time they spend at home in the morning. Similarly, the results suggest that on average individuals spend *less* time at home in the evening and more time away from home in the early afternoon in the spring on DST. Results for the effect of the fall DST change (Table 5) are generally smaller and less precisely estimated but also suggest that while on DST, individuals sleep less and are home more during the morning.

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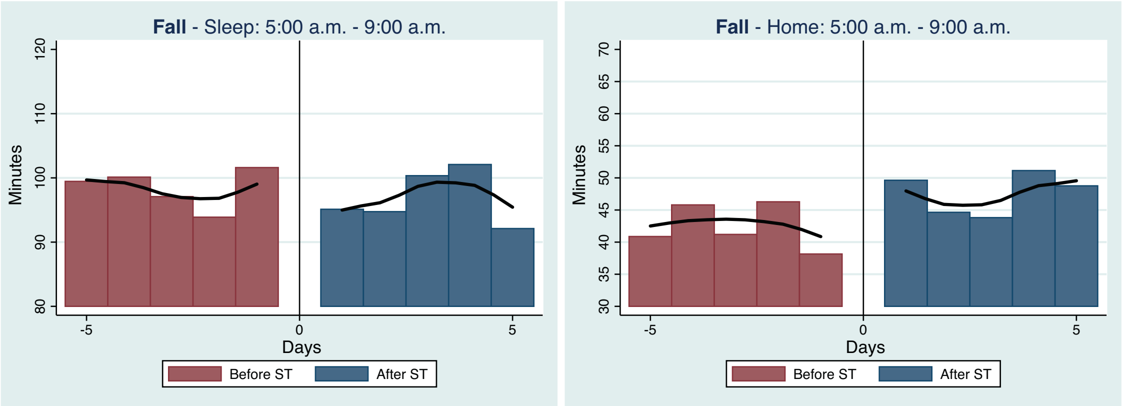
[5] Note that all equations were also estimated by residualizing the dependent variable. For this diagnostic check, a prediction of Y based on the baseline covariates X is subtracted from Y, and then RD regression is run using the residuals as the dependent variable. The sign and the significance of the treatment effect was robust to this method.

[6] Additional bandwidths were tested and are discussed in the robustness section.

[7] We thank Scott Holladay for emphasizing this point to us.


(a) Sleep (b) Home

(c) Away

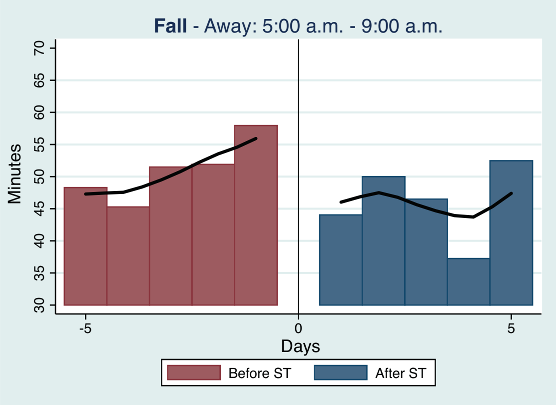


Fig. 7. Fall: 5 a.m. to 9 a.m.

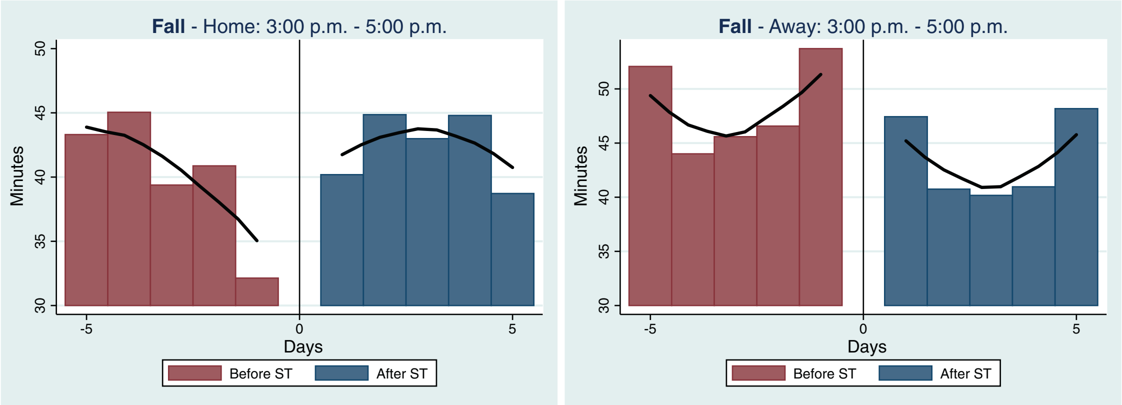
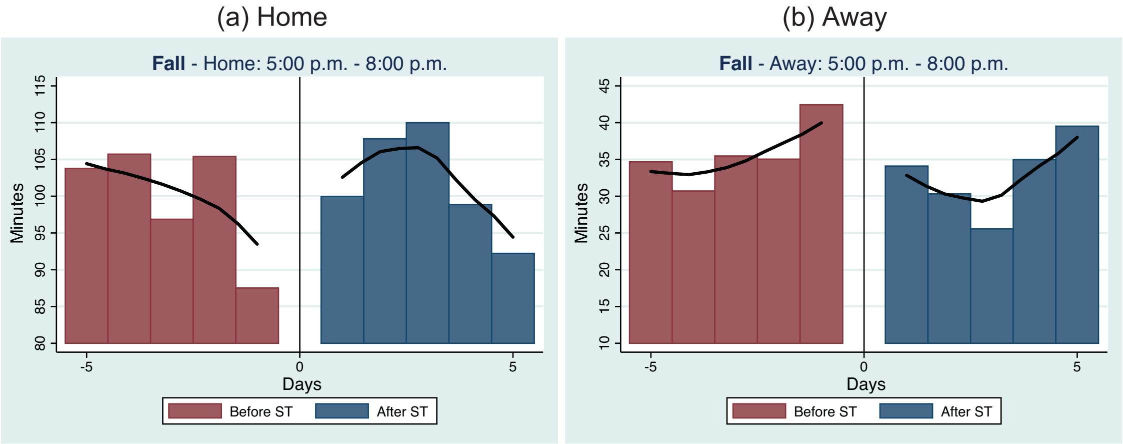

(a) Home (b) Away

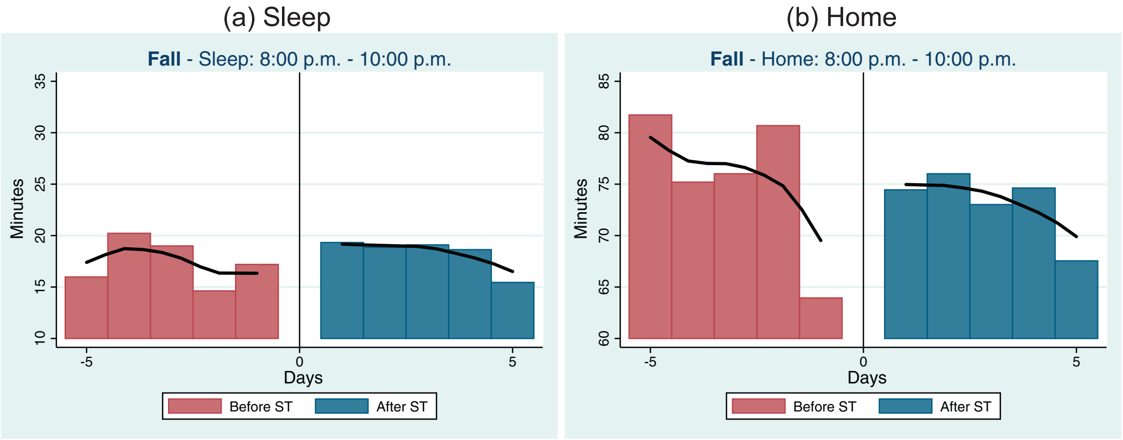
Fig. 8. Fall: 3 p.m. to 5 p.m.

Tables 4 and 5 report the estimates of the RD coefficient. Each row contains the estimates of the RD coefficient or jump in the dependent variable due to the DST transition for each of six different model specifications and thirteen distinct activity categories. Robust standard errors are reported in parentheses and significance is reported using stars (** 5% and * 10%). Specification A is a fully-nonparametric local-linear regression, where the bandwidth is estimated using the bandwidth recommended by Imbens and Kalyanaraman (2009). Model B is the linear parametric model described in Eq. (3) with no additional covariates. The remaining specifications add additional covariates; model *C* adds month and year dummies, model


(a) Home

(b) Away

Fig. 9. Fall: 5 p.m. to 8 p.m.


(a) Sleep

(b) Home

(c) Away

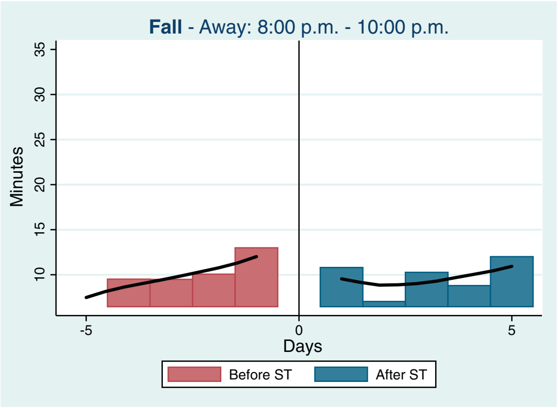
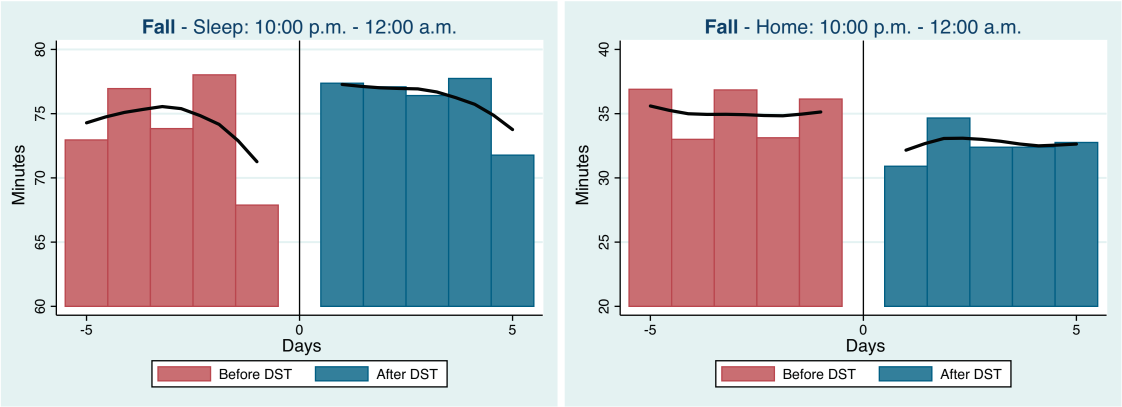
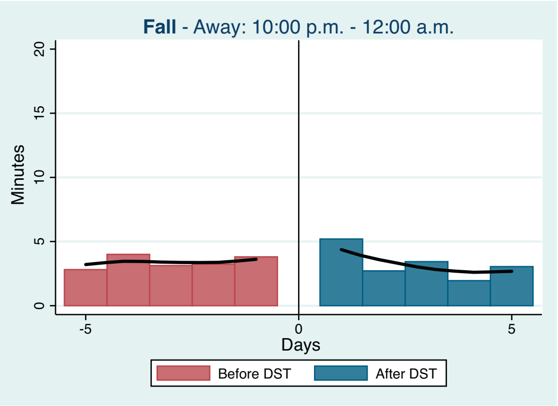


Fig. 10. Fall: 8 p.m. to 10 p.m.



(a) Sleep

(b) Home



(c) Away

Fig. 11. Fall: 10 p.m. to 12 a.m.

Table 2
Time in minutes: week before/after DST transition.

Time		Spring			Fall		
		DST	*ST*	*Diff*	*DST*	*ST*	*Diff*
5 a.m.–9 a.m.	Sleep	99.31	106.77	−7.46	97.72	96.47	1.25
		(75.68)	(75.28)	p 0.03	(72.66)	(72.82)	p 0.71
	Home	48.3	43.67	4.62	42.8	47.7	−4.9
		(58.13)	(54.25)	p 0.07	(51.90)	(55.46)	p 0.04
	Away	44.58	43.21	1.37	50.9	46.59	4.32
		(61.35)	(62.73)	p 0.63	(63.05)	(61.12)	p 0.12
3 p.m.–5 p.m.	Home	40.62	42.22	−1.6	40.29	42.05	−1.76
		(47.85)	(48.01)	p 0.46	(47.24)	(47.56)	p 0.41
	Away	44.7	44.76	−.06	47.92	43.55	4.37
		(50.4)	(50.8)	p 0.98	(51.21)	(49.45)	p 0.06
5 p.m.–8 p.m.	Home	98.31	100.68	−2.37	100.44	101.43	−.99
		(69.04)	(70.4)	p 0.46	(68.84)	(69.32)	p 0.75
	Away	33.61	35.23	−1.63	35.17	33.39	1.78
		(53.63)	(54.79)	p 0.51	(52.65)	(53.18)	p 0.46
8 p.m.–10 p.m.	Sleep	15.36	18.71	−3.35	17.61	18.48	−.87
		(31.85)	(33.94)	p 0.03	(33.17)	(33.39)	p 0.56
	Home	75.71	72.87	2.84	75.71	72.39	3.32
		(46.25)	(46.49)	p 0.18	(46.31)	(47.08)	p 0.12
	Away	10.8	11.08	−.27	9.53	10.12	−.59
		(29.15)	(30.02)	p 0.84	(27.29)	(28.34)	p 0.64
10 p.m.–12 a.m.	Sleep	72.26	74.4	−2.13	74.54	75.83	−1.3
		(47.07)	(46.99)	p 0.32	(47.09)	(46.36)	p 0.54
	Home	33.6	31.45	2.15	34.9	32.34	2.56
		(40.55)	(40.43)	p 0.24	(42.14)	(40.57)	p 0.17
	Away	4.34	4.63	−.28	3.29	3.72	−.42
		(19.95)	(20.44)	p 0.76	(16.74)	(18.49)	p 0.60

Table 3
Model description.

	Model description	
	Estimation approach	Control variables
A	Nonparametric Local Linear Regression	None
B	Linear Parametric Model	None
C	Linear Parametric Model	Month and Year
D	Linear Parametric Model	**C** and Demographic Variables
E	Linear Parametric Model	**D** and Time Zones and State Fixed Effects
F	Linear Parametric Model	**F** and Precipitation and Temperature

Table 4
Spring DST transition results: week before and week after.

	5 a.m. to 9 a.m.			3 p.m. to 5 p.m.		5 p.m. to 8 p.m.		8 p.m. to 10 p.m.			10 p.m. to 12 a.m.		
	Sleep	Home	Away	Home	Away	Home	Away	Sleep	Home	Away	Sleep	Home	Away
A	−17.71**	13.77*	1.97	9.49	−3.53	14.82*	−17.76**	7.69**	12.21	−13.00**	12.47**	−.81	−3.56
	(8.28)	(8.45)	(6.93)	(6.69)	(7.07)	(7.65)	(5.98)	(3.79)	(7.74)	(3.76)	(5.38)	(4.54)	(2.52)
B	−17.26**	15.38**	.75	7.39	−1.43	14.63*	−16.92**	6.23*	9.24*	−11.68**	12.92**	−.81	−3.69
	(8.20)	(6.38)	(6.79)	(6.79)	(5.57)	(7.61)	(5.92)	(3.67)	(5.11)	(3.41)	(3.41)	(4.5)	(2.42)
C	−16.77**	15.07**	.12	7.27	−1.95	14.86*	−17.27**	6.50*	8.88*	−11.73**	12.82**	−1.2	−3.56
	(8.21)	(6.39)	(6.81)	(5.28)	(5.57)	(7.66)	(5.93)	(3.66)	(5.12)	(3.42)	(5.19)	(4.5)	(2.43)
D	−17.63**	13.07**	2.44	5.2	.51	12.83*	−15.98**	6.37*	7.85	−11.11**	12.24**	−1.32	−3.21
	(7.78)	(6.07)	(6.3)	(4.71)	(4.99)	(7.18)	(5.7)	(3.64)	(4.99)	(3.35)	(5.11)	(4.45)	(2.41)
E	−19.55**	14.93**	2.1	5.28	.62	11.78*	−14.91**	6.3	8.15	−10.59**	12.57**	−1.62	−3.28
	(7.88)	(6.19)	(6.4)	(4.83)	(5.08)	(7.27)	(5.76)	(3.63)	(5.03)	(3.4)	(5.14)	(4.52)	(2.49)
F	−20.51**	18.73**	−.91	4.63	−.06	9.82	−10.96	4.22	10.08*	−9.10**	9.49*	1	−2.42
	(8.68)	(6.71)	(6.92)	(5.27)	(5.57)	(7.92)	(6.3)	(3.99)	(5.54)	(3.7)	(5.66)	(4.99)	(2.77)

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$.

D adds individual demographic controls[8], *E* adds time zone and state fixed effects, and *F* adds precipitation and temperature. Table 3 summarizes these specifications.

The first column of Table 4 shows the RD coefficients for the equations focused on the amount of time spent sleeping in the morning around the spring DST transition. The effect is negative and statistically significant across all specifications. Magnitudes, which are also broadly comparable across all specifications, suggest that that on average individuals sleep between 16 and 21 min less following the spring DST transition. Similarly, the positive and statistically significant coefficients in the second column suggest that, on average, individuals spend between 13 and 19 more minutes at home in the morning (5 a.m.–9 a.m.) following the spring DST transition. Combined, these results are consistent with recent empirical papers that find that DST leads to increased energy use in the mornings, and offer concrete evidence that Kellogg and Wolff's/Kotchen and Grant's critiques of previous simulation results are warranted.

We see that individuals spend more time at home, between 10 and 15 minutes, and less time away from home, between 11 and 18 min, in the early evenings. This is also true in the later evening when individuals spend between 4 and 8 more minutes asleep, 4–9 more minutes at home (though where significant, generally only at the 10% level) and fewer minutes away from home immediately following the spring DST transition. Results are broadly consistent across specifications in both signs and magnitudes. The broad picture that emerges is one of individuals waking up earlier in the morning and spending more time at home. The corresponding effect in the evening is broadly similar with individuals spending less time away from home and going to bed earlier, with a 9–13 min significant increase in time asleep between 10 p.m. and 12 a.m.

The discontinuity effects for the fall RD equations are reported in Table 5. Here, the RD coefficients reported are the estimates of the discontinuity that occurs due to the transition from DST back to ST. Results in Table 5 are somewhat less consistent than those in Table 4, and are typically smaller. The transition from DST back to ST has almost no significant impact on time use in the morning, save for an increase in time spent away from home in the morning, though significant only at the 10% level where significantly different from zero. The fall DST change seems to have a much larger impact during the 3–5 p.m. time than the spring DST transition, with individuals reporting between 10 and 17 fewer minutes at home. Further, individuals consistently report spending less time at home in the evenings, 7–16 min less between 5 and 8 p.m. and 8–16 min less at home between 8 and 10 p.m.

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[8] Specifically we include age, dummies for employment status, marital status, whether they are elderly, have and educational attainment. Reasoning from introspection, we also include information on the number of children in the household and the age of the youngest child.

Table 5
Fall DST transition results – week before and week after.

	5 a.m. to 9 a.m.			3 p.m. to 5 p.m.		5 p.m. to 8 p.m.		8 p.m. to 10 p.m.			10 p.m. to 12 a.m.		
	Sleep	Home	Away	Home	Away	Home	Away	Sleep	Home	Away	Sleep	Home	Away
A	3.42	−13.03*	12.38*	−9.38*	5.69	−15.34**	10.38	−5.23	−16.06**	4.42	−10.98	4.31	−1.46
	(7.95)	(7.65)	(7.04)	(5.02)	(5.42)	(7.70)	(6.02)	(3.63)	(7.46)	(3.18)	(6.90)	(5.91)	(2.00)
B	1.4	−5.52	12.36*	−9.62*	5.7	−16.6**	11.15	−5.21	−9.47*	4.73	−6.84	1.9	−1.32
	(7.78)	(5.82)	(6.79)	(5.00)	(5.41)	(7.44)	(5.84)	(3.55)	(5.02)	(3.09)	(5.09)	(4.47)	(1.95)
C	2.78	−7.04	11.86*	−8.29*	4.92	−15.57**	10.83	−5.29	−9.31*	5.15	−7.79	2.98	−1.09
	(7.98)	(5.91)	(6.88)	(5.09)	(5.49)	(7.61)	(5.98)	(3.67)	(5.12)	(3.15)	(5.14)	(4.53)	(1.95)
D	7.3	−4.13	6.54	−2.81	−1.25	−10.95	7.14	−5.06	−8.01	4.01*	−8.47*	4.42	−1.82
	(7.62)	(5.58)	(6.33)	(4.54)	(4.97)	(7.32)	(5.81)	(3.67)	(5.08)	(3.13)	(5.14)	(4.48)	(1.97)
E	9.55	−5.01	5.97	−3.58	−.68	−11.4	6.69	−5.16	−7.45	3.72*	−9.99*	6.26	−1.87
	(7.69)	(5.66)	(6.39)	(4.63)	(5.06)	(7.51)	(5.92)	(3.73)	(5.14)	(3.15)	(5.21)	(4.58)	(2.00)
F	9.56	−2.22	−.57	−6.96	−.42	−16.70**	8.73	−6.69	−13.51**	7.90*	−10.54*	4.46	−1.11
	(8.49)	(6.5)	(7.10)	(5.24)	(5.73)	(8.39)	(6.54)	(4.17)	(5.70)	(3.65)	(5.86)	(5.02)	(2.26)

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$.

Table 6
Spring DST transition results – two weeks before and two weeks after.

	5 a.m. to 9 a.m.			3 p.m. to 5 p.m.		5 p.m. to 8 p.m.		8 p.m. to 10 p.m.			10 p.m. to 12 a.m.		
	Sleep	Home	Away	Home	Away	Home	Away	Sleep	Home	Away	Sleep	Home	Away
A	−13.79**	10.26**	1.29	−.29	−.22	1.65	−8.45*	1.14	5.97*	−5.8**	1.99	2.42	−.88
	(5.83)	(4.34)	(4.87)	(3.94)	(3.93)	(5.81)	(4.81)	(4.09)	(3.58)	(2.79)	(4.43)	(3.11)	(1.59)
B	−15.15**	10.94**	1.81	−1.32	−1.28	1.74	−5.87	−4.07	6.37*	−2.61	−2.00	3.40	−.8
	(5.87)	(4.35)	(4.82)	(3.72)	(3.93)	(5.41)	(4.21)	(2.56)	(3.59)	(2.3)	(3.64)	(3.16)	(1.57)
C	−15.11**	12.10**	.19	−1.1	−1.43	2.95	−6.8	−3.8	7.1**	−3.31	−1.29	3.6	−1.36
	(5.98)	(4.41)	(4.92)	(3.80)	(4.00)	(5.51)	(4.26)	(2.61)	(3.67)	(2.35)	(3.71)	(3.23)	(1.61)
D	−17.05**	8.40**	4.7	−4.94	2.58	−1.29	−4.12	−3.94	5.39	−2.25	−1.88	3.1	−.8
	(5.67)	(4.14)	(4.55)	(3.40)	(3.57)	(5.21)	(4.09)	(2.60)	(3.6)	(2.31)	(3.68)	(3.21)	(1.59)
E	−17.00**	9.08**	4.32	−4.82	2.66	−.39	−4.35	−3.62	5.4	−2.18	−1.25	2.5	−.96
	(5.7)	(4.15)	(4.57)	(3.43)	(3.61)	(5.28)	(4.14)	(2.58)	(3.61)	(2.34)	(3.69)	(3.23)	(1.61)
F	−18.21**	10.84**	4.11	−3.61	3.87	−.08	−1.95	−4.99	5.27	−.96	−3.11	3.88	−.42
	(6.21)	(4.51)	(4.92)	(3.71)	(3.9)	(5.73)	(4.52)	(2.77)	(3.92)	(2.54)	(4.01)	(3.51)	(1.74)

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$.

6. Robustness

We now report additional results to explore whether our findings are robust to changes in our RD design choices. First, we extend the estimation window to two weeks (as before weekdays only) on either side of the ST/DST transition. Second, we conduct placebo tests. Finally, we tackle our research question using a differences-in-differences model that leverages the natural experiment provided by the 2007 shift of the DST start and end dates.

6.1. Robustness: two week window

In addition to being a standard robustness test for RD designs, extending the estimation window has the additional advantage of allowing us to control for day of week effects (DOW_i) to avoid confounding a DST effect with a day-of-week effect, i.e. in the limit, results are identified by comparing the last day of the period before the DST shift, a Friday, with the first day after the switch, a Monday. Day of week dummies control for the fact that scheduling may vary between say a Monday and a Friday. In order to preserve comparability with results presented earlier we again estimate a model linear in the running variable z_i, which as before is allowed to behave differently on either side of the discontinuity.[9] This yields an updated version of (3),

$$Y_i = \alpha_i + \tau \cdot D_i + \beta_1 \cdot z_i + \beta_2 \cdot D_i \cdot z_i + \delta \cdot \mathrm{DOW} + \gamma \cdot X_i + e_i. \tag{4}$$

As before, we estimate (4) for six model specifications, all of which include day-of-week dummy variables for 13 different time period/activity outcomes. Results for the spring transition are presented in Table 6 and results for the fall transition are presented in Table 7.

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[9] Our main results are robust to estimating the model using a quadratic/cubic/quartic polynomial on either side of the discontinuity.

Table 7
Fall DST transition results – two weeks before and two weeks after.

	5 a.m. to 9 a.m.			3 p.m. to 5 p.m.		5 p.m. to 8 p.m.		8 p.m. to 10 p.m.			10 p.m. to 12 a.m.		
	Sleep	Home	Away	Home	Away	Home	Away	Sleep	Home	Away	Sleep	Home	Away
A	.74	−6.45*	7.81*	−5.4	8.6**	−2.09	2.32	.34	12.09	−2.03	1.26	.77	−.87
	(5.22)	(3.83)	(4.48)	(3.38)	(3.60)	(4.99)	(3.80)	(2.44)	(8.92)	(2.03)	(5.22)	(2.98)	(1.27)
B	6.05	1.70	3.00	−6.22	3.61	−.81	2.60	1.00	6.14	−4.63	7.10	−1.62	−4.63*
	(9.88)	(7.41)	(8.53)	(6.26)	(6.76)	(9.35)	(7.23)	(4.31)	(6.32)	(3.98)	(6.46)	(5.74)	(2.54)
C	6.58	1.69	2.51	−6.02	3.24	−.62	2.52	1.13	6.03	−4.58	7.15	−1.72	−4.49*
	(9.88)	(7.39)	(8.52)	(6.26)	(6.77)	(9.37)	(7.24)	(4.31)	(6.34)	(3.98)	(6.44)	(5.72)	(2.54)
D	14.04	3.79	−4.13	.6	−4.17	4.24	−1.29	1.25	6.64	−5.36	5.65	.20	−5.04**
	(9.43)	(6.89)	(7.83)	(5.57)	(6.12)	(8.96)	(7.02)	(4.29)	(6.24)	(3.93)	(6.38)	(5.64)	(2.53)
E	16.7*	2.83	−4.33	.10	−3.25	4.06	−2.10	.96	6.78	−5.50	4.26	1.56	−4.85*
	(9.47)	(6.91)	(7.87)	(5.63)	(6.15)	(9.05)	(7.06)	(4.31)	(6.27)	(3.97)	(6.40)	(5.66)	(2.55)
F	18.3*	6.35	−11.39	−3.66	−1.90	−5.48	−.79	−1.40	1.97	−2.76	1.29	.64	−3.72*
	(10.23)	(7.68)	(8.58)	(6.20)	(6.79)	(9.92)	(7.70)	(4.70)	(6.80)	(4.46)	(7.01)	(6.14)	(2.77)

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$.

We find similar results for changes in time spent sleeping between 5 a.m. and 9 a.m., a significant reduction of between 14 and 18 min. Further, individuals increase time at home between 9 and 12 min after the DST transition. In general, the magnitudes of the RD coefficients are smaller with the two-week window as compared to the one-week window. This is particularly true for the fall DST results, where results are generally small and not statistically significant at conventional levels. The fact that sunrise and sunset times change naturally over this period – between roughly a minute and a half (Miami, FL) and three minutes (Minneapolis, MN) – exacerbates the natural bias in RD designs towards zero as the estimation window is expanded.

We also explore the sensitivity of our results to the interaction of the DST dummy and the DOW dummy. While day by DST interactions are less precisely estimated, they tell a similar story. In particular, in the mornings individuals spend less time sleeping after and more time at home the spring DST transition. Note that any non-zero coefficients across *any* day of the week would violate the assumptions found in most engineering models.[10]

Our main specification uses a range of five weekdays on each side of the DST transition, slightly smaller than that recommended of Imbens and Kalyanaraman (2009). As a robustness check, in addition to the wider window just described, we also estimate the equations using an estimation window of four weekdays (excluding Fridays before and after the time change). The signs of the estimated discontinuities were consistent across window choices; however, the results were somewhat less significant with the smaller window.

6.2. *Robustness: placebo*

We run standard falsification checks for our main specification by using the same RD approach but substituting arbitrary dates for the DST transition. Specifically, for the years 2003–2006 we used the dates of the newest DST policy (2nd Sunday in March and 1st Sunday in November), and for the years 2007–2011 we used DST dates from the original policy (1st Sunday in April and last Sunday in October). Under the assumptions of the RD model, we should not find discontinuities in time use at these alternate cutoff dates. The estimated RD coefficients are insignificant for all equations.

6.3. *Robustness: differences-in-differences*

An alternative method of estimating the behavioral effects of DST would be to take advantage of the policy change that occurred after 2006. For all subsequent years the DST transition occurred 3 weeks earlier in the spring (second Sunday in March) and 1 week later in the fall (first Sunday in November). This means that our data set can be divided into two groups – (1) observations occurring between 2003 and 2006 and (2) observations occurring between 2007 and 2011. For the spring transition we focus on observations occurring in either the week immediately before the second Sunday in March or the week immediately after.[11] By limiting the data set in this way we know that those observations in group 1 (2003–2006) were not exposed to DST in either week and those observations in group 2 (2007–2011) were exposed to DST in the second week, but not the first. Thus we can calculate the effect of DST by subtracting the average change in the activity variable, such as sleep, for the first (control) group from the average change for the second (treatment) group. This difference-in-differences (DID) method removes biases in second period comparisons between the treatment and control group that could be the result of permanent differences between those groups, as well as biases from comparisons over time in the treatment group that

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[10] Thanks to a referee for underlining this point.

[11] The spring DST transition was moved ahead by three weeks, and thus we tested larger date ranges. The signs of the coefficients of interest were robust to all specifications.

Table 8
Spring DID: DST transition results.

	5 a.m. – 9 a.m.			3 p.m. – 5 p.m.		5 p.m. – 8 p.m.	
	Sleep	Home	Away	Home	Away	Home	Away
Group 2 (2007–2011)	8.16	1.06	−5.92	3.02	0.37	5.51	-7.04^{*}
	(5.51)	(4.18)	(4.37)	(3.43)	(3.53)	(5.03)	(3.98)
Treatment – DST	13.22	−7.71	−2.86	4.10	−1.74	8.31	−1.60
	(8.82)	(6.21)	(6.94)	(5.39)	(5.55)	(7.81)	(5.97)
Group 2 × Treatment	-17.95^{**}	1.96	8.20	-8.61^{**}	0.95	−9.48	4.94
	(7.07)	(5.34)	(5.67)	(4.36)	(4.54)	(6.52)	(5.12)
Observations	1729	1729	1729	1729	1729	1729	1729
R^2	0.146	0.170	0.189	0.234	0.244	0.149	0.095

	8 p.m. – 10 p.m.			10 p.m. – 12 a.m.		
	Sleep	Home	Away	Sleep	Home	Away
Group 2 (2007–2011)	1.57	3.77	−3.17	1.92	0.65	−1.38
	(2.80)	(3.67)	(2.41)	(3.64)	(3.10)	(1.76)
Treatment – DST	−0.62	7.20	−1.16	−6.52	6.40	−0.42
	(4.24)	(5.56)	(3.69)	(5.51)	(4.75)	(2.52)
Group 2 × Treatment	−4.27	−0.32	2.19	−3.28	0.28	1.00
	(3.52)	(4.63)	(3.02)	(4.65)	(3.97)	(2.19)
Observations	1729	1729	1729	1729	1729	1729
R^2	0.065	0.088	0.068	0.082	0.055	0.062

Standard errors in parentheses.
$^{*}p < 0.10$, $^{**}p < 0.05$.

could be the result of changes in sunrise time. A limitation is that we reduce the number of observed DST to ST transitions from 9 to 5, as the period 2003–2006 is reserved as a control period. Because of the smaller number of transitions, we would expect these results to be somewhat less precise.

The DID results serve as a robustness and credibility check for the results previously discussed (Lee and Lemieux, 2010). In addition, the DID approach allows a more direct comparison with the most closely related studies, Kellogg and Wolff (2008) and Kotchen and Grant (2011). For the spring DST transition, we estimate:

$$Y_i = \beta_0 + \beta_1 W_{2i} + \beta_2 T_i + \beta_3 W_{2i} T_i + \gamma \cdot X_i + e_i,$$

where Y_i is the number of minutes spent in the activity of interest. W_{2i} is a dummy variable that equals one for all ATUS responses that occurred in the week after the second Sunday in March between 2007 and 2010 and zero otherwise. T_i is a dummy variable for the treatment group (i.e. group 2) and captures any differences between group 1 and group 2 outside of the DST policy change that would affect Y_i. Finally, X_i is a matrix of other covariates identical to those used in the RD regressions, specifically Model F. The DID estimate of the treatment effect (i.e., exposure to DST) is β_3, the coefficient on the interaction term between W_2 and T.

Similarly, for the fall transition we can narrow the analysis to observations falling in the week on either side of the first Sunday in November. By focusing on these two weeks of observations we know that those observations in group 1 will again act as the control group, because they were not exposed to DST in either week. Similar to the spring transition, the observations in group 2 (2007–2011) will represent the treatment group because they will be exposed to DST in the first week, but not in the second. Thus, the fall differences in differences estimating equation is:

$$Y_i = \beta_0 + \beta_1 W_{1i} + \beta_2 T_i + \beta_3 W_{1i} T + \gamma \cdot X_i + e_i,$$

where the only difference from the spring equation is that here we are interested in measuring the effect of being in the treatment group and in the earlier week (week 1) because in the fall we transition *off* of DST. Thus the coefficient of interest, β_3, is on the interaction term between W1 and T.

The DID estimates of the DST treatment effects are presented in Tables 8 and 9 respectively. The DID estimates of the treatment effect are given in the third row. The point estimate for the reduction in minutes of sleeping between 5 a.m. and 9 a.m. in spring – 17.95 – is directly comparable to the RD estimates. However, few other results are significant at conventional levels. This is expected given that we only observe treatment responses for observations in 2007–2011, as apposed to the RD methodology that uses treatment responses over the full 9 years. The fall results are generally not significant with the exception of time at home between 8 p.m. and 10 p.m. The reported coefficient is also comparable to earlier RD coefficients, though it is not significantly different from zero. In sum, these DID coefficients increase our confidence in the main finding that individuals sleep less in the morning after the spring DST transition.

Table 9
Fall DID: DST transition results.

	5 a.m. – 9 a.m.			3 p.m. – 5 p.m.		5 p.m. – 8 p.m.	
	Sleep	Home	Away	Home	Away	Home	Away
Group 2 (2007–2011)	0.59	−6.13	3.50	1.92	−0.84	0.14	2.44
	(5.10)	(3.74)	(4.11)	(3.26)	(3.26)	(4.91)	(3.89)
Treatment – DST	−1.42	−6.36	0.74	−5.07	8.50**	−11.13*	7.86
	(7.26)	(5.37)	(5.82)	(4.48)	(4.33)	(6.59)	(4.97)
Group 2 × Treatment	2.16	−1.79	3.25	−2.25	1.79	−2.61	2.38
	(6.30)	(4.72)	(5.18)	(3.91)	(4.01)	(5.99)	(4.65)
Observations	2015	2015	2015	2015	2015	2015	2015
R^2	0.143	0.154	0.201	0.220	0.253	0.120	0.116

	8 p.m. – 10 p.m.			10 p.m. – 12 a.m.		
	Sleep	Home	Away	Sleep	Home	Away
Group 2 (2007–2011)	0.18	−4.95	2.39	−0.81	2.71	−0.67
	(2.42)	(3.46)	(2.13)	(3.52)	(3.03)	(1.42)
Treatment – DST	5.32	−11.99**	1.39	8.79*	−7.29*	−2.95
	(3.44)	(4.65)	(2.77)	(4.61)	(4.09)	(2.17)
Group 2 × Treatment	−0.56	8.99**	−3.37	−1.81	0.68	0.56
	(3.01)	(4.15)	(2.44)	(4.21)	(3.66)	(1.70)
Observations	2015	2015	2015	2015	2015	2015
R^2	0.049	0.066	0.067	0.051	0.063	0.058

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$.

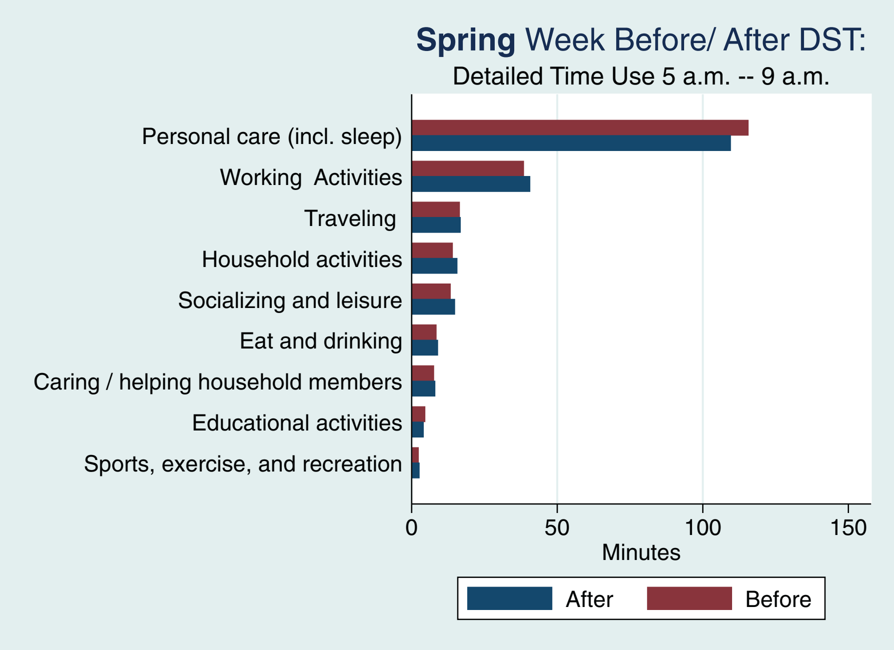

Fig. 12. Detailed time use.

7. Detailed activities

The result that is consistent across specifications and estimation approaches is a 15–20 min reduction in sleep between 5 a.m. and 9 a.m. in the week after the ST to DST switch. We now briefly explore time use in more detailed activities during this time period, to better understand the specific behavioral changes in activities that might explain our results. Fig. 12 shows the share of time by activity for the week before and after the spring DST transition.

The largest piece of the pie is spent in “Personal Care”, which includes sleeping. The decrease in “Personal Care” is offset by roughly proportionate increases in “Household Activities” – which includes cleaning, laundry, and food preparation – “Work Related Activities” – which includes working in primary or secondary jobs or in other income generating activity –, and

"Socializing and leisure" – which includes socializing and communicating, relaxing and leisure, and watching television. Note however that these differences are not significantly different at conventional levels. Decreased time asleep and increased time spent in home production provides further support for previous work that finds an increase in energy use after the Spring DST transition.

8. Discussion and conclusion

The results presented above provide modest evidence of several significant behavioral changes that occur as a result of DST. Before we consider how these changes may affect energy demand, we first set out the generally accepted changes in energy use caused by shifting sunlight forward by one hour. First, DST causes the sun to rise one hour later, meaning that mornings are darker and cooler than they would be on ST. During the cooler months in the spring and fall especially, this may cause individuals to use more lighting and heating electricity regardless of behavioral/time-use adjustments. Similarly, DST will cause the late afternoons and early evenings to be warmer and brighter. This should reduce lighting and electricity use, but will likely lead to increased air conditioning use, making it hard to establish the true effect on afternoon/evening energy demand. Most simulation models suggest that the afternoon energy savings more than offsets the increased use in the morning, making DST an energy-reducing policy. However, one cannot accurately draw such conclusions without information on how behaviors change on DST.

Fortunately, the results from our analysis can provide some of the additional detail needed. First, we find that individuals sleep less in the morning and spend more time awake at home following the spring DST transition. Using the results from the spring RD estimation we see that on average individuals sleep for 15–20 min less and spend most of that extra time awake and at home. This will encourage additional use of both lighting and heating energy during that – colder and darker – period. This result adds context to the recent empirical studies that have looked at energy demand in the morning on DST (Kellogg and Wolff, 2008). The spring RD results also suggest that on average DST causes individuals to spend less time at home in the afternoon/evenings, which would result in reduced residential electricity demand. Thus, although DST has mixed effects on energy use when at home, our results seem to suggest that decreases in energy use in the evening may be the result of less time spent at home. Shifts in time use during afternoon and evening are similar in magnitude but are less robust to variations in specification, suggesting that afternoon energy savings do not necessarily outweigh the morning increases in demand. If the increase in energy demand in the mornings combined with the increase in time spent at home outweighs savings from spending more time away from home, then DST will cause an increase in overall residential energy demand.

Although these results do not provide clear answers to the effectiveness of DST policies they do provide important insights. They suggest that the DST time shift causes individuals to get up earlier in the morning and spending the additional time at home. This shift towards morning chores was not predicted by simulation studies and provides insight into the discrepancies between the predicted energy savings and the realized savings. Are the changes in time use induced by DST large enough to explain differences between predicted savings of 0.5% and 3% and empirical findings of no savings or increased energy use? Our key finding of twenty minutes less sleep represents about an 8.3% percent reduction in sleep over the morning between 5 a.m. and 9 a.m. Between 15% and 20% of total electricity consumption occurs between 5 a.m. and 9 a.m. (though this varies by time of year and by Independent System Operator (ISO)[12]). Finally, 37% of electricity consumption is residential energy consumption.[13] A back of the envelope calculation suggests that our results are consistent with an increase in energy usage of between 0.46% and 0.61%, or approximately enough to offset the lower bound of the estimated savings, but perhaps not by enough to explain increased energy consumption.

Although these data did not provide significant evidence that the effects of the program vary geographically, it seems likely that the behavioral effects we found would change with latitude. Sunrise (and thus DST) varies with latitude and we clearly established that individuals do respond to changes in sunlight. Morning and afternoon temperatures also vary geographically, which would affect heating and air conditioning usage. Thus, future DST studies should investigate how shifts in energy demand during the different parts of the day vary by latitude. It might be that DST is effective as an energy-conservation tool in certain regions and not others.

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[12] These figures are for the New England ISO, for the week around the spring DST transition in 2013.

[13] http://www.eia.gov/electricity/annual/html/epa_02_02.html.

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