**Online Appendix for "Spring Forward at Your Own Risk: Daylight Saving Time and Fatal Vehicle Crashes" by Austin C. Smith**

This appendix proceeds in three sections. First, I provide additional descriptive information using the FARS crash data. Second, I present additional robustness checks for the central results, much of which is discussed within the main text. Finally, I explore whether the DST effect varies by region.

## Data Descriptives

As discussed in the introduction, much of the previous work on the impact of DST on fatal vehicle crashes has focused on the ambient light mechanism. Studies that find a net reduction in crashes through this channel suggest that the benefit from adding ambient light to a higher frequency crash period (the evening) outweigh the cost from removing ambient light from a lower frequency crash period (the morning) (Ferguson et al., 1995; Broughton, Hazelton and Stone, 1999; Coate and Markowitz, 2004). The figure below illustrates the daily profile of crashes throughout the day, showing that crashes are indeed more frequent in the evenings.

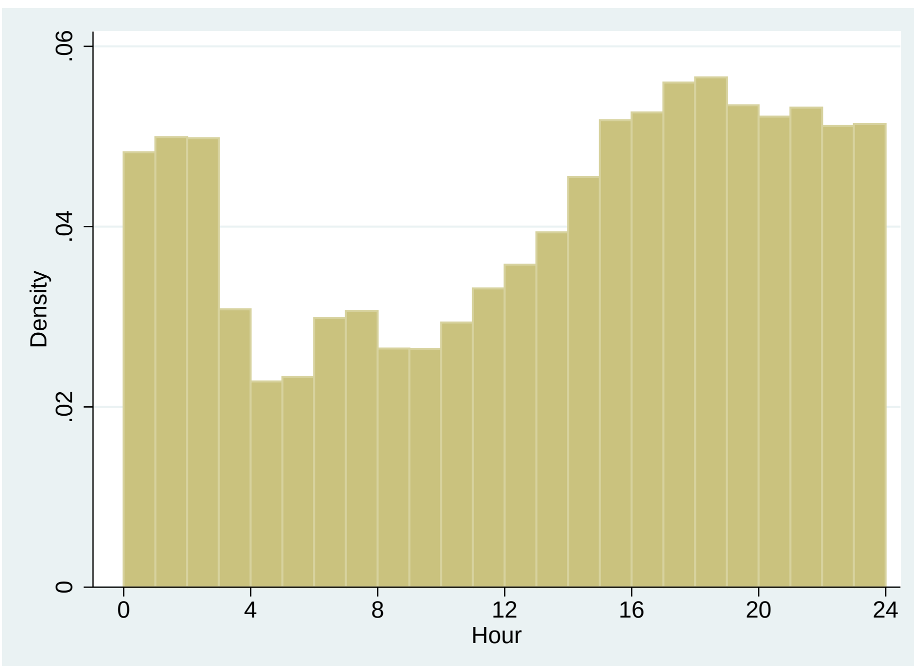


Figure A-1. : Daily Profile of Fatal Crashes

*Note:* Histogram uses all fatal crashes from 2002-2011 in the contiguous US except Arizona and Indiana.

Table A-1 provides suggestive evidence of a discontinuity in the raw crash data. Crashes during the first week of DST are significantly higher than during the previous week. However, due to seasonal trends a more appropriate comparison is seen in the final two columns. They compare the 1st week of DST with the average of the weeks before and after (or two weeks before and after). In both cases the crash count for the 1st week of DST is higher (by 4.9 percent and 6.1 percent) but the difference is not significant at conventional levels. The magnitude of these results are consistent with the findings of both regression models. Similarly the near zero change found by these models for the fall transition is echoed in Panel B.

Table A-1—: T-tests for equal means

| Panel A: Spring Transition | | | | | |
|---|---|---|---|---|---|
| | 1st Week of DST | Week Prior | Week After | Week before and after | 2 weeks before and after |
| Mean Fatal Crash Count | 89.33 | 83.17 | 87.17 | 85.17 | 84.16 |
| P-value of T-test for equal means relative to 1st week of DST | N/A | 0.087 | 0.552 | 0.1811 | 0.107 |
| Observations | 70 | 70 | 70 | 140 | 140 |

| Panel B: Fall Transition | | | | | |
|---|---|---|---|---|---|
| | 1st Week of Standard Time | Week Prior | Week After | Week before and after | 2 weeks before and after |
| Mean Fatal Crash Count | 94.79 | 94.73 | 94.83 | 94.78 | 94.086 |
| P-value of T-test for equal means relative to 1st week of Standard Time | N/A | 0.988 | 0.991 | 0.998 | 0.821 |
| Observations | 70 | 70 | 70 | 140 | 140 |

*Source:* Authors' calculations

## Robustness Checks

The Figures and Tables provided here complement the analysis in the main text.

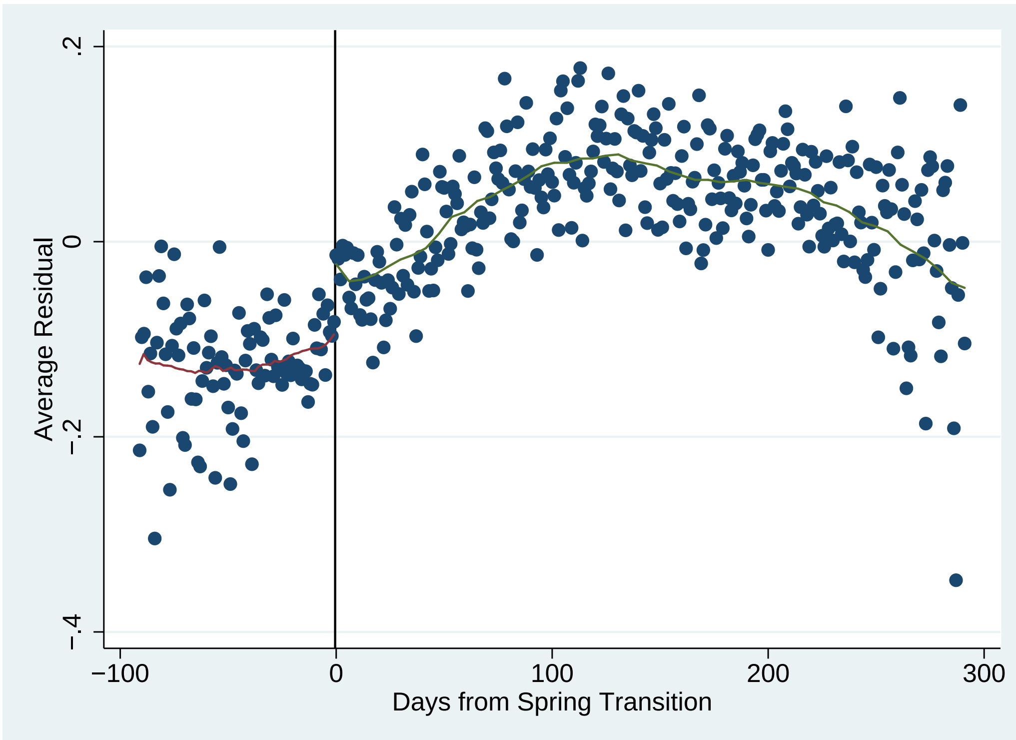


Figure B-1. : Spring Residual Plot

*Notes:* The residuals are generated from a regression of ln(fatal crash count) on day-of-week and year dummies. Each point is the average of all residuals for that date relative to the spring transition. Fitted lines are results of locally weighted regression. Greater variability on the ends is largely due to these average residuals being formed by only 5 observations rather than 10 towards the middle. This is a product of the 2007 DST extension; in 2002-2006 there are about 14 weeks before the spring transition but in 2007-2011 about 11.

Table B-1—: RD estimates of the impact of entering DST on fatal crashes – standard error robustness

| | | Clustering | | Newey West | | | |
|---|---|---|---|---|---|---|---|
| | Base | Week | Day-of-Year | 1-day lag | 3-day lag | 7-day lag | CCT Correction |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **DST** | 0.0649*** | 0.0649*** | 0.0649** | 0.0649*** | 0.0649*** | 0.0649*** | 0.0718*** |
| | (0.0233) | (0.0220) | (0.0264) | (0.0245) | (0.0250) | (0.0227) | (0.0262) |
| BW Selector | CCT | CCT | CCT | CCT | CCT | CCT | CCT |
| Observations | 550 | 550 | 550 | 550 | 550 | 550 | 550 |

Dependent Var: Log fatal crashes demeaned by day-of-week and year. All specs use a first order polynomial, a uniform kernel, and the bandwidth selector of Calonico, Cattaneo, and Titiunik (2014). DST is the estimate of the discontinuity in fatal crashes that occurs immediately following the spring transition. CCT Correction uses the bias correction and robust confidence intervals outlined in Calonico, Cattaneo, and Titiunik (2014).

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.
Source: Authors' calculations

Table B-2—: RD estimates of the impact of entering DST on fatal crashes – additional robustness

| | Alternative Kernels | | | 24/23rds | No Trans |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| **DST** | 0.0649*** | 0.0648*** | 0.0649*** | 0.0611*** | 0.0598** |
| | (0.0231) | (0.0227) | (0.0228) | (0.0226) | (0.0232) |
| Kernel | Uni | Tri | Epa | Uni | Uni |
| Observations | 550 | 710 | 650 | 570 | 580 |

Dependent Var: Log fatal crashes demeaned by day-of-week and year. All specs use a first order polynomial and the bandwidth selector of Calonico, Cattaneo, and Titiunik (2014). DST is the estimate of the discontinuity in fatal crashes that occurs immediately following the spring transition. Uni refers to a uniform kernel; Tri refers to a triangular kernel; Epa refers to an Epanechnikov kernel. 24/23rds is an alternative correction for the spring transition date where the crash count is weighted as 24/23rds. No Trans drops the spring transition date from the sample. Robust standard errors in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.
Source: Authors' calculations

Table B-3—: Global Polynomial RD estimates of the impact of leaving DST on fatal crashes

| | Alternate Polynomials | | | | Alternate Bandwidths | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **DST** | 0.0761** | 0.0798*** | 0.0624* | 0.0764*** | 0.0746* | 0.0556*** |
| | (0.0300) | (0.0302) | (0.0365) | (0.0295) | (0.0432) | (0.0214) |
| ln(GasPrice) | | | | -0.0629*** | | |
| | | | | (0.0174) | | |
| Bandwidth in Days | 30 | 30 | 30 | 30 | 15 | 60 |
| Polynomial Order | 4 | 3 | 5 | 4 | 4 | 4 |
| Observations | 610 | 610 | 610 | 610 | 310 | 1,185 |

Dependent Var: Log fatal crashes demeaned by day-of-week and year. DST is the estimate of the discontinuity in fatal crashes that occurs immediately following the spring transition. Bandwidth is the number of days used on each side of the transition. Robust standard errors in parentheses.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Source: Authors' calculations

Table B-4—: RD estimates of the impact of leaving DST on fatal crashes – additional robustness

| | Alternative Kernels | | | 24/25ths | No Trans |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| **Leaving DST** | 0.00114 | 0.0108 | 0.0124 | 0.00708 | 0.00925 |
| | (0.0236) | (0.0214) | (0.0217) | (0.0235) | (0.0243) |
| Kernel | Uni | Tri | Epa | Uni | Uni |
| Observations | 381 | 527 | 482 | 381 | 371 |

Dependent Var: Log fatal crashes demeaned by day-of-week and year. All specs use a first order polynomial and the bandwidth selector of Calonico, Cattaneo, and Titiunik (2014). Leaving DST is the estimate of the discontinuity in fatal crashes that occurs immediately following the fall transition out of DST. Uni refers to a uniform kernel; Tri refers to a triangular kernel; Epa refers to an Epanechnikov kernel. 24/25ths is an alternative correction for the fall transition date where the crash count is weighted as 24/25ths. No Trans drops the fall transition date from the sample. Robust standard errors in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Source: Authors' calculations

Table B-5—: RD estimates of fall placebo test – additional robustness

| | (1) | (2) | (3) |
|---|---|---|---|
| **Leaving DST** | 0.0361* | -0.00483 | 0.0234 |
| | (0.0218) | (0.0150) | (0.0228) |
| Bandwidth Selector | CCT | IK | CV |
| Observations | 381 | 850 | 347 |

Dependent Var: Log fatal crashes demeaned by day-of-week and year. All specifications use a first order polynomial and a uniform kernel. Placebo assigns the current November transition date to 2002-2006 data and the old October transition date to the 2007-2011 data. CCT refers to the bandwidth selector of Calonico, Cattaneo, and Titiunik (2014); IK is Imbens and Kalyanaraman (2012); CV is the cross-validation method of Ludwig and Miller (2007). Robust standard errors in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Source: Authors' calculations

Table B-6—: Simultaneous estimates of spring and fall effects

| | (1) | (2) | (3) |
|---|---|---|---|
| DST | 0.0649*** | 0.0499*** | 0.0626*** |
| | (0.0234) | (0.0178) | (0.0217) |
| Leaving DST | 0.00114 | -0.000182 | 0.00630 |
| | (0.0234) | (0.0152) | (0.0241) |
| Bandwidth Selector | CCT | IK | CV |
| Observations | 931 | 1,816 | 1,017 |
| p-value for test of equal and opposite effects between DST and Leaving DST | 0.0462 | 0.0337 | 0.0340 |

Dependent Var: Log fatal crashes demeaned by day-of-week and year. All specifications use a first order polynomial and a uniform kernel. DST is the estimate of the discontinuity in fatal crashes that occurs immediately following the spring transition into DST. Leaving DST is the estimate of the discontinuity in fatal crashes that occurs immediately following the fall transition out of DST. CCT refers to the bandwidth selector of Calonico, Cattaneo, and Titiunik (2014); IK is Imbens and Kalyanaraman (2012); CV is the cross-validation method of Ludwig and Miller (2007). Robust standard errors in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Source: Authors' calculations

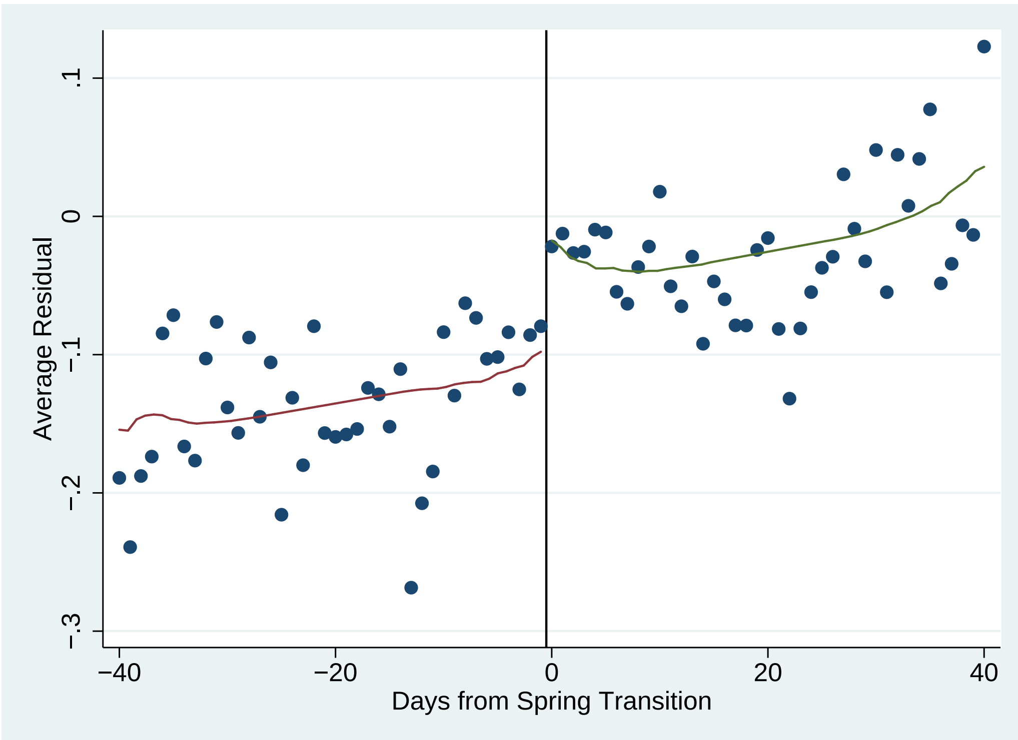


Figure B-2. : Spring Residual Plot - Least Light-Impacted Hours

*Notes:* The residuals are generated from a regression of ln(fatal crash count) on day-of-week and year dummies for the least light-impacted hours subsample. Each point is the average of all residuals for that date relative to the spring transition. Fitted lines are results of locally weighted regression.

Table B-7—: Spring RD estimates by time of day (spring analog to Table 3)

| | Morning | | | Evening | | | Least Light Impacted |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **Leaving DST** | 0.198*** | 0.188*** | 0.176*** | -0.0335 | -0.0197 | -0.0430 | 0.0751** |
| | (0.0485) | (0.0423) | (0.0358) | (0.0388) | (0.0292) | (0.0374) | -0.0266 |
| Bandwidth Selector | CCT | IK | CV | CCT | IK | CV | CCT |
| Observations | 810 | 1,040 | 1,414 | 790 | 1,336 | 830 | 530 |

Dependent Var: Log fatal crashes demeaned by day-of-week and year. All specifications use a first order polynomial and a uniform kernel. Leaving DST is the estimate of the discontinuity in fatal crashes that occurs immediately following the fall transition out of DST. "Morning" is defined as +/- 2 hours from the average sunrise time in that location around the spring transition; "Evening"is defined as +/- 2 hours from the average sunset time in that location around the spring transition. Least Light Impacted are the remaining hours. CCT refers to the bandwidth selector of Calonico, Cattaneo, and Titiunik (2014); IK is Imbens and Kalyanaraman (2012); CV is the cross-validation method of Ludwig and Miller (2007). Robust standard errors in parenthesis.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Source: Authors' calculations

Table B-8—: Negative binomial analog to Table 5

| | All Hours | | | | Least Light Impacted | Morning | Evening |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Spring DST | 1.036** | 1.034** | | | | | |
| | (0.0159) | (0.0159) | | | | | |
| First 6 Days of DST | | | 1.064*** | 1.064*** | 1.067** | 1.213*** | 0.970 |
| | | | (0.0234) | (0.0233) | (0.0276) | (0.0544) | (0.0407) |
| Next 8 days of DST | | | 1.026 | 1.024 | 1.027 | 1.165*** | 0.940 |
| | | | (0.0183) | (0.0183) | (0.0215) | (0.0601) | (0.0416) |
| Remainder of Spring DST | | | 1.018 | 1.016 | 1.016 | 1.145*** | 0.950 |
| | | | (0.0182) | (0.0182) | (0.0219) | (0.0541) | (0.0370) |
| Fall DST | 1.028 | 1.027 | 1.027 | 1.026 | 1.049* | 1.292*** | 0.860*** |
| | (0.0245) | (0.0242) | (0.0244) | (0.0241) | (0.0298) | (0.0861) | (0.0380) |
| Ln(Gas Price) | | 0.960* | | 0.959* | 0.960 | 0.924 | 0.974 |
| | | (0.0217) | | (0.0217) | (0.0250) | (0.0462) | (0.0408) |
| Observations | 3,341 | 3,341 | 3,341 | 3,341 | 3,341 | 3,341 | 3,341 |

Dependent Var: Crash counts; all specs use day-of-year, day-of-week, and year dummys. Remainder of Spring DST is an indicator variable equal to one if the day occurs after the first two weeks of DST and before July 1st. Fall DST is an indicator variable equal to one if the day falls under DST and occurs after June 30th. Reported estimates are incidence rate ratios from a negative binomial model with tolerance of 0.0001 for convergence. "Morning" is defined as +/- 2 hours from the average sunrise time in that location around both transitions; "Evening" is defined as +/- 2 hours from the average sunset time in that location around both transitions; Least Light Impacted are the remaining hours. Robust standard errors in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Source: Authors' calculations

A key omitted variable in this analysis and previous studies is Vehicle Miles Traveled (VMT). If VMT increases at the DST transition date, this behavioral change could be driving results rather than sleep loss. While national VMT data is not available, the Performance Measurement System (PeMS) in California tracks VMT on many major highways within the state. A common way to probe the validity of the RD design is to test for the continuity of other observable variables at the cutoff (Lee, Moretti and Butler, 2004). Using the same RD model from equation 1 with log(VMT) as the dependent variable yields an insignificant 0.016 percent increase in VMT. The lack of a visual or statistical discontinuity helps assuage fears about the underlying assumption of the RD model, that the conditional expectation function is continuous at the DST transition date.

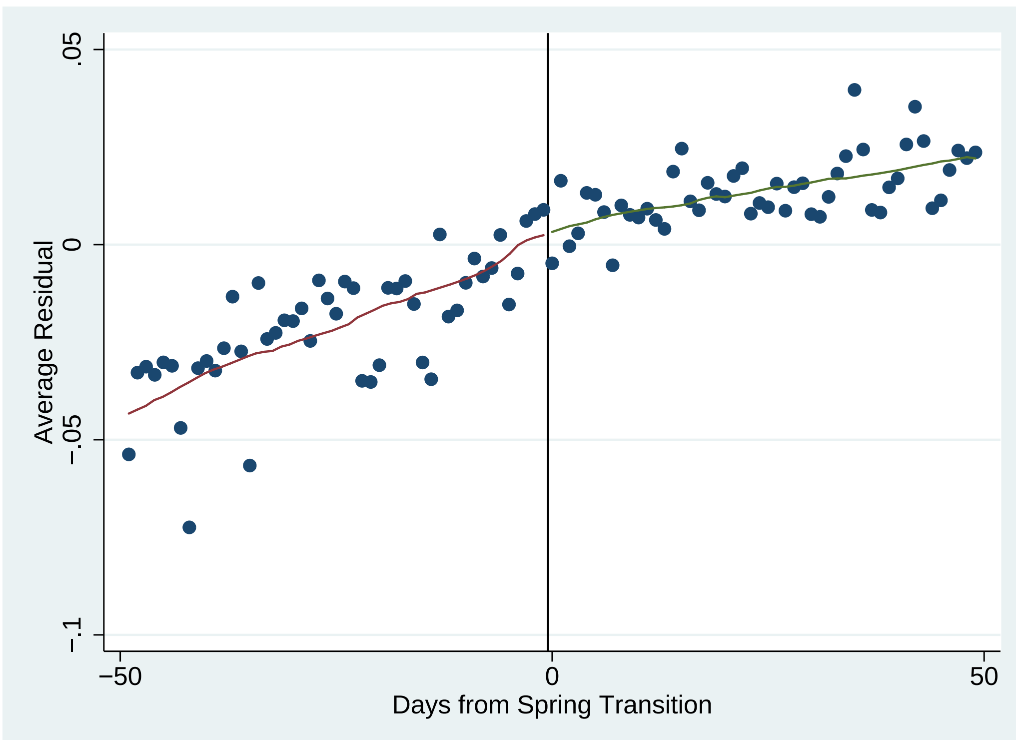


Figure B-3. : VMT Residual Plot

*Note:* Residuals from a regression of ln(VMT) on day-of-week and year dummies.

*Source:* Authors' calculations using aggregate VMT data from Caltrans PeMS.

The ambient light mechanism appears to have caused a net reduction in crashes historically, but not in the more recent period from 2002-2011. Recall the intuition for a net reduction is that the benefit from adding ambient light to a higher frequency crash period (the evening) should outweigh the cost from removing ambient light from a lower frequency crash period (the morning). This would be mechanically true if ambient light uniformly reduced crash risk by an equal percentage at all hours. However, previous evidence has shown that additional light plays a somewhat larger role in the morning relative to the evening (Coate and Markowitz, 2004).[46] Hence, there will only be a net reduction in crashes if the relative disparity in crash frequency between the morning and evening is large enough to offset the disparity in the importance of ambient light between the morning and the evening.

Figure B-4 illustrates how the daily crash profile has changed from the historical sample to the baseline sample for crashes near the spring transition. Notably, the difference in crash frequency between the morning and evening hours has become smaller over time. Examining the treated hours around sunrise and sunset, signified by the vertical lines, reveals that the share of morning crashes has risen by about 1/3rd while the share of evening crashes has remained constant or fallen slightly. This change in the daily crash profile provides a plausible explanation why the ambient light mechanism no longer leads to a net reduction in fatal crashes. The morning period, subject to increased risk from a reduction in ambient light during DST, is a higher frequency crash period in the baseline sample than it was in the historical sample. Hence, while shifting ambient light from the morning to the evening historically reduced total crashes, changes in when crashes occur within a day have likely reduced this effect.

[46]This is also seen in Table 5, where there is a larger percentage increase in morning crashes during DST than the percentage decline in evening classes.

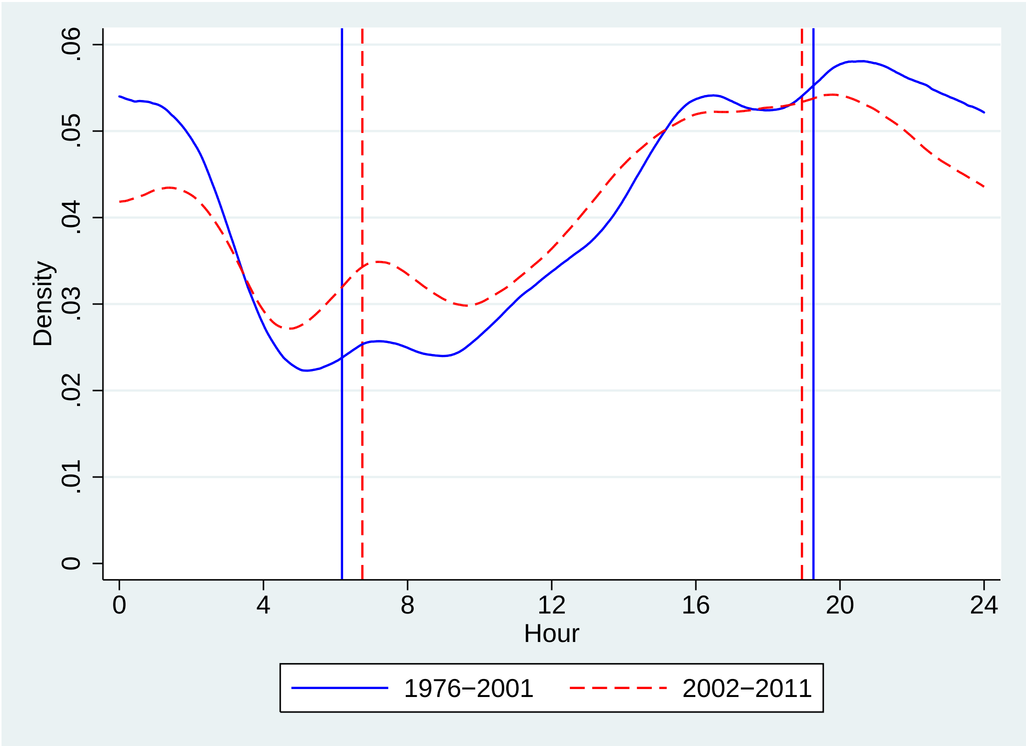


Figure B-4. : Daily Distribution of Crashes Across Time

*Notes:* The kernel density functions use an Epanechnikov kernel and show the distribution of fatal crashes across the day. Data are all crashes occuring within a 4-week window around the spring transition. Vertical lines depict average sunrise and sunset times at the spring transition in those years.

### Geographic Heterogeneity

At the national level, the spring transition into DST leads to a significant increase in fatal crashes. However, this could be due to a constant treatment effect where all regions experience the same 5-6.5 percent increase in crashes, or a heterogeneous treatment effect where some regions experience a larger increase and others experience little or no effect. In this section, I explore two pathways through which geography could lead to heterogeneous impacts of DST, one through the sleep mechanism and the other through the light mechanism.

Sleep deprivation could be more detrimental when driving in already dangerous area. If there are more situations where a delayed response can lead to a crash, the sleep mechanism has more scope to operate. To test this hypothesis, I split my sample in two based on the median number of fatal crashes per capita in each county.[47] The counties with a higher per capita fatal crash rate, I refer to as high risk counties. Running a fully interacted version of the RD analysis with these subsamples (Table C-1) provides weak evidence that high risk counties are subject to a larger initial increase in fatal crashes (in percentage terms) than their low risk counterparts. While the estimates are not statistically different at conventional levels, in all cases the point estimate for high risk counties is above that of low risk counties. This provides tentative evidence that sleep loss is more detrimental when performing a more difficult task.

If ambient light is more important in certain hours than others, heterogeneity in sunrise and sunset times could lead to differential impacts of DST. Sunrise occurs earliest in the Eastern portion of any time zone; in Boston, sunrise the day before DST occurs at 5:45 a.m. whereas in Louisville, Kentucky, it occurs at 6:44 a.m. In Boston, the onset of DST moves sunrise back an hour to roughly 6:45 a.m. while in Louisville sunrise is moved to roughly 7:45 a.m. If light is more important for fatal crashes (perhaps due to more driving) during the 6:45-7:45 a.m. hour relative to the 5:45-6:45 a.m. hour, Louisville should experience a bigger morning increase in fatal crashes (in percentage terms) than Boston.[48] To test this mechanism, I split the sample in half on the basis of sunrise times around the transition dates. Areas with sunrise times before the median are characterized as early sunrise areas and those with sunrise times after the median are characterized as late sunrise areas. The analogous cut is made for sunset times, as these are not a 1:1 mapping.

Table C-2 shows the RD results using a fully interacted model. The reference group, areas with early sunrises, experience a significant increase in crashes. In contrast to what might be expected based on common commute times, results are not significantly different across these groups. If anything, areas with later sunrise times are characterized by a smaller increase in fatal crashes, though these

[47] 2010 census counts used for county population.

[48] In the evening, sunset shifts from 17:57 to 18:58 in Boston and 18:45 to 19:45 in Louisville. Again, it would appear that Boston is helped more, as 17:57 to 18:58 is more of a peak travel time than 18:56-19:57. Sunrise and sunset times listed assume a March 23rd transition date, the average in the sample.

Table C-1—: RD estimates of the impact of entering DST on fatal crashes – by county risk level

| | (1) | (2) | (3) |
|---|---|---|---|
| DST | 0.0542** | 0.0344* | 0.0492** |
| | (0.0251) | (0.0192) | (0.0234) |
| DST x High-Risk County | 0.0381 | 0.0565 | 0.0478 |
| | (0.0529) | (0.0404) | (0.0487) |
| Bandwidth Selector | CCT | IK | CV |
| Observations | 1,100 | 1,932 | 1,340 |

Dependent Var: Log fatal crashes demeaned by day-of-week and year within each class of county. All specifications include a dummy for High-Risk County and use a first order polynomial and a uniform kernel. DST is the estimate of the discontinuity in fatal crashes that occurs immediately following the spring transition into DST. DST x High Risk County is the extra effect of DST in high-risk counties. Optimal bandwidth chosen for full sample are imposed. CCT refers to the bandwidth selector of Calonico, Cattaneo, and Titiunik (2014); IK is Imbens and Kalyanaraman (2012); CV is the cross-validation method of Ludwig and Miller (2007). Robust standard errors in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Source: Authors' calculations

estimates are far from statistically significant. The analogous estimates for early versus late sunset times are reported in columns 4-6. Again, there is never a significant difference between groups. Figure A-1 helps to elucidate this finding. While the darkened hour in early sunrise areas has fewer fatal crashes and the brightened hour has more fatal crashes, it is a very minor difference. Further, the average difference in sunset and sunrise times is under 30 minutes rather than the full hour seen in the Boston - Louisville example. This geographic heterogeneity could be explored further in other applications where higher frequency events would increase the power of the test and allow for more narrow groupings.

Table C-2—: RD estimates of the impact of entering DST on fatal crashes – by sunrise and sunset times

| | Cut based on sunrise | | | Cut based on sunset | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| DST | 0.0792** | 0.0653*** | 0.0652** | 0.0680** | 0.0603** | 0.0561* |
| | (0.0320) | (0.0239) | (0.0293) | (0.0322) | (0.0238) | (0.0294) |
| DST x Late Sunrise | -0.0237 | -0.0289 | -0.00294 | | | |
| | (0.0428) | (0.0326) | (0.0392) | | | |
| DST x Late Sunset | | | | -0.00347 | -0.0192 | 0.0144 |
| | | | | (0.0433) | (0.0327) | (0.0396) |
| Bandwidth Selector | CCT | IK | CV | CCT | IK | CV |
| Observations | 1,100 | 1,932 | 1,340 | 1,100 | 1,932 | 1,340 |

Dependent Var: Log fatal crashes demeaned by day-of-week and year within each subset of sunrise and sunset times. All specifications include a dummy for late sunrise (col 1-3) or late sunset (col 4-6) and use a first order polynomial and a uniform kernel. DST is the estimate of the discontinuity in fatal crashes that occurs immediately following the spring transition into DST. DST x Late Sunrise/Sunset is the extra effect of DST in areas with sunrise or sunset later than the median. Optimal bandwidth chosen for full sample are imposed. CCT refers to the bandwidth selector of Calonico, Cattaneo, and Titiunik (2014); IK is Imbens and Kalyanaraman (2012); CV is the cross-validation method of Ludwig and Miller (2007). Robust standard errors in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.
Source: Authors' calculations

## Additional References not in Main Text

**Lee, David S, Enrico Moretti, and Matthew J Butler.** 2004. "Do voters affect or elect policies? Evidence from the US House," *The Quarterly Journal of Economics*, 807-859.