Saving Light, Losing Lives: How Daylight Saving Time Impacts Deaths of Despair

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Abstract

This paper estimates the impact of Daylight Saving Time (DST) on deaths of despair (DoD) in the United States. Using Multiple Cause-of-Death Mortality Data from the National Vital Statistics System of the National Center for Health Statistics from 1979-1988, the effect is identified in two ways: a regression discontinuity design (RDD) that exploits discrete time changes in the Spring and Fall; and a fixed effects model (FE) that is identified with a policy change and a switching mechanism that introduces random variation to DST's start and end dates. This is one of the first attempts to estimate the impact of DST on DoD and is the first to use either identification strategy. The results from both methods suggest that the sleep disruptions during the Spring transition cause suicide rates to rise by 6.25 percent and all DoD to increase by 6.59 percent. There is no evidence for any change in suicide or all DoD during the Fall transition. The contrasting results from Spring to Fall suggest the entire effect can be attributed to disruptions in sleep patterns rather than changes in ambient light exposure.

1 Introduction

For the first time since 1915-1917, life expectancy in the United States fell for three consecutive years between 2015 and 2017. This was largely due to a dramatic rise in suicides and deaths from drug or alcohol overdose and abuse. In 2017 alone, more than 150,000 American died from one of these so-called "deaths of despair" (DoD), representing a six percent increase from 2016 and a

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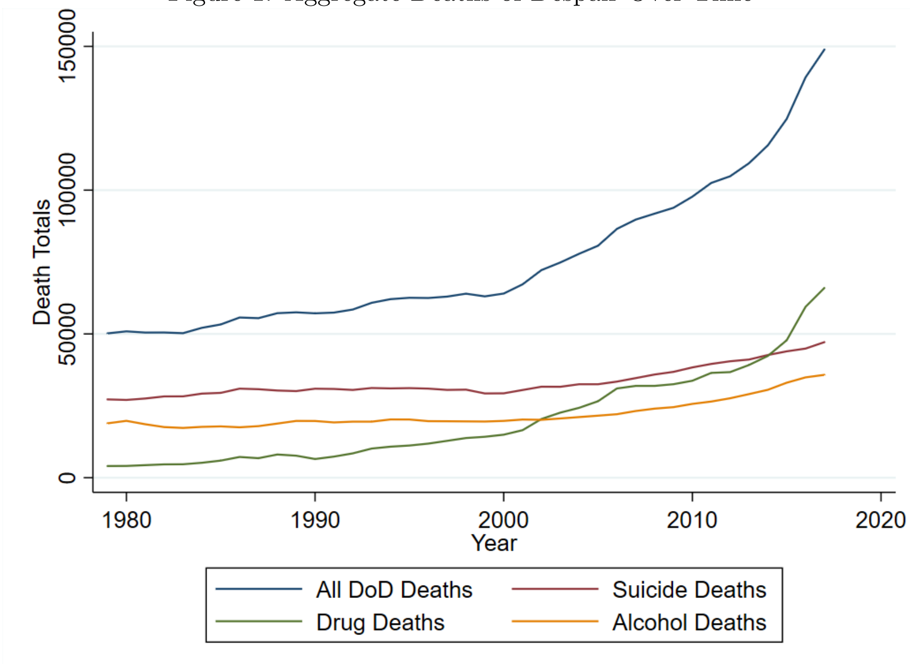
more than 100 percent increase since 1999 (see Figure 1). All told, accidental deaths including those related to drug and alcohol overdose is now the 3rd leading cause of death in the United States while suicide is ranked 10th.[1]

Figure 1: Aggregate Deaths of Despair Over Time



Notes: Data from CDC WONDER Online Database, Compressed Mortality Files.

The underlying mechanisms driving DoD are no doubt numerous. Understanding even one of them could help motivate policy that save lives. The goal of this paper is to investigate two such potential causes: changes in ambient light exposure and disruptions to the circadian rhythm that arise from the use of Daylight Saving Time (DST).

DST is the practice of advancing clocks forward by an hour during late

[1]All numbers here are from the Trust for America's Health (TFAH) and Well Being Trust (WBT) with mortality data from the US Centers for Disease Control and Prevention (CDC). Data obtained from the WONDER database in December 2018

Spring, Summer, and early Fall months before reverting to Standard Time (ST) the rest of the year. It has been used through most of the United States since Lyndon Johnson signed The Uniform Time Act of 1966. Currently, over 300,000 million Americans are impacted by it, as well as over 1.5 billion people worldwide.

DST was first proposed by George Hudson in 1895. He argued that it would encourage people to be awake during daylight hours, thus making them less likely to use lights and waste electricity. The German Empire and Austria-Hungary were the first to implement the policy nationwide on April 30, 1916 as resources became scarce during World War I. Other countries, including the United States, followed suit before largely abandoning it after the war. It again became a fixture during World War II and during the 1970's energy crisis, at which point it became a standard peacetime practice for the first time across large swaths of the world.

Despite its long history and widespread use, there is little evidence that DST actually accomplishes its goal (Kellogg and Wolff 2008). In fact, some research suggests it may cause energy consumption to raise, mostly because any reduction in light use is offset by increases in heating and air conditioning (Momani et al. 2009; Krarti and Hajiah 2011; Kotchen and Grant 2011; Sexton et al. 2014).

The existing literature also suggests DST has a negative impact on society outside of energy consumption. Doleac and Sanders (2015) estimate a 7 percent increase in robberies following the shift to DST, amounting to a social cost of $59 million annually. Smith (2016) estimates a 5.6 percent increase in fatal automobile accidents during the spring transition at a social cost of $275 million yearly. Janszky et al. (2012) find a 3.9 percent increase in acute myocardial infarction for the first week after Spring clocks shift forward.

The evidence for the impact of DST on mental health, including incidents of drug/alcohol dependence, suicide, or suicidal behavior, is more mixed. Shapiro et al. (1990) find no evidence for an increase in the incidence of a host of mental health symptoms. Similarly, Lahti et al. (2008) find no effect of DST transitions on hospital treatments due to manic episodes in Finland for the years 1987–2003. That said, van Cauter and Turek (1986) find a strong relationship between disruptions in circadian rhythm and depression; and Quercioli (2010), which uses time discontinuities along time zone boundaries, finds that being on the west side of the threshold causes a 10 percent increase in the suicide rate.

The literature on DST as it relates to DoD specifically is limited. The first to address the subject is Berk et al. (2008), which uses data from the Australian Bureau of Statistics on deaths potentially due to suicide between 1971 and 2001. After accounting for season and year trends, they find weak effects of DST transitions on the number of suicides for men, but no effect for women. These findings represent an important first step in understanding the relationship between DST and suicide, but the authors were also constrained by significant data limitations. First, due to Australia's relatively small population, there was a total of only 61,598 deaths over the 31 year period, or an average of only 5.4 deaths per day. In comparison, there have been more deaths by suicide in the United States over the last year and a half alone. Furthermore, their mortality data was aggregated at the national level, but each state has its own DST transition date, so the authors could not be precisely sure of the number of deaths on each side of the threshold. These factors combined raise questions about the precision of the estimates.

Jin and Ziebarth (2016) looks at human capital more broadly using 160 million hospital admissions from Germany and 3.4 million survey responses from the Behavioral Risk Factor Surveillance System in the United States from 2000 to 2008. They use this to estimate the impact of DST on a large set of health outcomes, including hospitalizations for attempted suicide and drug overdose. Their primary specification uses daily dummy variables around the DST transition and a set of seasonal controls. In doing this they find no evidence that DST increases the rate of suicide attempts or drug overdoses. Given the underwhelming results and the broad scope of their research, a more robust treatment of these particular outcomes was left for future research.

Most recently, Lindinberger, Ackermann, and Parzeller (2019) estimate the impact of DST on suicide using data from forensic autopsies performed at the Institute of Legal Medicine, University Clinic of the Goethe University of Frankfurt/Main, Germany from 2005 to 2015. To do this, they perform a difference in means test for deaths occurring two weeks before and two weeks after the transition. They find a statistically significant increase in suicides following the Spring transition and no effect during the Fall shift. This was primarily a descriptive paper, however, and no further analysis was done. There were also only 65 total suicides over this 10 year period, which suggests a need for further investigation.

Building on this research, this paper advances the literature in a number of ways. First, following methodology in Smith (2016), it is the first attempt to estimate the impact of DST on DoD using a regression discontinuity design (RDD). Given the discrete nature of the discontinuity, DST transitions are particularly well suited for this sort of analysis. Furthermore, like Smith (2016), I address Sood and Ghosh's (2007) concern that seasonal variation could drive RDD results by verifying them with a fixed effects (FE) approach that exploits a policy change in the timing of DST and an assignment mechanism that exogenously introduces variation in the DST start and end date. This is also the first paper that attempts to disentangle the impact of sleep disruptions and light exposure on DoD brought about by DST. It does this by comparing estimates in the Spring, where Americans lose between 32-40 minutes of sleep (Barnes and Wagner 2009; Harrison 2013; Medina et al 2015), with the Fall, where there is no evidence of any change to sleep patterns (Barnes and Wagner 2009; Harrison 2013). Lastly, this paper uses aggregate, day-level mortality data from the United States between 1979 and 1988, so it benefits from having a large data set and knowledge of precise DST transition dates.

The results from both identification strategies are strongly suggestive of Spring DST transitions having a large and meaningful impact on DoD. Using multiple bandwidth selectors and kernels, all RDD estimates suggest the transition increases suicide and all DoD by between 6 and 8 percent around the threshold, while the FE specification estimates a 3 to 4 percent jump. The results for the Fall DST transitions suggest no impact on DoD, regardless of identification strategy. Since there is no evidence for any change in sleep patterns during the Fall, this last conclusion suggests the jump in DoD during the spring can be attributed to the loss of sleep exclusively.

The rest of this paper is organized as follows: (2) *Daylight Saving Time* gives a brief overview of DST in the United States and describes the mechanisms through which it impacts DoD; (3) *Data* describes the data, its restrictions, and the features that make it suited for this analysis; (4) *Empirical Strategy* outlines the RDD and FE identification strategies and the assumptions required for them to give unbiased estimates; (5) *Results* presents results and robustness checks; (6) *Conclusion* summarizes the salient outcomes and discusses their implications.

2 Daylight Saving Time

During his time as an American envoy to France, Benjamin Franklin published a satirical letter in the Journal de Paris suggesting that Parisians economize on candles by waking up with the sun, and proposed they enforce the behavior by taxing window shutters, rationing candles, and waking the masses with church bells and cannons. Despite his urging, DST didn't come to France or the United States until WWI, and didn't become a permanent fixture in the US until almost 200 years later when Lyndon Johnson signed the Uniform Time Act of 1966. The bill set universal start and stop dates for DST, but gave states the autonomy to opt in or out. With the exception of Hawaii, Indiana, and Arizona, all states joined.

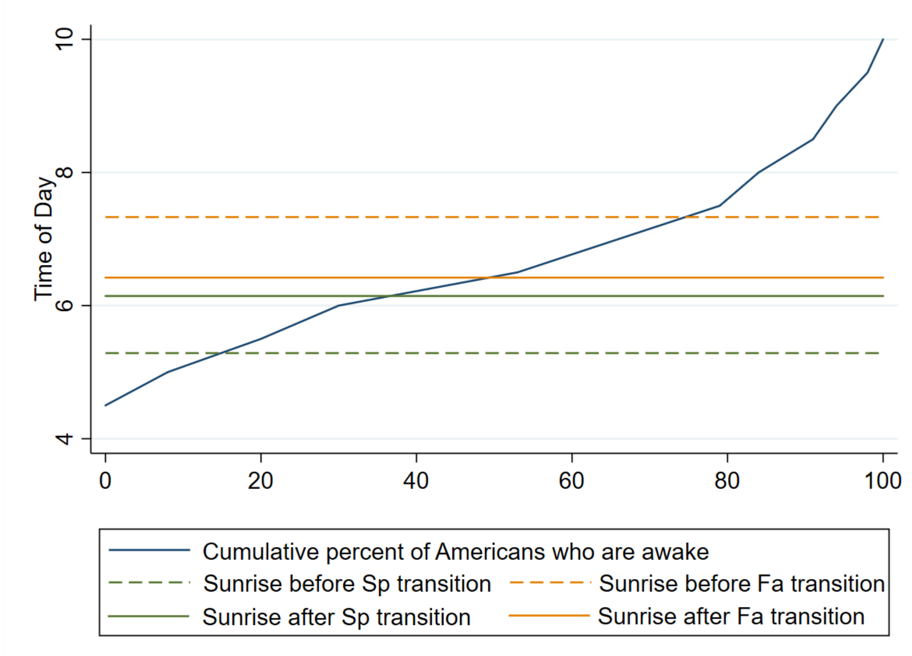
The guidelines outlined in 1966 have remained largely unchanged since, and were only altered once for the years under consideration in this paper. This happened when the Uniform Time Act was amended in 1986, moving the date forward by three weeks in the Spring. In 1986 and before, clocks changed on the third Sunday in April. Afterward, they moved forward on the first Sunday in April. Guidelines for the Fall remained the same.

There are two possible channels through which these laws could impact DoD. First, there are discrete changes in light exposure. In the Spring, there is less light in the morning and more light in the evening. However, as many as 65 percent of Americans wake up after sunrise around the transition, meaning the net effect in the Spring is an increase in exposure to sunlight.[2] In the Fall, there is more light in the morning and less light in the evening. As in the Spring, many Americans are still asleep when the sun rises, so the net effect in the Fall is a decrease in light exposure. This effect is illustrated in Figure 2, which shows the cumulative distribution of wake-up times for Americans overlaid with the average sunrise times during the first week after the Spring and Fall transitions, and the last week before the Spring and Fall transitions. Following Smith (2016),

[2]Estimates using data from a survey conducted by Edison Research that included 1,550 respondents ages 18-54. It was conducted in January 2015. Data was obtained August 2019.

Figure 2 uses sunrise times for St. Louis, MO, which is the closest city to the population weighted center of the continental United States.

Figure 2: Sunrise and Wake-Up Times Around DST Transitions



Notes: Following Smith (2016) this demonstration uses St. Louis, MO for its sunrise times, since it is the closest city to the population weighted center of the continental US. This figure shows the cumulative wake-up times for Americans overlaid with the average sunrise times for the first week after the Spring and Fall transitions and the last week before the Fall and Spring transitions.

It is also possible for DST transitions to disrupt sleep patterns. In the Spring, clocks move forward an hour at 2:00am, which reduces to total number of hours in the day to 23. Evidence suggests the bulk of this loss falls on sleep hours. Using the American Time Use Survey data from 2003-2006, Barnes and Wagner (2009) find that this lost hour causes people to sleep 40 minutes less on average. Using electronic monitors to precisely measure hours of sleep for 40 high school students, Medina et al (2015) find that teens lose approximately 32 minutes of sleep a night. The effect of this loss can be felt between two and 14 days (Barnes and Wagner 2009; Harrison 2013; Medina et al 2015). Therefore, the Spring transition causes observers to enjoy more exposure to sun but discretely lose between 32-40 minutes of sleep and cumulatively lose up to two hours and 42 minutes of sleep in the weeks following the transition.

In the Fall, clocks move backward an hour at 2:00am, which increases the total number of hours in the day to 25. While it's possible the extra hour would cause people to sleep more, there is little evidence that they do (Barnes and Wagner 2009; Harrison 2013). Therefore, the cumulative impact of the Fall transition is solely a loss in sun exposure. This aspect of DST makes it possible to tease out how its different features impact suicide individually. Estimates for the impact of DST in the Fall can be interpreted as the impact of losing light exposure alone, while the impact of sleep disruptions can be estimated by subtracting the impact of the Fall transition from the impact of the Spring transition.

3 Data

For mortality data, this paper uses Multiple Cause-of-Death Mortality Data from the National Vital Statistics System of the National Center for Health Statistics from 1979-1988. These exact years were chosen for three reasons. First, while records exist as far back as 1959, Daylight Savings wasn't implemented until 1967. Furthermore, death totals by day of year are not available between 1967-1971 and from 1989-present. Since this is crucial for the RDD design, these years have to be excluded, as well. Lastly, many specific causes of death related to this topic were not reliably coded until 1979, so all previous years are removed.

For a death to be included in the sample, its primary cause has to be suicide, drug overdose or dependence, or alcohol overdose or dependence.[3] Any instance where cause of death was in the least bit unclear is excluded. Deaths that occur in Arizona, Hawaii, or Indiana are also excluded, as all or parts of these states did not observe DST during the sample period. Following Smith (2016), death totals are adjusted for hours in the day, so that deaths occurring at the Spring transition are increased by 4.3 percent, while deaths during the Fall transition are decreased by 4 percent. All results in this paper are robust to the exclusion of these adjustments.[4]

Because of these restrictions and the relative paucity of DoD at the daily level, the dependent variable (the natural log of deaths on a given day) is aggregated to the national level. Over the study period, there are approximately 87 suicides or deaths related to drug/alcohol overdose/dependence across the country per day. This means daily, state-level totals would often be zero, and variation from day to day would be likely be large. Aggregating smooths out these totals and minimizes the possibility of external factors like weather influencing local results. Furthermore, DoD death totals are dominated by suicide, so the proceeding analysis is performed using a suicide only sample and an all DoD sample. Unfortunately, the small number of non-suicide related DoD deaths preclude any analysis of those deaths in isolation.

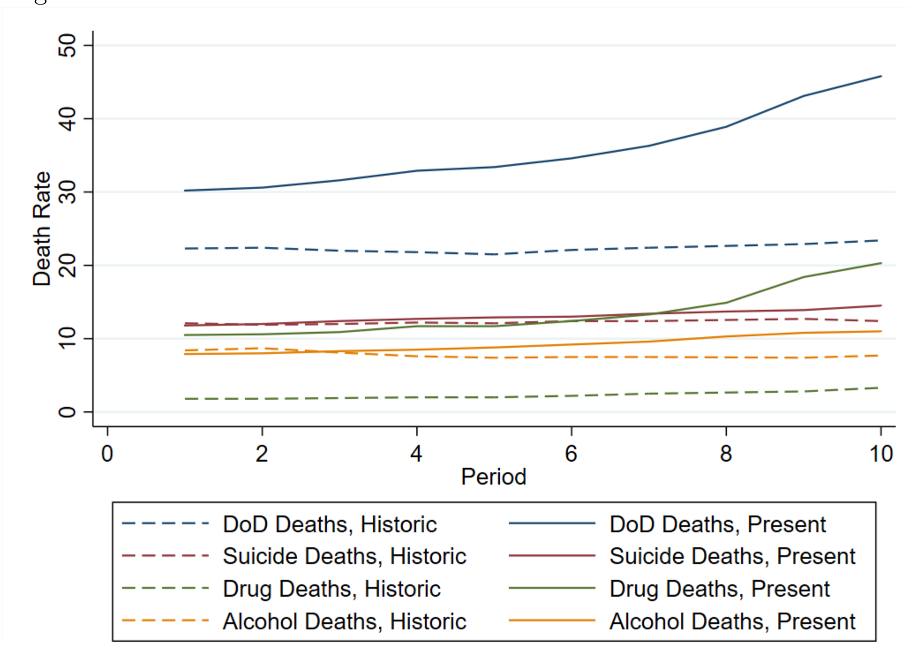
One concern with the use of data from this time period is that it pre-dates the sharp upswing in DoD that began in the early part of the 21st century. It is important to note that the objective of this paper is not to answer why DoD has increased so dramatically in recent years. Rather, its goal is to explain one contributing factor to the overall number of deaths. Furthermore, while the direct relationship between DST and DoD has not been tested exhaustively

[3]Technically, the definition of DoD includes drug and alcohol related disease, but these conditions result from long standing behavior and cannot reasonably be attributed to any one discrete event. As such, they are not included in the sample.

[4]The replicated primary results can be found in the Appendix Table A.2.

in the past, the broader literature on sleep deprivation and DoD has remained largely consistent over time (Wirz-Justice and Van den Hoofdakker 1999; Goldstein, Bridge, and Brent 2008; Andersen et al. 2010; Kohyama 2011).[5] So, even if other factors exist that are driving the rise in DoD today, there is evidence that the effect of this particular input on its prevalence has remained consistent. Lastly, during the time under consideration, results are largely driven by suicide, whose rate has not hanged markedly since the sample period (see Figure 3).

Figure 3: DoD Rate from 1979-1988 Overlaid with DoD Rate from 2007-2017



[5] As will be shown shortly, changes in sleep patterns are the the primary driver for a change in DoD around the DST threshold.

4 Empirical Strategy

4.1 Regression Discontinuity Design (RDD)

The primary identification strategy uses an RDD. Every year there are two discrete changes to the observed time of day: once when clocks are set forward an hour in the Spring and once when clocks are set back one hour in the Fall. These are sharp transitions are for all states under consideration, making this strategy particularly well suited for addressing the impact of DST on DoD. Following Smith (2016), the primary specification uses a local linear regression, since there is no practical benefit to using higher order polynomials of the running variable (Gelman and Imbens 2018). DoD varies by day-of-week, month, and by year (Maldonado and Kraus 1991), so all death totals are demeaned by day-of-week, month, and year. Outside of these alterations, the estimating equation mirrors Imbens and Lemieux (2008) and is as follows:

$$lnDoD_{dy} = \beta_0 + \beta_1 DST_{dy} + f(Tran) + f(DST_{dy} \cdot Tran_{dy}) + u_{dy} \tag{1}$$

$lnDoD_{dy}$ is defined as the natural log of aggregate DoD for day d in year y.[6] In some specifications this is replaced with $lnSuicides_{dy}$, the natural log of aggregate suicides for day d in year y. DST_{dy} is a dummy variable equaling 1 if day d in year y occurs during DST. $Tran_{dt}$ is centered at the transition date for each year. The primary specification uses a uniform kernel and Calonico, Cattaneo, and Titiunik's (2014) optimal bandwidth selector. For robustness, specifications

[6]The first Sunday under DST is only 23 hours long, which means the total number of fatalities appear artificially low. Following Smith (2016), the death total on these days are adjusted upward 4.3 percent. Likewise, since the first Sunday under ST is 25 hours long, death totals are adjusted downward by 4 percent. All estimates are robust to the exclusion of these adjustments. Replication of the primary specification can be found in the Appendix Table A.2.

using alternative bandwidth selectors and Epanechnikov and triangular kernels are also estimated. The parameter of interest is β_1, which can be interpreted as the local average treatment effect on DoD caused by the DST transition. Note that regressions for the Spring and Fall transitions are performed independently. In both cases the variables are defined the same, with the exception being the transition date under consideration.

There are three assumptions that must be met for a sharp RDD design to give unbiased results. First, assignment to treatment must occur through a known, measurable, and deterministic decision rule. Second, the probability of assignment must jump from 0 to 1 at the cut-off. Third, factors that could influence DoD must be locally continuous about the threshold. The first two assumptions are met by construction. The United States has known DST transition dates, and all states that choose to be bound by them are, in fact, bound by them absolutely. All situations where this is not necessarily true have been dropped from the sample.

To test the third assumption, factors related to DoD where daily data is available are inserted into the primary estimating equation as the dependent variable. The first of these variables is precipitation, since weather is related to suicide rates (especially among the elderly) (Salib 1997; Deisenhammer, Kemmler, and Parson 2003)[7] and drug overdose (Veysey, Kamanyire, and Volans 1999). Data for this variable comes from daily totals for the 40 largest cities in the United States between 1979 and 1988. The second variable tested is the NASDAQ Composite's closing price, since wealth, income, and fluctuations in the business cycle are also related to suicide (Saucer 1993; Viren 1996) and drug overdose. For this variable, the transition date is centered at the Monday following the Sunday threshold since there is no trading on weekends. In both

[7]There is research that contradict these findings (Ajdacic-Gross et al. 2007)

cases, there is no evidence of any discontinuity across the DST threshold.[8] This is not conclusive evidence that the third identifying assumption is met, but it is highly suggestive.

4.2 Fixed Effects (FE) Model

One advantage of the RDD is that it looks at variation within year, which means it's able to account for trends in DoD within each study year. This is important because of the potential for suicide contagion - a phenomenon where instances of suicide can themselves lead to more suicide - and epidemics like crack cocaine or fentanyl that can flood a market during particular years or periods in time. However, given the consistent nature of DST transitions - eighth of 10 years under consideration use the same time in the Spring and all ten years use the same time in the Fall - there is a risk that it's capturing season or time-of-month effects rather than the DST transition in particular.

To ameliorate this concern, Sood and Ghosh (2007) and Smith (2016) suggest a FE model to estimate the impact of DST. The estimating equation for this identification strategy is:

$$lnDoD_{dy} = \beta_0 + \beta_1 spDST_{dy} + \beta_2 faDST_{dy} + DYear_d + DWeek_{dy} + Year_y + u_{dy} \tag{2}$$

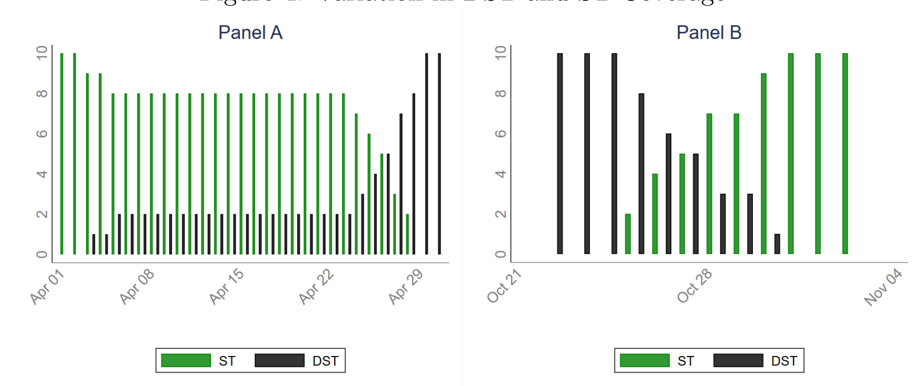
$lnDoD_{dy}$ is defined as the natural log of aggregate DoD for day d in year y. In some specifications this is replaced with $lnSuicides_{dy}$, the natural log of aggregate suicides for day d in year y. $spDST_{dy}$is a dummy variable equaling 1 if day d in year y occurs during DST and before July 1st. $faDST_{dy}$is a dummy

[8] Results of this test are in the Appendix, Table A.1.

variable equaling 1 if day d in year y occurs during DST and after June 30th. $DYear_d$, $DWeek_{dy}$, and $Year_y$ are day-of-year, day-of-week, and year dummies, respectively. $\beta_1$and β_2 are the parameters of interest. β_1 can be interpreted as the average effect of DST during the dates that change their DST status over the sample period in the Spring. Similarly, β_2 can be interpreted as the average effect of DST during the dates that change their DST status over the sample period in the Fall.

For this strategy to be identified there must be random variation in the start and end dates for DST. There are two sources of this variation. First, there was an amendment to the Uniform Time Act in 1986 that changed the beginning of DST to the first Sunday in April. Before this change, the Spring transition had been the last Sunday of April. This means that for 1987 and 1988, DST began three weeks earlier than it had before. Second, the assignment mechanism ("the first Sunday in April" or "the last Sunday in April") means there is variation in the precise day of year each transition occurs. The variation from both sources can be seen in Figure 4. Panel A shows the variation in Spring while Panel B shows the variation in Fall.

Figure 4: Variation in DST and ST Coverage



Notes: These graphs illustrate the variation in starting and stopping day for DST. Each bar shows the frequency particular days of the year fall under ST and DST during the ten year sample period. Panel A represents the Spring transition while Panel B represents the Fall transition. Variation in Panel A comes from the DST assignment mechanism and an Amendment to the Uniform Time Act that changed the starting day for DST for the last two years of the sample. Variation in Panel B comes just from the assignment mechanism alone.

5 Results

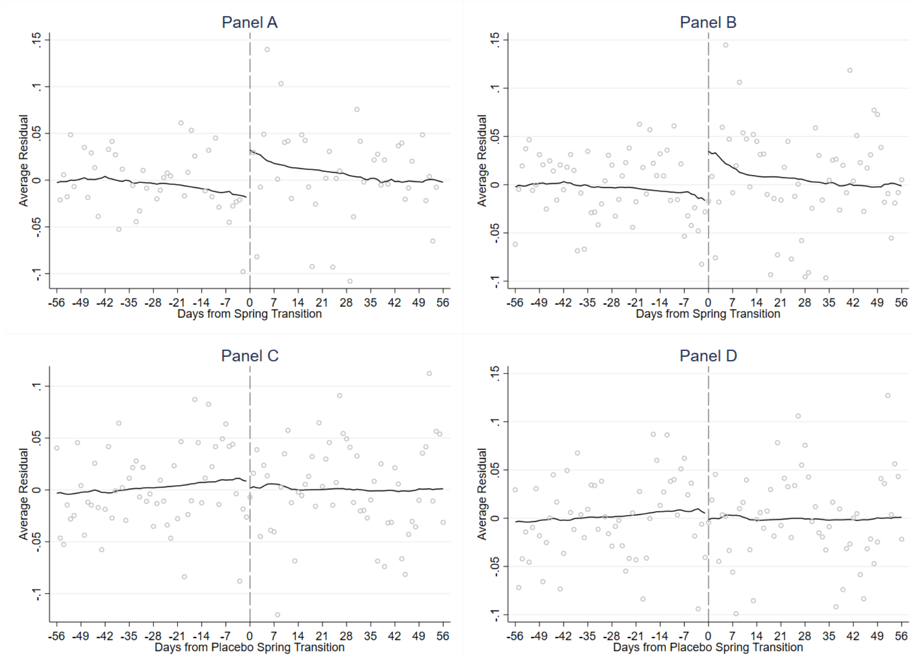
The primary results for the RDD for Spring are represented visually in Panel A (suicide) and Panel B (all DoD) from Figure 5. Here, the average residuals from a regression of the log of suicides and all DoD demeaned by day-of-week, month, and year are plotted against the $Tran_{dt}$ variable. A break in the trend line at the transition date indicates the magnitude of DST's impact on suicide and total DoD discreetly around the threshold, and can be interpreted as the estimate of β_1 from equation (1).[9] Visual inspection suggests a meaningful jump in suicides and all DoD during the Spring transition. Consistent with previous literature, the trend line drops back to its baseline within two weeks. This suggests the mechanism through which DST impacts DoD is predominantly the disruption in sleep pattern, as the change in ambient light exposure remains

[9]Results remain significant and similar in magnitude when not demeaned by day-of-week, month, and year. Results available upon request.

mostly unchanged after the transition date, while sleep disruption is a discrete event whose effect would wane over time.

The results for a placebo test can be found in Figure 5, Panels C and D for suicide and all DoD, respectively. This test addresses a concern by Smith (2016) that the transition date itself might have something unique about it that drives the results. To do this, it exploits the 1986 amendment to the Uniform Time Act that changed the transition into DST in the Spring. For the years 1979-1986, the placebo transition date is assigned using the mechanism from 1987-1988; while the placebo transition date in 1987-1988 is assigned using the mechanism from 1979-1986. For both suicide and DoD, there is no visual break at the placebo DST threshold, suggesting it's DST itself that drives the results in Panels A and B.

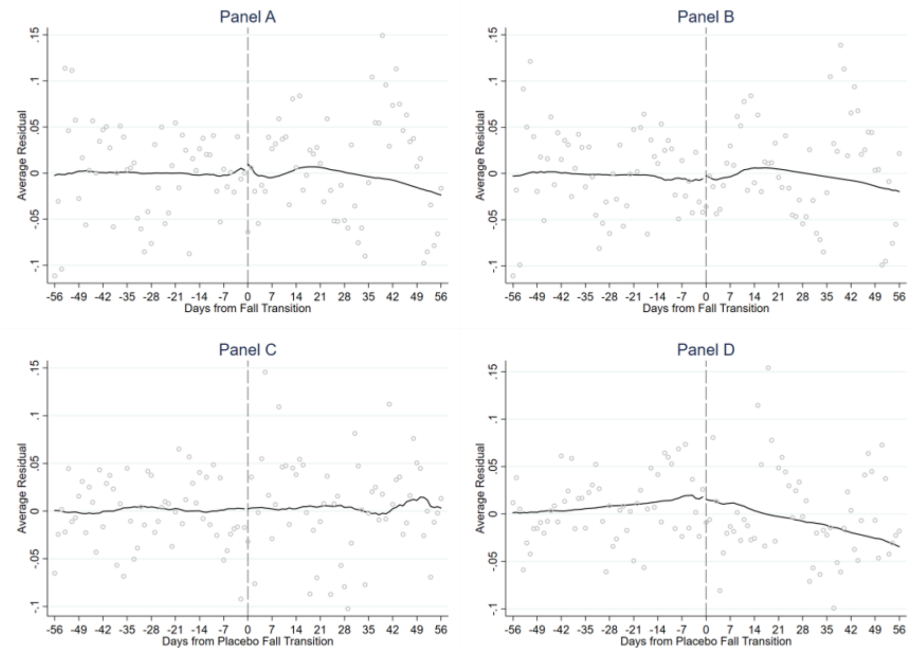
Figure 5: The Effect of DST on Suicide and DoD, Spring



Notes: The residuals are from a regressions of log of suicide or all DoD (panels A/C and B/D, respectively) on day-of-week, month, and year dummy variables. Each point is the average of all residuals for that date relative to the Spring transition date (Panels A and B) or the placebo Spring transition date (Panels C and D). Fitted lines are from locally weighted regressions.

The primary results for the RDD for Fall are represented visually in Panel A (suicide) and Panel B (all DoD) from Figure 6. As before, the average residuals from a regression of the log of suicides and all DoD demeaned by day-of-week, month, and year are plotted against the $Tran_{dt}$ variable. A break in the trend line at the transition date indicates the magnitude of DST's impact on suicide and total DoD discreetly around the threshold, and can be interpreted as the estimate of β_1 from equation (1). Visual inspection suggests the Fall DST threshold has no impact on suicide or all DoD. The same placebo test conducted in the Spring is repeated in the Fall. Again, there is no evidence of a break. These results corroborate the conclusion above that the effect in the Spring is driven by the disruption to sleep patterns, as any effect in the Fall would come entirely from a change in ambient light exposure.

Figure 6: The Effect of DST on Suicide and DoD, Fall



Notes: The residuals are from a regressions of log of suicide or all DoD (panels A/C and B/D, respectively) on day-of-week, month, and year dummy variables. Each point is the average of all residuals for that date relative to the Fall transition date (Panels A and B) or the placebo Fall transition date (Panels C and D).Each point is the average of all residuals for that date relative to the Fall transition date. Fitted lines are from locally weighted regressions.

The regression results associated with Figure 5 are in Table 1. Panel A reveals estimates for suicide alone, while Panel B includes all DoD. The preferred specification in both cases is in column 1. Here, the Spring transition into DST is associated with a 6.25% increase in the prevalence of suicide and an 6.59% increase in the prevalence of all DoD. Both of these results are highly significant. Columns 2 and 3 replicate the estimates using alternate bandwidth selectors. For both suicide and all DoD, the results are robust to these alternative specifications.[10] Column 4 presents results of the placebo test described above.

[10]They are also robust to alternative kernels, results for which can be found in the Appendix,

Table 1: The Effect of DST on Suicide and DoD using RDD, Spring

	(1)	(2)	(3)	(4)
Panel A				Placebo
DST	0.0625***	0.0709***	0.0713***	-0.00455
	-0.0202	-0.024	-0.0211	-0.0168
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel B				Placebo
DST	0.0659***	0.0811***	0.0708***	-0.00282
	(0.0182)	(0.0222)	(0.0197)	(0.0153)
Bandwidth Selector	mserd	cerrd	cersum	mserd

Notes: The dependent variable is the natural log of total deaths due to suicide (Panel A) and all DoD (Panel B) demeaned by day-of-week, month, and year. All specifications use a local linear regression and a uniform kernel. 1979-1986, the placebo transition date is assigned using the mechanism from 1987-1988; while the placebo transition date in 1987-1988 is assigned using the mechanism from 1979-1986. Robust standard errors are in parenthesis.

*** Significant at a 1 percent level

** Significant at a 5 percent level.

* Significant at a 10 percent level.

The regression results associated with Figure 6 are in Table 2. Panel A reveals estimates for suicide alone, while Panel B includes all DoD. The preferred specification in both cases is in column 1. Here, the Fall transition into DST is associated with a 0.53 percent increase in the prevalence of suicide and an -0.38 percent decrease in the prevalence of all DoD. The estimates for both are highly insignificant. Columns 2 and 3 replicate the estimates using alternate bandwidth selectors, and the results remain small and insignificant under these alternative specifications.[11] The placebo test used for the Spring transition is applied here, as well. Like the Spring, the estimates around the placebo transition date are small and insignificant.

Tables A.3 and A.4.

[11]They are also robust to alternative kernels, results for which can be found in the Appendix, Tables A.3 and A.4.

Table 2: The Effect of DST on Suicide and DoD using RDD, Spring

	(1)	(2)	(3)	(4)
Panel A				*Placebo*
DST	0.00525	-0.0115	-0.0150	-0.0047
	(0.0190)	(0.0224)	(0.0246)	(0.0178)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel B				*Placebo*
DST	-0.00375	0.00967	0.0128	-0.0076
	(0.0166)	(0.0207)	(0.0226)	(0.0172)
Bandwidth Selector	mserd	cerrd	cersum	mserd

Notes: The dependent variable is the natural log of total deaths due to suicide (Panel A) and all DoD (Panel B) demeaned by day-of-week, month, and year. All specifications use a local linear regression and a uniform kernel. 1979-1986, the placebo transition date is assigned using the mechanism from 1987-1988; while the placebo transition date in 1987-1988 is assigned using the mechanism from 1979-1986. Robust standard errors are in parenthesis.

*** Significant at a 1 percent level

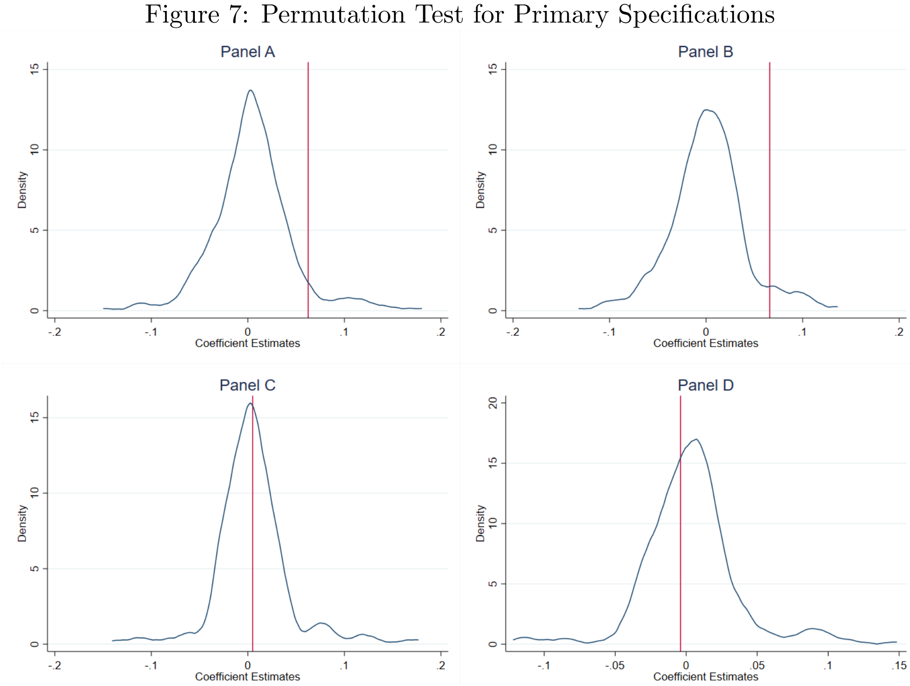
** Significant at a 5 percent level.

* Significant at a 10 percent level.

To further test the robustness of these estimates and to put their magnitude in perspective, permutation tests suggested by Smith (2016) are run for all primary specifications. This test uses the same estimating procedure as above for every date and generates a distribution of estimate coefficients. Results are in Figure 7. Here, the vertical red line indicates the placement of the estimates from column 1 of Panels A and B in Table 1. For Panel A (suicide), the p-value is .10. For Panel B (all DoD), the p-value is also .10. This means the point estimates at both of these transition dates are relatively large compared to other dates throughout the year. That the p-value is not lower is understandable. There are likely other events that impact DoD more than DST, such as the days major holidays or after events like the World Series or Superbowl. This likelihood notwithstanding, both estimates represent outliers.

This procedure is duplicated for the Fall Transition. For Panel C, the p-value is .83. For Panel D, the p-value is .90. This is further evidence that the Fall DST transition has no measurable effect on DoD. There doesn't appear to be anything particularly unique about the coefficient estimates at this particular threshold relative to other dates throughout the year.

Figure 7: Permutation Test for Primary Specifications



Notes: These are the result of a permutation test for the primary estimates of DST. The kernel density function uses a uniform kernel and shows the distribution of coefficient estimates for equation (1) for all dates through the year. The vertical red line represents the true estimate. Panel A is from a regression of suicides alone during the Spring transition. It has a point value of .0625, and has a p-value of .10. Panel B is from a regression of all DoD for the Spring transition. It has a point value of .0659, and has a p-value of .10. Panel C is from a regression of suicides alone during the Fall transition. It has a point value of .0053, and has a p-value of .83. Panel B is from a regression of all DoD for the Fall transition. It has a point value of -.0638, and has a p-value of .90.

The results for the FE model are in Table 4. Here, $SpDST_{dy}$ indicates , while $FaDST_{dy}$ indicates . Column 1 gives estimates for suicides alone while column two includes all DoD. In both cases, estimates are statistically significant and qualitatively similar to the RDD results for $spDST_{dy}$. However, the magnitude for both regressions is smaller. For the Fall, the results are again small and insignificant, validating the findings from the RDD model.

Table 3: The Effect of DST on Suicide and DoD using FE Model

	(1)	(2)
SpDST	0.0394**	0.0292*
	(0.0174)	(0.0171)
FaDST	0.0235	-0.000435
	(0.0392)	(0.0390)
Constant	4.229***	4.388***
	(0.0157)	(0.0150)
Observations	3,653	3,653
R-squared	0.330	0.324

Notes: The dependent variable is the natural log of total deaths due to suicide (column (1)) and all DoD (column (2)) demeaned by day-of-week, month, and year. SpDST is the effect of the Spring DST transition on suicide and all DoD for Panel A and B, respectively. faDST is the effect of the Fall DST transition on suicide and all DoD for Panel A and B, respectively. Robust standard errors are in parenthesis.

The smaller magnitude of the coefficients could be because the effects of sleep loss diminish with time. Indeed, the prevailing literature suggests the effects of a sleep disruption last approximately a week. Re-estimating Table 3 with the inclusion of dummies for being within a week of the transition ($spDST1_{dy}$ for Spring, $FaDST1_{dy}$ for Fall), the coefficient estimates become much closer to the RDD estimates. These results are in Table 4.

Table 4: The Effect of DST on Suicide and DoD using FE Model

	(1)	(2)
SpDST1	0.0517**	0.0454**
	(0.0220)	(0.0209)
SpDST2	0.0268	0.0155
	(0.0204)	(0.0198)
FaDST1	0.000849	0.0290
	(0.0389)	(0.0393)
FaDST2	0.0234	0.0590
	(0.0498)	(0.0472)
Constant	4.2333	4.3989
	(0.0130)	(0.0121)
Observations	3,653	3,653
R-Squared	0.330	0.325

Notes: The dependent variable is the natural log of total deaths due to suicide (column (1)) and all DoD (column (2)) demeaned by day-of-week, month, and year. SpDST is the effect of the Spring DST transition on suicide and all DoD for Panel A and B, respectively. faDST is the effect of the Fall DST transition on suicide and all DoD for Panel A and B, respectively. Robust standard errors are in parenthesis.

6 Conclusion

DoD has been on the rise over the past twenty years, and it's become increasingly important to understand its triggers and underlying causes. This paper attempts to do that by addressing how changes in ambient light and disruptions to the circadian rhythm brought on by DST impacts DoD. DST is unique in that it lends itself well to well to two complementary identification strategies. First, it has two defined thresholds every year that starkly changes treatment status for everyone in an area where DST is observed, which makes it ideal an RDD. Using within year variation in this way gives unbiased estimates of local average treatment effects, but leaves questions about seasonality impacting the results. Second, the DST transition date assignment mechanism introduces natural variation in the starting and stopping days between years, making it equally well suited for analysis with a FE model. Getting similar results using across year variation in this way helps minimizes any concerns with the primary specification.

The results from both cases are strongly suggestive of Spring DST transitions having a large and meaningful impact on DoD. Using multiple bandwidth selectors and kernels, all RDD estimates suggest the transition increases suicide and all DoD by between 6-8 percent around the threshold. These estimates are verified with a permutation test, which suggests the jump in DoD at the Spring DST threshold is an outlier among all days throughout the year. The results from the FE approach corroborate these results, though the magnitude found here suggests the jump is between 3-4 percent. The difference is likely because the effect of the DST transition is most acute directly after the change, which is more directly estimated with the RDD.

The results for the Fall DST transitions suggest no impact on DoD. Using multiple bandwidth selectors and kernels, all RDD estimates remain small and insignificant. Results from a permutation test suggest there is nothing unique about the change in deaths around this date relative to other days throughout the year. The results from the FE approach corroborate these findings.

Estimates for the Spring can be interpreted as the combined effect of more sun exposure and less sleep, since there is more ambient light during the waking hours and people sleep on average 32-40 minutes less at the transition. Estimates for the Fall can be interpreted as the impact of less light exclusively, since there is no evidence of people sleeping more despite the day having an extra hour. Since there is no evidence of any effect during the Fall, the jump in fatalities around the Spring DST can be attributed to loses in sleep exclusively.

This paper adds to a thread of literature on the adverse effects of the Spring DST transition. In addition to the findings here, evidence suggests it does not accomplish its primary objective of saving energy (Momani et al. 2009; Krarti and Hajiah, 2011; Kotchen and Grant 2011; Sexton et al. 2014); it increases automobile crashes by 5.6 percent (Smith 2016); and it increases robberies by 7 percent; among other potentially negative outcomes. Interestingly, there is some evidence for positive effect of ambient light exposure around the Fall transition. For example, there is some evidence that it helps reduce crime (Doleac and Sanders 2015) and encourage exercise (Wolff and Makino 2013). Combined, the policy implication from this paper and others in this vein is to abandon yearly DST transitions and remain on DST all year. This would eliminate the deleterious effects of sleep loss during the Spring transition while allowing more ambient light exposure through the evenings year round.

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7 Appendix

Table A.1: The transition of other factors contributing to DoD over the DST threshold

	(1)	(2)	(3)	(4)
Panel A				
DST	-0.00235	-0.0107	-0.0337	0.0612
	(0.0128)	(0.0139)	(0.127)	(0.133)
Bandwidth Selector	mserd	mserd	mserd	mserd

Notes: The dependent variable is the natural log of closing NASDAQ price (columns (1) and (2)) and inches of precipitation (columns (3) and (4)) demeaned by day-of-week, month, and year. All specifications use a local linear regression and a uniform kernel. DST is the effect of the Spring DST transition in the Spring for columns (1) and (3). DST is the effect of the Fall DST transition for columns (2) and (4). Robust standard errors are in parenthesis.

*** Significant at a 1 percent level

** Significant at a 5 percent level.

* Significant at a 10 percent level.

Table A.2: The Effect of DST on Suicide and DoD using RDD, no adjustment

	(1)	(2)	(3)	(4)
Panel A				*Placebo*
DST	0.0557***	0.0704***	0.0647***	-0.00820
	(0.0196)	(0.0233)	(0.0211)	(0.0168)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel B				*Placebo*
DST	0.0598***	0.0667***	0.0669***	-0.00792
	(0.0182)	(0.0228)	(0.0201)	(0.0155)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel C				*Placebo*
DST	-0.00523	0.00951	-0.00754	-0.000983
	(0.0169)	(0.0209)	(0.0246)	(0.0180)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel D				*Placebo*
DST	0.00135	0.0153	0.0153	-0.00862
	(0.0162)	(0.0198)	(0.0207)	(0.0166)
Bandwidth Selector	mserd	cerrd	cersum	mserd

Notes: The dependent variable is the natural log of total deaths to to suicide (Panel A and C) and all DoD (Panel B and D) demeaned by day-of-week, month, and year. Here, there is no adjustment for hours per day at the transition date. All specifications use a local linear regression and a uniform kernel. DST is the effect of the Spring DST transition on suicide and all DoD for Panel A and B, respectively. DST is the effect of the Fall DST transition on suicide and all DoD for Panel C and D, respectively. Robust standard errors are in parenthesis.

*** Significant at a 1 percent level

** Significant at a 5 percent level.

* Significant at a 10 percent level.

Table A.3: The Effect of DST on Suicide and DoD using RDD, Epanechnikov Kernels

	(1)	(2)	(3)	(4)
Panel A				*Placebo*
DST	0.0542***	0.0716***	0.0685***	-0.0128
	(0.0173)	(0.0210)	(0.0200)	(0.0149)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel B				*Placebo*
DST	0.0722***	0.0730***	0.0728***	-0.0155
	(0.0181)	(0.0218)	(0.0191)	(0.0138)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel C				*Placebo*
DST	-0.00493	-0.0231	-0.0126	0.0251
	(0.0416)	(0.0493)	(0.0391)	(0.0455)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel D				*Placebo*
DST	0.00847	0.00404	0.0000	0.0152
	(0.0415)	(0.0501)	(0.0384)	(0.0352)
Bandwidth Selector	mserd	cerrd	cersum	mserd

Notes: The dependent variable is the natural log of total deaths to to suicide (Panel A) and all DoD (Panel B) demeaned by day-of-week, month, and year. All specifications use epanechnikov kernel. DST is the effect of the Spring DST transition on suicide and all DoD for Panel A and B, respectively. DST is the effect of the Fall DST transition on suicide and all DoD for Panel C and D, respectively. Robust standard errors are in parenthesis.

*** Significant at a 1 percent level

** Significant at a 5 percent level.

* Significant at a 10 percent level.

Table A.4: The Effect of DST on Suicide and DoD using RDD, Triangular Kernels

	(1)	(2)	(3)	(4)
Panel A				*Placebo*
DST	0.0554***	0.0687***	0.0677***	-0.0131
	(0.0175)	(0.0212)	(0.0201)	(0.0149)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel B				*Placebo*
DST	0.0693***	0.0687***	0.0698***	-0.0159
	(0.0182)	(0.0220)	(0.0194)	(0.0139)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel C				*Placebo*
DST	-0.0085	-0.0179	-0.0133	0.0288
	(0.0416)	(0.0493)	(0.0396)	(0.0476)
Bandwidth Selector	mserd	cerrd	cersum	mserd
	(1)	(2)	(3)	(4)
Panel D				*Placebo*
DST	0.0082	0.0077	-0.0005	0.0315
	(0.0420)	(0.0508)	(0.0380)	(0.0385)
Bandwidth Selector	mserd	cerrd	cersum	mserd

Notes: The dependent variable is the natural log of total deaths to to suicide (Panel A) and all DoD (Panel B) demeaned by day-of-week, month, and year. All specifications use triangular kernel. DST is the effect of the Spring DST transition on suicide and all DoD for Panel A and B, respectively. DST is the effect of the Fall DST transition on suicide and all DoD for Panel C and D, respectively. Robust standard errors are in parenthesis.

*** Significant at a 1 percent level

** Significant at a 5 percent level.

* Significant at a 10 percent level.