Ambient Lighting and Arrests: Evidence from a Natural Experiment

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Abstract
Objectives This study assesses whether changes in outdoor lighting affect the likelihood that a crime results in an arrest.

Methods This study uses crime data from the FBI's National Incident-Based Reporting System (NIBRS) to measure the change in the odds that a crime results in an arrest when the amount of evening lighting changes. Using a logistic regression, this study compares the odds that a crime results in an arrest in the week after the transition to and from daylight saving time (DST) compared to the previous week. Several robustness checks are used.

Results Following the transition to daylight saving time, when there is an extra hour of daylight during the evening, the odds of an arrest increase significantly for violent crime, and particularly for robbery. At the end of DST in the fall, when the evening has one hour less of daylight, there is no significant change in the odds of an arrest for any crime category.

Conclusions These results suggest that the crime-reducing effect of lighting seen in past studies is caused, at least partially, by incapacitating offenders through arrest.

Keywords: outdoor lighting, daylight saving time, arrest rate, CPTED, Routine Activity Theory

Article Type: Original Research

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For helpful comments and suggestions, thank you to Sara-Laure Faraji, Kristina Block, and Aaron Chalfin. All remaining errors are my own.

1 Introduction

Prior to the 17th century, the threat of crime prevented city residents from using outdoor spaces during the night. In response to residents' growing desire for more leisure and commercial activities at night, local governments began to organize and maintain streetlights by the end of the 17th century.[1] The installation of streetlights was meant to "introduce law and order" to cities during the night, improving public safety enough to allow residents to roam the city without fear of crime (Schivelbusch 1987, 62).

Prior to government-run streetlights, individual homeowners were required to light candles outside their homes to provide some level of lighting during the night (Beer 1941; Koslofsky 2002). The shift from private to public control of outdoor lighting was a major growth in government control of society. Streetlights permitted residents to use the city at night while the government took responsibility for their safety. Streetlights are still used today - now equipped with electrical lights that are far brighter than historical torches - to combat both fear of crime and crime itself (Painter 1996; Trickey 2017b; Hendrickson 2018; Hurd 2019; Staff 2019). Although societies have ubiquitously used lighting to control crime for centuries, the literature on light's effect on crime is sparse.

Over three centuries after the first streetlights were established, Welsh and Farrington's (2008) seminal meta-analysis of research on streetlights revealed that only thirteen studies on this topic compared pre-post counts of crime in a treated area to a control area. From their analysis of these thirteen studies, they found that improving street lighting reduces crime, both at night when the lights affect visibility as well as during the day, with similar effect sizes for both periods. They offered two mechanisms for how street lighting affects crime, one of which was that improving visibility reduces the number of attractive targets of crime as these targets are better lit and therefore more observable to any witnesses.

That surveillance affects crime is a core tenet of Crime Prevention Through Environmental Design (CPTED), which attempts to reduce criminal opportunities by altering the physical environment (Crowe and Zahm 1994; Cozens, Saville, and Hillier 2005; Cozens and Love 2015). Areas with high levels of surveillance allow the public to observe anyone entering their street and alert the authorities if they see something suspicious. Improving streetlights can have a dramatic effect on surveillance opportunities by brightly illuminating an area, significantly reducing the number of opportunities an offender has to commit crimes without witnesses.[2] While an increased risk of detection due to better nighttime lighting likely affects crime at night, it is insufficient to explain the reduction in daytime crime. Welsh and Farrington's second mechanism, that improved lighting affects the community through increasing its cohesion and informal social control, provides some answers to how streetlights could affect daytime crime.[3]

Areas with strong informal social control are able to maintain order informally, primarily by residents monitoring or confronting undesirable activities, without necessitating involvement of the police. Areas with high informal social control may experience fewer disorderly activities or crimes as offenders choose areas with better opportunities for crime. A neighborhood with more streetlights could signal to would-be offenders that the residents are invested in their neighborhood and the activities that occur within the area, and thus may be a signal that the area has strong informal social control. Improvements to street lighting has also been found to increase pedestrian usage of the area, further increasing the number of community members who know each other and can serve as witnesses to any crimes (Painter 1996). The role of informal social control on crime is an important aspect of Wilson and Kelling (1982)'s influential Broken Windows Theory which states that areas with visible signs of disorder signals to would-be offenders that the area is ripe for crime. These high-disorder areas signal that crime is tolerated as previous offenders were unobstructed and may lessen the perceived severity of the crime as it would merely be one of many crimes. A community with few signs of disorder and high levels of activity or surveillance opportunities signals to offenders that they risk apprehension if they do commit a crime as any suspicious behavior could be noticed and interrupted. Welsh and Farrington's (2008) findings that crime decreased by similar amounts during both the night and the day suggests that streetlights have an effect on both opportunities at night and informal social control during the day.

As Welsh and Farrington (2008) noted, these two mechanisms likely work hand in hand. However, it is not entirely clear whether improvements to lighting also improve informal social control, or if informal social control leads to the improved lighting. A community with growing cohesion and informal social control, for example, may request additional crime-reducing services from the local government, such as improved streetlights. Improved lighting may increase a community's level of informal social control if the improved safety due to increased illumination causes community members to become more willing to assert themselves and take ownership of the activities in the community. Thus, the temporal ordering of the relationship between the changes in lighting and informal social control is unclear.

A recent experiment on lighting by Chalfin et al. (2019) can address this time-order question. Chalfin and his colleagues randomly assigned light towers to housing projects in New York City and found significant declines in nighttime crime in the housing projects that received the lights relative to a comparison group. As the lights were randomly assigned, they preceded any change in social cohesion in the community. The results indicate that improving lighting does itself reduce crime. This is important to the criminology field as it suggests that these policy measures - installing or improving outdoor lighting - can reduce crime. Though this experiment studied only a relatively narrow type of location - areas high in crime and thus ideal for targeted crime-prevention efforts - it provides strong evidence that high social cohesion in a community is not necessary at the start of the intervention for lighting to be effective. However, there are likely heterogeneous effects of lighting based on the community and further research is needed to ascertain how to best use lighting in a variety of communities.

1.1 Light and Risk: A Simple Model

This section provides a simple model of the effect lighting has on crime to help understand which types of crimes and offenders are likely to be responsive to changes in lighting. Similar to Doleac and Sanders' (2015) model of light's effect on crime, a crime is expected to occur if the offender perceives the benefit of that crime to be greater than the product of the perceived chance that they are detected and the expected severity of punishment for that crime.

$$E[Benefit_{crime}] > E[Detection] * E[Punishment] \tag{1}$$

In situations where either the expected chance of detection or the severity of the punishment increase, crime will decrease in response. As lighting's primary influence is through its effect on perceived detection, changes in lighting will only matter in situations where visibility affects perceived detection. For crimes where the victim and offender know each other, such as in domestic violence situations, changes in lighting will have no effect on the offender's perception of detection because the victim can identify them regardless of lighting.[4] Changes in lighting are likely to be most effective at reducing outdoor crimes between strangers as the risk of detection will be altered by changes in lighting.[5]

Crimes between people who know each other but are in a public area where a witness may still alert the police may be responsive to changes in lighting. A Bureau of Justice Statistics report on the National Crime Victimization Survey (NCVS) found vast differences in the location of offenses depending on if the victim and offender knew each other (Rand and Robinson 2011, Table 63). In violent crimes when the victim and offender know each other - which make up about half of all violent crimes committed - nearly a third of crimes are in the victim's residence, where it is unlikely that there will be witnesses. Violence between strangers was far more likely to occur outside and in public areas such as a parking lot or playground than violence between people who know each other. This indicates that changes in lighting will have a larger effect for crimes between strangers than crimes among non-strangers.

Studies on offender's perception of risk have found that the perceived risk of detection plays a major role in their decision to commit a crime. Armitage (2018) surveyed 22 prolific burglars incarcerated in England about how attractive or risky a burglary target is based on a photo of the home.[6] She found that burglars were most concerned with surveillance as every burglar mentioned the possibility of being observed as a significant factor in their decision to burgle a home. A similar study by Carmel-Gilfilen (2011) interviewed shoplifters about their perception of the risk of detection while shoplifting during a walk-along of a large department store. These shoplifters were most concerned with being observed, both by CCTV in the store and by employees. This suggests that offenders are responsive to changes in surveillance opportunities, such as increased lighting. These findings may not generalize for offenders under the use of mind-altering substances or suffering from mental illnesses as these individual may not perceive risk in a standard way.

Offenders who commit crimes out of economic necessity, for example to support a drug addiction, may be less responsive to changes in lighting as their perceived benefit may outweigh even high levels of risk. Reppetto's (1974) study of residential burglary found substantial differences in the number of burglaries committed depending on if the offender was a drug user or not. Drug users committed over twice as many burglaries per week as the average non-drug user.[7] Nearly half of drug users committed five or more burglaries per week compared to 16% of non-drug users. As the risk of apprehension is largely the same for both drug and non-drug offenders, this suggests that drug users have a far higher risk tolerance than non-drug users, likely due to their higher monetary needs.[8]

While increased lighting could alter the potential costs of engaging in a criminal act, it may also alter an offender's perception of the benefit of the crime by improving their information about what they stand to gain from the act. Better lighting can improve the offender's observation of victims and "allow better judgments [by the offender] of [the victim's] vulnerability" and what goods they have to steal (Welsh and Farrington 2008, 5). In cases where increased lighting provides illumination of potential targets while still offering offenders a suitable area to commit the crime, the increase of light may actually increase crime. Some of the burglars in Armitage's (2018) study said they preferred areas where they could observe the house to assess the risk of detection and the available valuables to steal while avoiding being seen themselves. Streetlights may offer these areas of concealment to offenders, increasing crime if they inadequately illuminate the areas where victims are.[9] While streetlights are a common policy tool to affect crime, they leave substantial areas in darkness in the locations where they are installed, making studies of lighting on crime limited. In recent years, a number of studies have started to use daylight saving time, which increases lighting across the entire city studied, as a natural experiment to avoid this issue.

1.2 Daylight saving time and behavior

While introduced in the early 20th century in the United States as an energy saving measure, daylight saving time (DST) increases the amount of daylight that is available in the evening. The transition to DST in spring pushes sunrise and sunset times back by an hour, effectively making mornings darker and evenings brighter. In fall, DST ends and sunrise and sunset times return to their earlier hour, making mornings brighter and evenings darker. Figure 1 visualizes this effect by showing how DST impacts the amount of evening light on the Sunday that DST begins (ends) in the spring (fall) compared the same Sunday one week before and after.[10]

Studies of DST have often focused on public safety, measured primarily through fatal vehicle accidents (Ferguson et al. 1995; Varughese and Allen 2001; Sullivan and Flannagan 2002; Coate and Markowitz 2004; Stevens Jr and Lord 2006; Sood and Ghosh 2007; Huang and Levinson 2010; Harrison 2013; Smith 2016). Other studies have examined daylight saving time's effect on the stock market (Kamstra, Kramer, and Levi 2000; Berument, Dogan, and Onar 2010; Gregory-Allen, Jacobsen, and Marquering 2010), SAT scores (Gaski and Sagarin 2011), elementary school test scores (Herber, Quis, and Heineck 2017), life satisfaction (Kountouris and Remoundou 2014), mental health disorders (Heboyan, Stevens, and McCall 2018), workplace accidents (Holland and Hinze 2000; Robb and Barnes 2018), and heart attacks (Manfredini et al. 2018). Yet the field of criminology has only sparingly used the change in both sleep patterns and evening lighting caused by DST to examine crime.[11]

The majority of studies in criminology that do use DST use it to measure racial disparities in traffic stops (Grogger and Ridgeway 2006; Pierson et al. 2017; Ridgeway 2019). These studies use Grogger and Ridgeway's (2006) Veil of Darkness technique where the change in the amount of evening light available is used to measure an officer's ability to identify the race of a driver before stopping them. If the racial mix of drivers changes when lighting changes due to DST, that indicates that the ability to identify a driver's race is an important factor in traffic stops, and that racial profiling is occurring. However, studies using DST to measure crime, rather than police behavior, remain rare.

One notable study that does use DST to measure changes in evening lighting's effect on crime is Doleac and Sanders' (2015) study on light's effect on violent crime. Daylight saving time does not change the total number of hours of daylight in a day, it only shifts an hour of daylight from morning to evening. This can have significant effects on crime as there are far more crimes during the evening than in the morning (Van Koppen and Jansen 1999; Felson and Poulsen 2003; Tompson and Townsley 2010; Ceccato and Uittenbogaard 2014). Doleac and Sanders used DST to assess how murder, rape, aggravated assault, and robbery changed in response to the increased evening lighting caused by DST. They found that robbery decreased significantly, both throughout the entire day and specifically during sunset hours.[12] The probability that a city experienced at least one robbery during the day decreased by 19% while the probability that they experienced at least one robbery specifically during sunset hours decreased by 27%. The other crimes they studied had no significant effect in response to DST.[13] Umbach, Raine, and Ridgeway (2017) measured the effect of the loss in sleep caused by the spring start of DST and found that DST significantly reduces assault.[14] Their study found that the Monday immediately after spring DST, when people lose about 40 minutes of sleep, had 2.9% fewer assaults than the following Monday.[15]

The model of crime detailed in the prior section suggests that outdoor crimes among strangers are more likely to be responsive to changes in outdoor lighting than other crimes. Doleac and Sanders' (2015) finding that only robbery is responsive to the increased evening lighting caused by DST supports this model. According to the NCVS, two-thirds of robbery victims do not know their offender, far higher than for other serious violent crimes (Rand and Robinson 2011). Robberies are also more likely to occur outdoors than other violent crimes with over half of robberies being in public outdoor areas such as public streets or parking garages. In comparison, only one-fifth of rapes and one-third of aggravated assaults occur outside.

Past studies have found that increasing outdoor lighting decreases crime, however, they have yet to determine by which mechanism lighting affects crime. To evaluate one possible mechanism, this study tests the first of Welsh and Farrington's (2008) proposed mechanisms: that increased lighting alters the risk of detection for criminals. How lighting affects criminal behavior, rather than whether it does at all, as many past studies examine, is important in creating efficient crime-control lighting measures. This study addresses the question empirically by examining whether the likelihood of an arrest changes when an evening is brighter as a result of DST.

Almost all existing studies of lighting focus on its effect on crime, measured by the number of crimes committed, or on residents' fear of crime. The mechanism by which light affects crime is an important policy question as it affects both the measure of light's benefit to society as well as offers guidance to accompanying measures to maximize the benefits of lighting. If more light is associated with fewer crimes as well as fewer arrests, the implementation of lights can have a “double dividend” effect, improving public safety without any additional costs of incarcerating offenders. However, if crime is reduced because light increases arrests, the crime-reduction benefits could come at a significant financial cost to society by increasing incarceration. As the arrest rate for most crimes has declined in recent decades, increased lighting may offer one partial solution to reverse this trend if it is associated with increased arrests.

2 Data

The data used in this study comes from the FBI’s National Incident-Based Reporting System (NIBRS) for the years 2001 to 2016.[16] NIBRS provides detailed information about the circumstances regarding each crime reported to the police including where the crime occurred (in categories such as ‘Restaurant’ rather than exact locations in the city), the date and hour that the crime happened, and whether the offender was arrested. As outdoor lighting should not affect lighting indoors, this study only includes crime that happens outdoors.[17] As DST only affects evening lighting, this study examined crimes that occurred during the evening hours of 6:00 pm to 7:59 pm local time.

Reporting to NIBRS is voluntary and while the number of police agencies that report has grown over time, the majority of agencies do not report. Agencies that do report tend to be disproportionately small and located in the Appalachian region, the Midwest, or northwest parts of the United States. Figure **??** shows the location of all agencies included in this study. As the number of agencies reporting to NIBRS grows each year, there are different numbers of agencies reporting on any given year. According to the 2017 NIBRS report, almost 7,000 agencies, covering nearly one-third of the country’s population reported to NIBRS.[18] Agencies that do report to NIBRS may not do so every month. As this study compares days across different months, only agencies that report all 12 months of the year are included, which are the clear majority of agencies that do report at all. As Arizona and the majority of

Indiana do not follow DST, agencies from these states are removed from the data.[19] This study analyzes data from 3,985 agencies.

For each crime, NIBRS indicates if an arrest was made. Arrests can be "On-View Arrests" where an offender is arrested without a warrant, "Summoned/Cited" where the offender is ordered to appear in court but is not taken into custody, or "Taken into Custody" based on an arrest warrant as the result of an investigation. The change in evening illumination from DST may affect all of these forms of arrest. More outdoor light may make police patrols more effective, thus making more on-scene arrests. Likewise, the additional light could improve witness identification of the offender, improving the chances that the police identify and arrest the offender in the course of their investigation. As such, this study does not differentiate between forms of arrest.

In cases where there are multiple offenders, only one of the offenders needs to be arrested for NIBRS to report that the crime resulted in an arrest. For crime incidents in which multiple crimes are committed, all offenders involved are considered to have committed all crimes. Therefore, NIBRS considers a single arrest of any offender for any crime in the incident to be an arrest for every crime in the incident.[20] To avoid double-counting arrests when multiple offenses are committed in the same incident, only the most serious offense per incident is kept.[21]

This study examines whether the likelihood that an arrest is made changes for three crime categories: total index crimes, violent index crimes (murder, rape, robbery, and aggravated assault), and property index crimes (burglary, motor vehicle theft, theft, and arson).[22] In addition, robbery is examined by itself, as well as part of the violent crime category, as past studies have found robbery to be particularly responsive to changes in outdoor lighting (Doleac and Sanders 2015)

Table 1 shows the proportion of crimes that end in an arrest for each crime category examined. Overall, most crimes do not result in an arrest. Row (1) shows the proportion of crimes that have an arrest in the period after DST begins in spring and Row (2) shows the period before the transition. Rows (3) and (4) follow this pattern with data from the fall. Column (1) shows the results for total index crimes. During spring DST, there is a 1.3 percentage point increase in arrests from 8.2% in the period before DST begins to 9.5% in the period after; during the fall the effect is smaller with a 0.6 percentage point decrease from 7.8% to 7.2% after DST ends. Property crimes (Column (3)) are the least likely to result in an arrest and are least responsive to changes in lighting from DST. In spring, the transition to DST causes a 0.5 percentage point increase in arrests, from 4.6% of crimes resulting in an arrest to 5.1% of crimes; in the fall, there is nearly no change. The largest change is for violent crimes, particularly robbery. Violent crimes are the most likely type of offense to result in an arrest, though fewer than one-third of violent crimes do lead to an arrest. During spring, the percent of violent crimes that lead to an arrest (Column (2)) increases from 27% to 31.7% following the start of DST, a 4.7 percentage point increase. The effect is smaller in the fall, with a change from 25.4% of violent index crimes leading to an arrest prior to the end of DST to 21.6% following the change, a difference of 3.8 percentage points. Finally, robbery (Column (4)) has 3 percentage points more arrests following DST in spring than just before, and a similar difference in the fall when there are 3.4 percentage points fewer arrests after the end of DST than before. To visualize these effects, Figures **??** and **??** show the proportion of crimes that end in an arrest each day for a 30-day period around the start (end) of DST in spring (fall).

Figure **??** shows that as the pre-period days get closer to DST, the proportion of crimes that have an arrest increase, suggesting that as days get longer, and there are fewer minutes of evening darkness, the likelihood of an arrest naturally increases. At day 0, when DST begins and there is an extra hour of evening light, the proportion of crimes that have an arrest jumps significantly. This is most pronounced for violent index crimes (Panel B) and robbery (Panel D), indicating that violent crimes in general and robbery specifically are most affected by changes in lighting, in line with prior finding on the effect of lighting (Doleac and

Sanders 2015). While there is a spike in arrests for both total index crimes (Panel A) and property index crimes (Panel C), that effect quickly disappears in the days following DST.

Figure **??** shows this same visualization for the end of DST in the fall. As seen in Figure **??**, the proportion of crimes that have an arrest naturally changes over time, decreasing as fall progresses and there are naturally fewer minutes of evening daylight. However, these results show a much smaller change in arrests when DST ends, suggesting that any effect of DST is far weaker in the fall than during spring.

3 Empirical Strategy

To determine whether outdoor lighting affects the likelihood that an arrest is made, this study uses logistic regression to estimate the change in the odds of an arrest in the week following the start (end) of DST in spring (fall) relative to the previous week. Comparing days one week apart also offers the advantage that variables related to crime or broader behavioral changes, such as weather, are similar.

Days that fall on a holiday are removed because crime on these days is unlikely to be comparable to other days.[23] Additionally, NIBRS data contains a first-of-the-month error where the first day of each month has approximately 20% more crimes than any other day. As this appears to be a data error, these days are excluded from the study.[24]

This study measures the effect of changes in evening lighting on the odds of an arrest using the following estimation:

$$log\frac{p(arrest)}{1-p(arrest)} = \beta_0 + \beta_1 DST + \eta i + \zeta year + \lambda DayOfWeek_i \tag{2}$$

where *arrest* is a binary variable indicating if the crime resulted in an arrest. *DST* takes the value of 1 if the day is during the week immediately after the start (end) of DST (including the day of the transition) and a value of 0 if it in the previous week. This is the variable of interest and will indicate whether the odds of an arrest changes as a result of changes in evening lighting caused by DST. To control for potential differences in arrest rates between cities and over time, fixed effects for the city, the year, and the day of week are used. ηi is the agency fixed effect to control for differences in arrest rates between agencies. $\zeta year$ is the year fixed effect and $\lambda DayOfWeek$ is the day of week fixed effect to control for differences in trends across all agencies that vary by time, such as year or day of week.

3.1 Regression Discontinuity

Following Doleac and Sanders (2015), this study also uses a regression discontinuity (RD) design to study a three-week period before and after the start (end) of DST.[25] This analysis seeks to estimate the following model:

$$log\frac{p(arrest)}{1-p(arrest)} = \beta_0 + \beta_1 DST + \beta_2 days + \beta_3 DST * days + \zeta year + \lambda DayOfWeek \quad (3)$$

where $arrest$ is a binary variable with the value of 1 when the crime ends in an arrest and 0 otherwise. DST is measured the same as in Equation (2) and is 1 on the day of the change to start (end) DST and on following days and is 0 on previous days. As in the previous model, this is the variable of interest and will indicate the effect of DST on arrests. $days$ is a running variable from -21 to 20 which is the number of days since the change in DST. This value is 0 on the day that DST starts (ends) in spring (fall) and 1 on the next day, 2 on the following day, and so on. $DST * days$ is the interaction between the DST indicator variable (DST) and the number of days from DST ($days$). As in Equation (2), this model uses agency and time fixed effects (year and day of week) represented by ηi, $\zeta year$, and $\lambda DayOfWeek$, respectively.

4 Robustness Checks

This study checks the robustness of the findings through three falsification checks, all of which are expected to yield null results.

In 2005, the United States Congress passed the Energy Policy Act of 2005 which altered the start and end dates of daylight saving time starting in 2007. The beginning of DST moved from the first Sunday in April to the second Sunday in March. The end of DST changed by one week from the last Sunday in October to the first Sunday in November. Following Umbach, Raine, and Ridgeway (2017), this study uses this policy change as the first robustness check by reverse coding the dates of DST such that years prior to 2007 would use post-2007 dates while years after 2007 would use pre-2007 dates.

The second robustness check compares the week immediately after DST with the week one week after that. As both weeks are after DST, the differences between the amount of evening daylight they have is minimal, and there should be no difference between the likelihood of an arrest. As the following week is already included in the RD analysis, this robustness check is not used for that model.

For the final robustness check, this study examines crimes that occur during the day. As DST affects the time in which the sun sets, there should be no effect during daytime hours. For this check, the analyses are rerun with the data using hours from 10:00 am - 3:59 pm rather than during the sunset hours of 6:00 pm - 7:59 pm.[26]

The states of Arizona and Hawaii, and part of the state of Indiana, do not follow daylight saving time meaning that these areas could be used as a robustness check as they do not experience the change in lighting from DST.[27] However, there was not a sufficient number of offenses in the agencies from these states that report to NIBRS to analyze.

5 Results

5.1 Spring: More evening lighting

Table 2 presents results from the analysis for the effect of the start of DST during spring. Panel A shows the main results while Panels B-D show the three robustness checks. In Panel A, Row (3) reports the exp(B) or the odds ratio which indicates that the transition to DST in the spring significantly increases the likelihood that a crime ends in an arrest.[28] This effect is driven by violent crime, particularly robbery. Column 1 shows the effect on total index crimes, with the start of DST increasing the odds of an arrest by about 12%. The odds ratio for Columns 3 and 4 show the effect for violent crimes and robbery, respectively. The odds of an arrest for a violent crime increased by 27%. For robbery, the odds of an arrest increased by 46% relative to the week before the start of DST. Column 3 shows a modest increase in the odds of an arrest at approximately 5%, however, this effect is not statistically significant. While these increases are large in percentage terms, the change in the probability of an arrest is more modest due to the low base rate of arrests. As seen in Table 1, in the three weeks prior to DST in the spring, the likelihood of an arrest for robbery, for example, is approximately 17%. The odds ratio for DST's effect on robbery is 27%, an increase of the likelihood of an arrest from 17% to about 22%. As such, readers should be cautious when interpreting these results as the change in the probability of an arrest remains modest.

The robustness check using the reverse coding as a result of the U.S. Congress changing the date of DST beginning in 2007 are shown in Panel B of Table 2 and follow the same layout as in Panel A. All results are non-significant. Panel C shows the second robustness check, comparing the week following DST to the week after that. In all checks except for robbery in the spring, the results are non-significant. The final robustness check, shown in Panel D, examined crime during the morning and early afternoon as DST does not affect daylight during these hours. All tests except for violent index crimes in the fall are non-significant. Given the large number of tests ran, and the relatively high p-values for the significant results, these findings are likely spurious.

Table 3 shows results for the regression discontinuity design shown in Equation (3). This table presents results for the spring analysis and follows the organization of Table 2 except, as noted in the previous section, does not use the week after robustness check. As in the previous table, results from this model have a significant and large effect for violent index crimes and robbery. The odds of a violent index crime resulting in an arrest is 34.9% higher during DST in spring than before DST and is 65.3% higher for robbery specifically.

While these results are larger in magnitude than shown in the Table 2, their findings support the model from Section 1.1 that suggests that violent crimes are responsive to increases in lighting, particularly robberies. Panel B shows the results for the reverse coding robustness check. Both total index crimes and violent index crimes are statistically significant, failing the robustness check. While violent index crimes are not significant when correcting for multiple hypothesis tests, total index crimes remains significant. As this result is statistically significant and has a large effect size with an odds ratio of 60.2%, this provides evidence that the RD design to analyze DST is flawed. As such, readers should be cautious in interpreting results solely from this model. However, as results are substantively similar to those presented in Table 2, which follows the method done in past research on this topic, and that other robustness checks pass, the overall results likely hold. Panel C shows results of the daytime check and no result is statistically significant.

5.2 Fall: Less evening lighting

Table 4 follows the same organization as Table 2 and presents results from the fall analysis when DST ends and this is less daylight during the evening. In the fall, when DST ends and there is less evening light, the odds ratio for all crimes are less than one, indicating that the reduction in outdoor lighting reduces the odds of an arrest. However, all of the crimes studied have non-significant effects, meaning that the effect is not significantly different from no effect. In this analysis, the only significant result is for violent index crimes in the daytime robustness check shown in Panel D. However, after correcting for multiple hypothesis tests, this result is not significant.

The final results are presented in Table 5 and show results for the fall analysis using the regression discontinuity design. As with the previous fall results, no results are statistically significant when correcting for multiple hypothesis tests.

6 Discussion

Through the use of the natural experiment of daylight saving time, this study was able to measure the effect of a major change in evening lighting on arrests. The findings provide evidence that improving outdoor lighting significantly increases the likelihood that an offender is arrested following their crime. This indicates that the crime-reduction effect of lights is driven, at least partially, by incapacitating offenders through arrest. Another possible mechanism is that the increase in lighting reduces the number of opportunities to offender with a low risk of being caught, reducing the window in which offenders can comfortably operate. This means that offenders have both fewer offenses to commit and a higher risk for each offense. If some offenders are deterred from offending and the remaining offenders are more likely to be caught, that could explain the results from this study. More research is required to confirm which mechanism is responsible.

Results show that the increase in evening lighting at the start of DST in spring significantly increases the odds of an arrest, however the opposite is not true when evening lighting declines at the end of DST in the fall. This suggests that the effect of lighting is not homogeneous - conditions such as the current level of outdoor lighting and how people use public space during different parts of the year likely affect how lighting impacts arrests. As such, future research should examine the heterogeneous effect of lighting to see in what conditions lighting is most effective at reducing crime and increasing arrests. This study's findings support Welsh and Farrington's (2008) first hypothesis on how lighting affects crime: increased lighting leads to a higher risk of apprehension for offenders.

These findings have important implications for criminal justice policy as they suggest one tool to improve arrest rates. In recent years, significant attention has focused on the quandary that while crime has declined significantly since the 1990s, the arrest rate for crimes have been largely stagnant. Figure 1 shows national arrest rates for violent and property crimes in the United States from 1980-2017. During each year since 1980 approximately 40% of violent crimes and under 20% of property crimes were cleared by arrest. This has garnered attention toward how law enforcement could increase their arrest rates, especially for violent offenses (Cook et al. 2019; Raphael 2016; Blanes Vidal and Kirchmaier 2018; Braga and Dusseault 2018; Scott et al. 2019; Kingshott and Meesig 2019; Avdija 2019; Morgan and Dowling 2019; Pizarro, Terrill, and LoFaso 2018). This study's findings suggest that policy makers who wish to prioritize increasing arrest rates should increase lighting in dark areas that have both a high crime rate and a low arrest rate.

While the NIBRS data used in this study provides more detailed information than nearly all other publicly available crime data sets, it is limited as it only records crimes reported to the police. Victimization surveys have found that a substantial percent of victims do not report their crimes to the police (Rand and Robinson 2011). As police cannot make an arrest for crimes that are not brought to their attention, this study measures lighting's effect on only a subset of the total number of offenses committed. Future research should examine how lighting affects these unreported offenses, in particular whether it changes the likelihood of reporting (if a victim can better identify their offender, they may be more willing to report) or victim-level outcomes such as injury seriousness. The NIBRS data also does not indicate where exactly in the city the crime occurred, it only gives the location in broad categories. Daylight saving time significantly alters the amount of evening lighting a city has overall, however within the city the effect of DST is likely heterogeneous depending on the amount of ambient light already present.

As blocks that are brightly lit by streetlights are less affected by DST than ones that are dark, this provides opportunities for future research. Horrace and Rohlin (2016) used DST to measure racial disparities in traffic stops in Syracuse, New York, and found that there was no difference between races stopped by police. After controlling for the amount of lighting due to nearby streetlights at each stop, they found a significant racial disparity, indicating that the effect of DST may be imprecisely measured at the city-level due to variations in lighting within a city. Future studies should examine the effect of DST on the likelihood of an arrest within a city while controlling for the level of light near each crime incident. The difference in arrest rates between bright and dark blocks can provide valuable information as to what effect existing streetlights have on arrest rates.

This study provides evidence that an increase in crimes resulting in an arrest contributes to the decline in crimes found in past research on lighting. Though more frequent changes in DST to further improve evening lighting is unlikely, policy makers are able to manipulate lighting through installing or improving streetlights in their community. Indeed, a number of cities have begun increasing the brightness of existing streetlights by replacing the current bulbs with brighter LEDs (Trickey 2017a; Bliss 2019; Wisniewski 2019; Jaramillo 2020). Along with the crime-reducing result found by past studies, these improved lights may increase arrest rates; policy makers should be attentive to this when considering how to prioritize locations to receive these improvements. While future research is required to determine precisely how increased lighting affects arrest rates, this study provides a starting point in explaining the mechanism by which lighting affects crime.

Notes

[1] In some cities this duty was assigned to the local police in recognition that a primary objective of the streetlights was to improve public safety.

[2]Indeed, as early as 1692, witness testimony during a trial for a murder in London that occurred at night was accepted because the streetlamps that lit the road illuminated the area enough for the offenders to be adequately identified (Beer 1941).

[3]The reduction in daytime crime may also be a result of the reduced familiarity offenders have with the area if they commit fewer crimes at night in response to the improved nighttime lighting. The resulting lack of familiarity may encourage offenders to refrain from committing crime during the daytime in areas they know less well in favor of locations they know better.

[4]An important exception is when the change in lighting alters other behaviors that affect crime, such as alcohol consumption.

[5]While changes in lighting are likely to reduce the probability of an individual crime from occurring, it may not reduce the total number of crimes committed in a city. For example, consider an offender who requires X amount of money a week to satisfy their needs, and acquires that money through robbery. That offender decides to commit a robbery only if they believe there is no more than a 10% chance they will be caught. If an increase in outdoor lighting reduces the number of suitable targets, based on the robber's acceptable degree of potential detection, but still provides enough victims to reach the X amount of dollars they desire, the total number of crimes committed would be unchanged.

[6]A prolific burglar is defined as one who committed about five burglaries per month.

[7]The drug users in Reppetto's (1974) study were primary heroin users. The opioid epidemic currently ongoing in the United States is fueled primarily through heroin users, making Reppetto's findings likely generalizable to current users who commit crimes to afford drugs. Over three-quarters of the burglars interviewed by Armitage (2018) admitted to being under the influence of drugs, primarily heroin and cocaine, during their burglaries.

[8]While all property offenders are likely to be economically motivated, except for some young offenders who report offending for the thrill of the crime, drug users report requiring far more money from crimes than non-drug users, which is why they offend so frequently. Reppetto (1974) found that while drug users received approximately the same amount of money per burglary as non-drug users, their need for money for drugs caused them to commit about three times as many burglaries.

[9]As victims and witnesses are likely to stay on designated walking paths, such as sidewalks or running trails, there are likely unlit areas off these paths where offenders can stay.

[10]For places that observe daylight saving time, the time adjustment always occurs at 2:00 am on a Sunday.

[11]The reduction of crime has been one of daylight saving time's purported benefits since its adoption, though with little evidence until recently to support this claim (Gurevitz 2005)

[12]Doleac and Sanders (2015) defined sunset hours as the hour of sunset and the following hour in the day prior to DST. This is done to compare hours which, "prior to DST, were dark but are now light" (pp. 1097). When defining evening crime as any occurring between 6:00 pm and 7:59 pm, they found similar results.

[13]A working paper by Dominguez and Asahi (2017) on DST in Santiago, Chile found similar results.

[14]Umbach, Raine, and Ridgeway (2017) defined assault as the sum of aggravated and simple assault; Doleac and Sanders (2015) defined assault as only aggravated assault.

[15]As DST adds an hour to the day during spring and removes it during fall, it is hypothesized to reduce sleep by an hour in spring and increase sleep by an hour in fall. Studies that examine this empirically find that the shift to DST during spring reduces sleep by approximately 30-40 minutes with sleep patterns returning to normal by the sixth day after the change (Monk and Folkard 1976; Kantermann et al. 2007; Barnes and Wagner 2009; Harrison 2013; Sexton and Beatty 2014). The effect of the end of DST in fall is unclear with studies finding either a small effect size or no effect on sleep.

[16]Data for this study was downloading from the National Archive of Criminal Justice Data (NACJD). 2016 is the latest year available.

[17]Outdoor crimes are ones which location is one of the following: atm separate from bank, construction site, camp/campground, dock/wharf/freight/modal terminal, field/woods, highway/road/alley/street/sidewalk, lake/waterway/beach, park/playground, parking/drop lot/garage, or rest area.

[18]https://ucr.fbi.gov/nibrs/2017/tables/pdfs/num_of_law_enforce_agen_and_pop_cov_enrolled_part_stat_method_of_data_sub_by_pop_group_2017_.pdf

[19]Hawaii also does not follow DST but no Hawaiian agencies report their data to NIBRS.

[20]As crimes with multiple offenders offer the police more opportunities to clear the case, these cases are likely to be cleared more often than incidents with only one offender. However, this is unlikely to influence this study's findings as DST is unlikely to alter the number of crimes committed by multiple offenders.

[21]This affects only a small number of incidents as 90% of incidents contain only one offense and 99% of incidents contain two or fewer offenses (Investigation 2015).

[22]In 2013, the FBI changed their definition of rape to include sodomy and sexual assault with an object. As NIBRS does provide data on sodomy and sexual assault with an object for all years studied, this study uses the revised definition of rape and includes all three of these crimes as violent index crimes.

[23]Halloween and St. Patrick's Day both occur within the window of days studied in certain years

[24]To the author's knowledge this issue has not been previously reported but is likely due to crimes where the date is unknown or not entered being put as the first of the month.

[25]As this period is longer than the previous model, more days that fall on holidays are included. Any days that fall on Halloween, St. Patrick's Day, Easter, or the first day of Passover are removed.

[26]Due to irregularities with NIBRS data where the noon hour has 1.5 times as many crimes reported than neighboring hours, indicating that when some crimes have an unknown time they are reported as occurring at noon, this hour is not included in the data.

[27]The entire state of Indiana began following DST in 2006. Prior to 2006, only parts of the state following DST.

[28]This table shows p-values not adjusted for multiple hypothesis testing. If the p-values were adjusted using the conservative Bonferroni correction, results would still be statistically significant.

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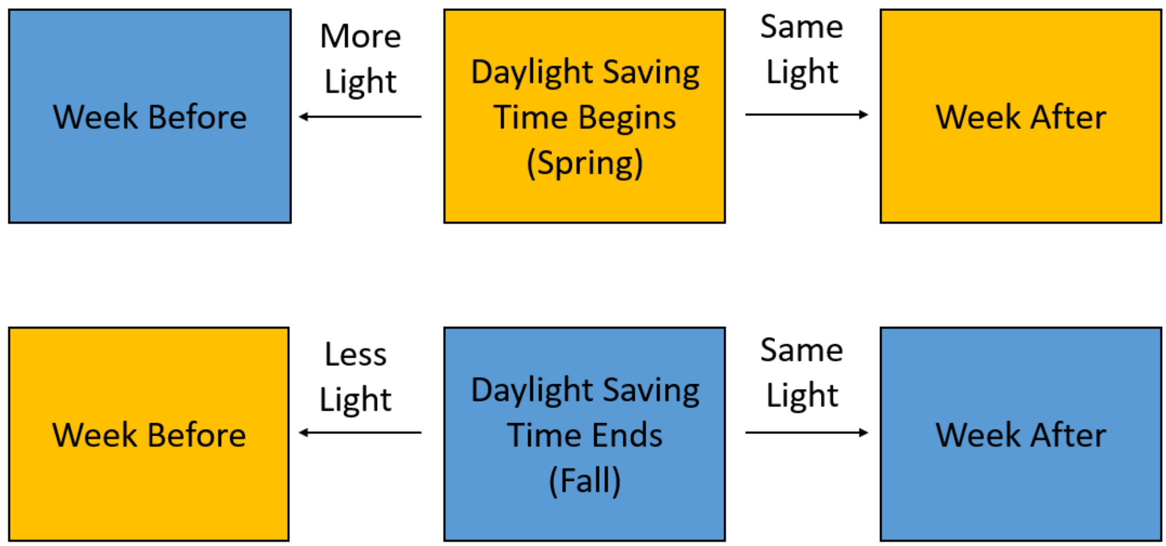
Week Before
More Light
Daylight Saving Time Begins (Spring)
Same Light
Week After
Week Before
Less Light
Daylight Saving Time Ends (Fall)
Same Light
Week After

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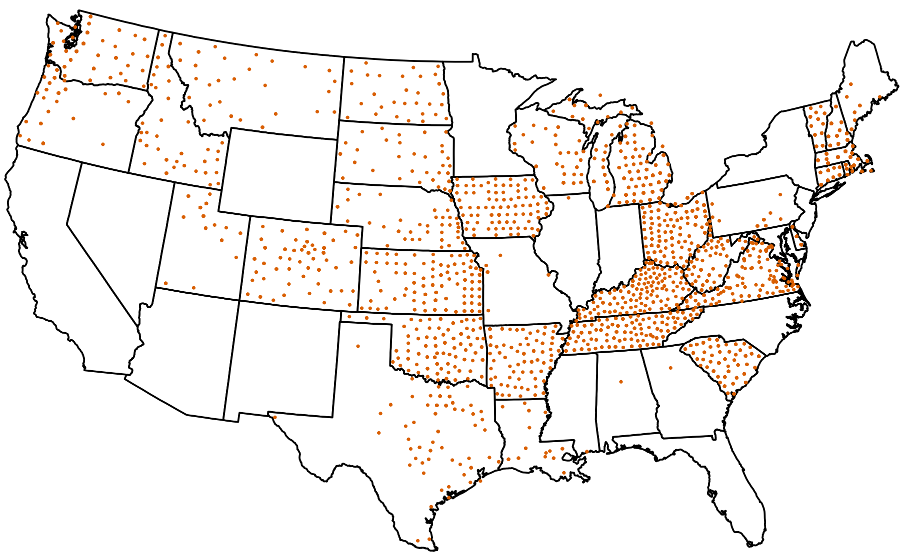

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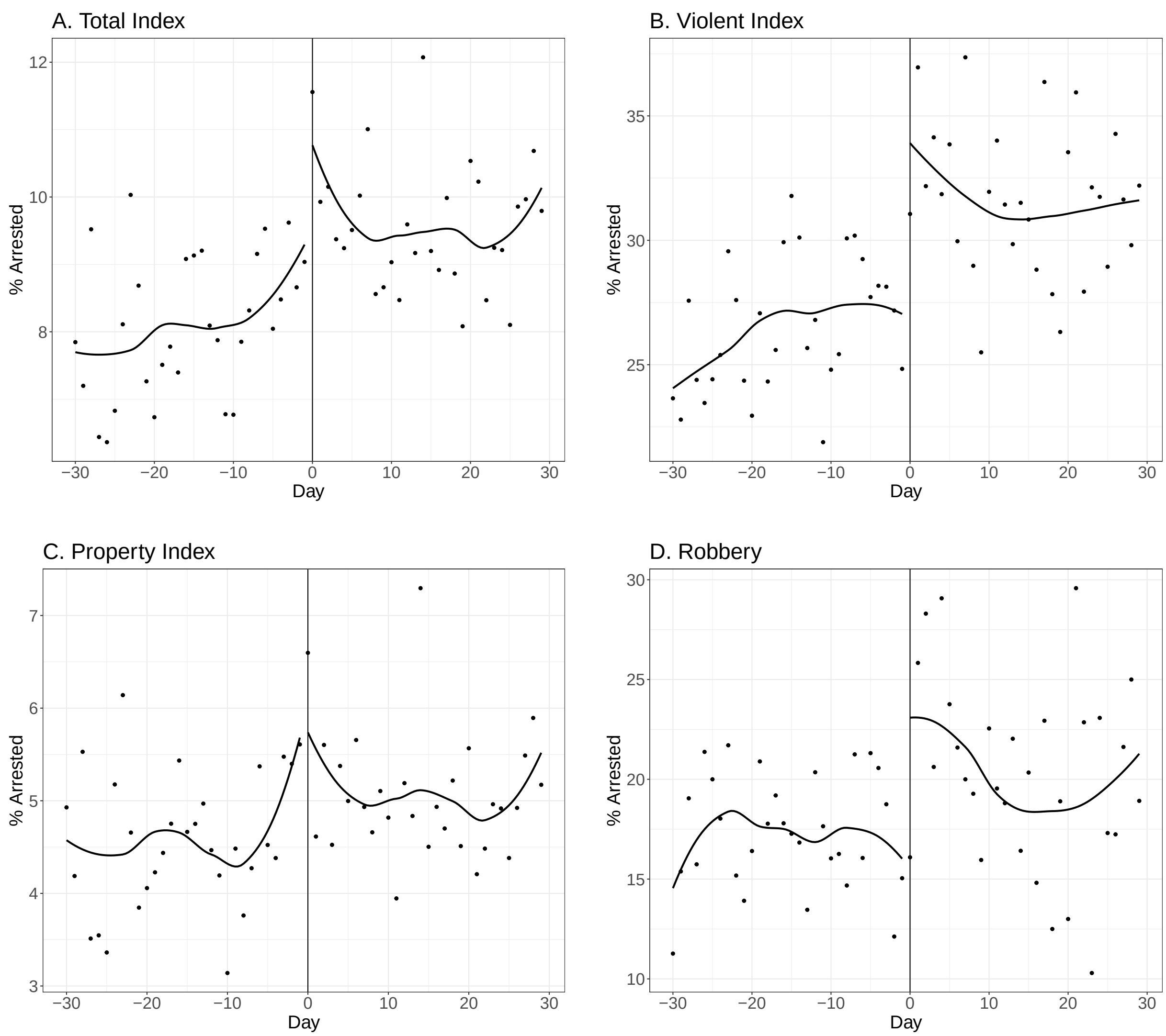
A. Total Index
B. Violent Index
C. Property Index
D. Robbery
% Arrested
Day
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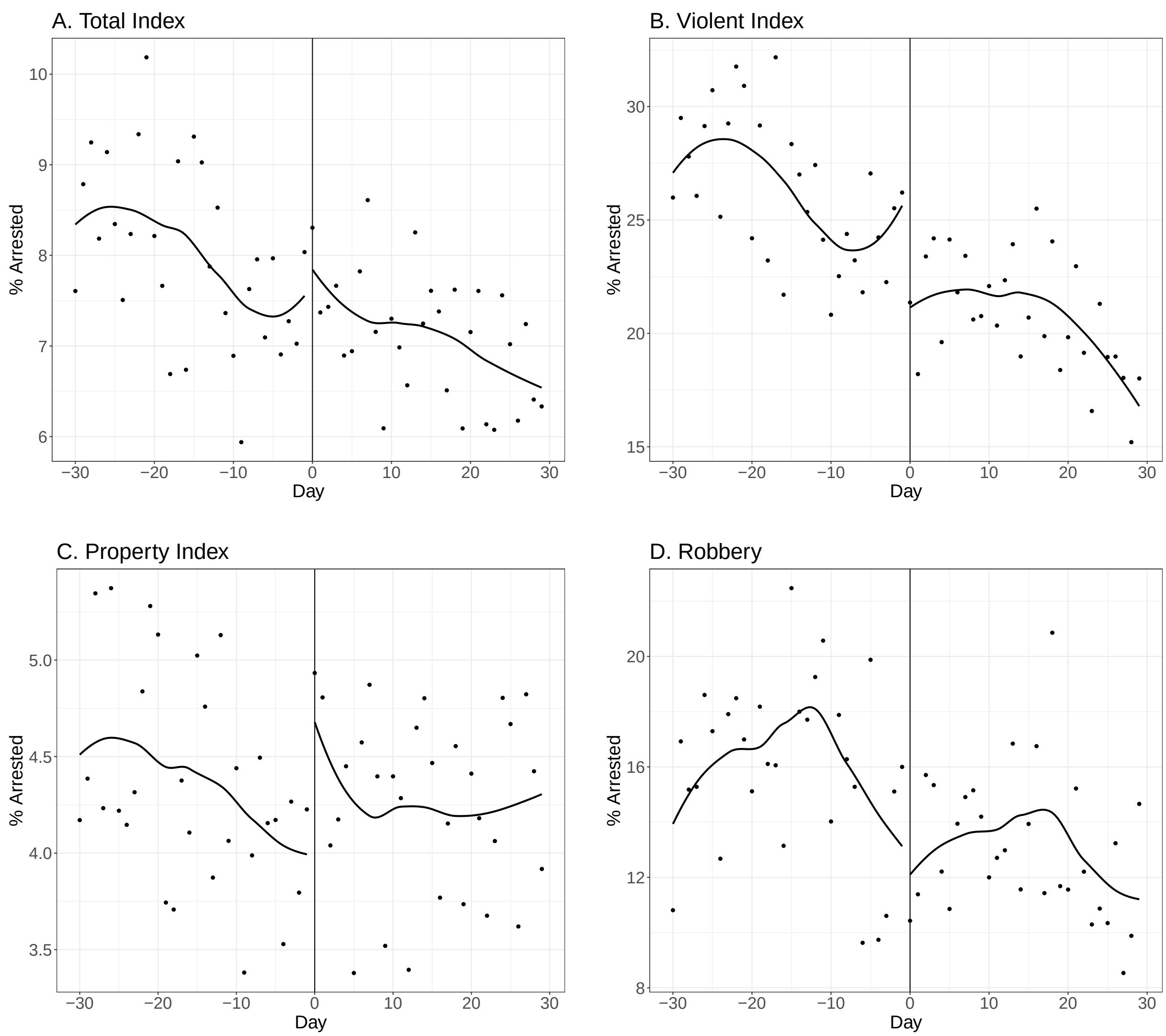
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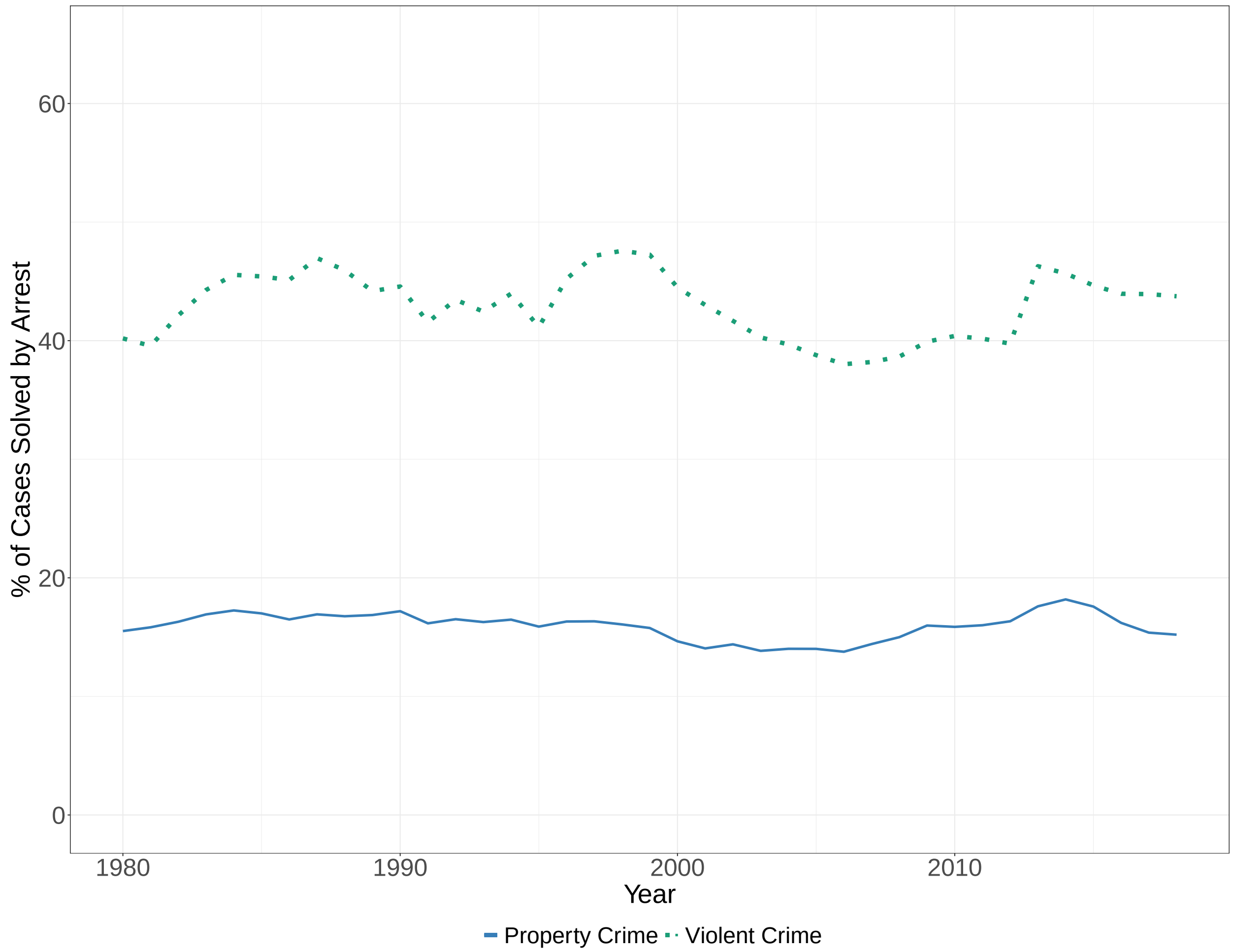

Figure 1: The percent of violent crimes (murder, rape, robbery, and aggravated assault) and property crimes (burglary, motor vehicle theft, and theft) that result in at least one offender being arrested. This figure shows national data using all agencies that have reported to the FBI's Uniform Crime Reporting (UCR) Program data for 12 months of the year for every year shown.

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Table 1: The proportion (and standard deviation) of outdoor, evening hours (6:00 pm - 7:59 pm) crimes ending in an arrest for each crime category during spring and fall comparing the three weeks after the start (end) of daylight saving time compared to the previous three-week period.

	Index Crimes	Violent Index	Property Index	Robbery
Spring				
DST Begins (more light)	0.095 (0.294)	0.317 (0.465)	0.051 (0.219)	0.203 (0.402)
Pre-DST (less light)	0.082 (0.274)	0.27 (0.444)	0.046 (0.21)	0.173 (0.378)
Fall				
DST Ends (less light)	0.072 (0.259)	0.216 (0.411)	0.042 (0.202)	0.136 (0.343)
During DST (more light)	0.078 (0.267)	0.254 (0.435)	0.043 (0.202)	0.162 (0.369)

Table 2: The effect of spring changes to DST (more evening lighting), including robustness checks.

	Index Crimes	Violent Index	Property Index	Robbery
A. Main Effects				
Beta	0.117*	0.239**	0.047	0.379**
Std. Err.	0.051	0.069	0.071	0.119
exp(Beta)	1.124	1.27	1.048	1.461
[CI]	[1.017, 1.242]	[1.11, 1.454]	[0.912, 1.206]	[1.156, 1.846]
p-value	0.022	0.001	0.506	0.002
B. Robustness Check: Reverse Code				
Beta	0.035	0.059	0.037	0.104
Std. Err.	0.046	0.074	0.071	0.137
exp(Beta)	1.036	1.061	1.038	1.11
[CI]	[0.946, 1.133]	[0.918, 1.226]	[0.902, 1.192]	[0.848, 1.454]
p-value	0.449	0.428	0.606	0.448
C. Robustness Check: Following Week				
Beta	0.088	0.087	0.098	0.245*
Std. Err.	0.047	0.067	0.066	0.125
exp(Beta)	1.092	1.091	1.103	1.278
[CI]	[0.996, 1.196]	[0.957, 1.244]	[0.969, 1.255]	[1, 1.632]
p-value	0.061	0.195	0.136	0.050
D. Robustness Check: Daytime				
Beta	0.052	0.102	0.008	-0.045
Std. Err.	0.038	0.053	0.050	0.104
exp(Beta)	1.053	1.107	1.008	0.956
[CI]	[0.978, 1.134]	[0.998, 1.23]	[0.913, 1.113]	[0.78, 1.174]
p-value	0.171	0.056	0.867	0.668

Note:
**p<0.01, *p<0.05

Table 3: Regression Discontinuity (RD) Design: The effect of spring changes to DST (more evening lighting), including robustness checks.

	Index Crimes	Violent Index	Property Index	Robbery
A. Main Effects				
Beta	0.075	0.299**	-0.012	0.503**
Std. Err.	0.057	0.096	0.084	0.178
exp(Beta)	1.078	1.349	0.988	1.653
[CI]	[0.964, 1.206]	[1.116, 1.629]	[0.838, 1.165]	[1.167, 2.342]
p-value	0.189	0.002	0.886	0.005
B. Robustness Check: Reverse Code				
Beta	0.471**	0.428*	0.247	0.32
Std. Err.	0.101	0.173	0.146	0.357
exp(Beta)	1.602	1.534	1.28	1.378
[CI]	[1.316, 1.951]	[1.093, 2.153]	[0.962, 1.703]	[0.685, 2.772]
p-value	0	0.013	0.09	0.369
C. Robustness Check: Daytime				
Beta	0.054	0.035	0.031	0.028
Std. Err.	0.043	0.078	0.058	0.148
exp(Beta)	1.056	1.036	1.032	1.028
[CI]	[0.971, 1.149]	[0.89, 1.206]	[0.92, 1.156]	[0.769, 1.375]
p-value	0.205	0.652	0.594	0.852

Note:
**p<0.01, *p<0.05

Table 4: The effect of fall changes to DST (less evening lighting), including robustness checks.

	Index Crimes	Violent Index	Property Index	Robbery
A. Main Effects				
Beta	-0.009	-0.120	0.045	-0.065
Std. Err.	0.048	0.070	0.071	0.122
exp(Beta)	0.991	0.887	1.046	0.937
[CI]	[0.902, 1.089]	[0.773, 1.017]	[0.91, 1.203]	[0.738, 1.19]
p-value	0.848	0.087	0.524	0.594
B. Robustness Check: Reverse Code				
Beta	-0.013	-0.027	-0.024	-0.029
Std. Err.	0.047	0.070	0.067	0.121
exp(Beta)	0.987	0.973	0.976	0.971
[CI]	[0.899, 1.083]	[0.848, 1.117]	[0.856, 1.113]	[0.766, 1.231]
p-value	0.781	0.698	0.720	0.811
C. Robustness Check: Following Week				
Beta	0.025	-0.006	0.026	-0.119
Std. Err.	0.047	0.074	0.063	0.136
exp(Beta)	1.025	0.994	1.026	0.888
[CI]	[0.936, 1.124]	[0.861, 1.149]	[0.908, 1.161]	[0.679, 1.16]
p-value	0.587	0.938	0.678	0.381
D. Robustness Check: Daytime				
Beta	-0.007	-0.122*	0.025	-0.210
Std. Err.	0.033	0.059	0.044	0.117
exp(Beta)	0.993	0.885	1.025	0.811
[CI]	[0.931, 1.061]	[0.788, 0.788]	[0.994, 0.994]	[0.94, 1.02]
p-value	0.844	0.039	0.574	0.073

Note:
**p<0.01, *p<0.05

Table 5: Regression Discontinuity (RD) Design: The effect of fall changes to DST (less evening lighting), including robustness checks.

	Index Crimes	Violent Index	Property Index	Robbery
A. Main Effects				
Beta	0.046	-0.042	0.073	-0.127
Std. Err.	0.06	0.098	0.087	0.165
exp(Beta)	1.047	0.958	1.075	0.881
[CI]	[0.931, 1.178]	[0.791, 1.161]	[0.908, 1.274]	[0.637, 1.218]
p-value	0.443	0.664	0.4	0.443
B. Robustness Check: Reverse Code				
Beta	0.027	-0.071	0.026	-0.176
Std. Err.	0.053	0.087	0.077	0.142
exp(Beta)	1.027	0.931	1.026	0.839
[CI]	[0.925, 1.14]	[0.786, 1.104]	[0.883, 1.193]	[0.635, 1.108]
p-value	0.617	0.412	0.738	0.216
C. Robustness Check: Daytime				
Beta	0.027	-0.089	0.046	-0.328*
Std. Err.	0.043	0.078	0.058	0.143
exp(Beta)	1.028	0.915	1.047	0.72
[CI]	[0.944, 1.118]	[0.785, 1.066]	[0.934, 1.173]	[0.544, 0.953]
p-value	0.529	0.256	0.432	0.021

Note:
**p<0.01, *p<0.05