2020

The Effect Of Lighting And Building Security On Crime

Jacob Kaplan
University of Pennsylvania

The Effect Of Lighting And Building Security On Crime

Abstract

Changing the physical design of an area has been long understood to be an effective way to change people's behavior. Within the field of criminology, Crime Prevention Through Environmental Design (CPTED) is an approach that alters the physical environment to decrease opportunities for crime. This dissertation examines two common tools used to reduce opportunities for crime: door locks and outdoor lighting. Though these tools are ubiquitously used, there are limitations in the current research on what effect these tools have on crime. This dissertation uses three papers to extend the CPTED literature by filling in some of these gaps in knowledge.

The first paper assesses the effect of installing smart locks on the exterior doors of campus buildings on a major urban university campus. Results show that there is no significant change in the number of crimes per month on buildings that install these locks relative to a comparison group. The second paper measures how the number of outdoor, nighttime crimes change as the amount of moonlight - a relatively dim source of light - changes. Results show that nights with more moonlight have more crime, a finding in contrast to much of the literature on lighting. This suggests that the effects of lighting are non-linear - that a small increase of lighting may increase crime while significant increases in lighting decrease crime. The final paper evaluates one possible mechanism for the bulk of the lighting literature's finding that lighting decreases crime: that more light increases the risk of detection. This study uses the change in evening lighting when the United States transitions to (from) daylight saving time in spring (fall) which causes the evening the gain (lose) an hour of daylight. Results show that when evenings are brighter, the odds of an arrest for violent crimes - and for robbery in particular - significantly increase.

Together, these studies advance the field of criminology by providing evidence on the effectiveness of two widely utilized crime control tools - door locks and outdoor lighting - to affect criminal behavior. This contribution can assist both researchers in the CPTED field as well as policy makers who must decide whether - and in which situations - to use door locks or outdoor lighting as crime control measures.

Degree Type

Dissertation

Degree Name

Doctor of Philosophy (PhD)

Graduate Group

Criminology

First Advisor

John MacDonald

Keywords

CPTED, crime, lighting, moon

Subject Categories

Criminology | Criminology and Criminal Justice

THE EFFECT OF LIGHTING AND BUILDING SECURITY ON CRIME

Jacob Kaplan

A DISSERTATION

in

Criminology

Presented to the Faculties of the University of Pennsylvania

in

Partial Fulfillment of the Requirements for the

Degree of Doctor of Philosophy

2020

Supervisor of Dissertation	Graduate Group Chairperson
____________________	____________________
John MacDonald Professor Departments of Criminology and Sociology University of Pennsylvania	Charles Loeffler Associate Professor Department of Criminology University of Pennsylvania

Dissertation Committee

John MacDonald	Professor of Criminology and Sociology
Greg Ridgeway	Associate Professor of Criminology and Statistics
Aaron Chalfin	Assistant Professor of Criminology

THE EFFECT OF LIGHTING AND BUILDING SECURITY ON CRIME

Acknowledgment

I have too many people to thank individually. Without you, I never would have completed this. Thank you first to my advisor John Macdonald and my committee member Greg Ridgeway. I learned a lot working with you both. I'd especially like to thank Aaron Chalfin who I've worked with or sought advice from for nearly every paper I've worked on. It has been an honor to work with you. I owe my gratitude to Nelson Lim who was my mentor during his time at Penn. I try to always act in the manner that you do.

Thank you to Asminet Ling who has kept me company, and helped me keep my sanity, during our long time at Penn. Thank you to Sal D'Angelo who taught me to box five years ago and has been a great friend ever since. Boxing has been one of my refuges during hard times at Penn so thanks for teaching me and for being my friend. To Derek McCammond, thank you for helping me with programming and gains, and for being my friend. One day you'll accept that beer > R > Python. {0U::OUhj4DOOjkUj1hhU_nU,j:0hj_0pUjyUDX0q_j8hDpUrj#1OODX5jDnjX04r

Finally, thank you to my family, friends, and cat who have supported my throughout my life, and especially during these past four years. This dissertation wouldn't have been done without you.

ABSTRACT

THE EFFECT OF LIGHTING AND BUILDING SECURITY ON CRIME

Jacob Kaplan

John MacDonald

Changing the physical design of an area has been long understood to be an effective way to change people's behavior. Within the field of criminology, Crime Prevention Through Environmental Design (CPTED) is an approach that alters the physical environment to decrease opportunities for crime. This dissertation examines two common tools used to reduce opportunities for crime: door locks and outdoor lighting. Though these tools are ubiquitously used, there are limitations in the current research on what effect these tools have on crime. This dissertation uses three papers to extend the CPTED literature by filling in some of these gaps in knowledge.

The first paper assesses the effect of installing smart locks on the exterior doors of campus buildings on a major urban university campus. Results show that there is no significant change in the number of crimes per month on buildings that install these locks relative to a comparison group. The second paper measures how the number of outdoor, nighttime crimes change as the amount of moonlight - a relatively dim source of light - changes. Results show

that nights with more moonlight have more crime, a finding in contrast to much of the literature on lighting. This suggests that the effects of lighting are non-linear - that a small increase of lighting may increase crime while significant increases in lighting decrease crime. The final paper evaluates one possible mechanism for the bulk of the lighting literature's finding that lighting decreases crime: that more light increases the risk of detection. This study uses the change in evening lighting when the United States transitions to (from) daylight saving time in spring (fall) which causes the evening the gain (lose) an hour of daylight. Results show that when evenings are brighter, the odds of an arrest for violent crimes - and for robbery in particular - significantly increase.

Together, these studies advance the field of criminology by providing evidence on the effectiveness of two widely utilized crime control tools - door locks and outdoor lighting - to affect criminal behavior. This contribution can assist both researchers in the CPTED field as well as policy makers who must decide whether - and in which situations - to use door locks or outdoor lighting as crime control measures.

Table of Contents

List of Tables

List of Illustrations

Chapter 1

General Introduction

Crime Prevention Through Environmental Design (CPTED) is an approach to crime that reduces the number of opportunities for criminal behavior by changing the physical (built) environment (Cozens, Saville, and Hillier 2005; Cozens and Love 2015; MacDonald, Branas, and Stokes 2019). For example, improving lighting to a street may reduce the number of opportunities for offending as any offense will be brightly lit to anyone looking towards the street, increasing the risk that offenders are detected. While CPTED is a broad and diverse field that spans from physically obstructing crime opportunities to conferring ownership of spaces to "legitimate users" of these spaces (Cozens and Love 2015, 396), this dissertation focuses on two of the most frequently used tools to prevent crime: door locks (Dijk, Kesteren, and Smit 2007; National Statistics 2019; Budd 1999) and outdoor lights (Welsh and Farrington 2008; Chalfin et al. 2019).

Controlling access to an area through physical devices such as locks and walls is an ancient manner of controlling deviancy (Poyner 1983). The majority of studies on door locks find that locks are associated with a decrease in crime

(Amandus et al. 1995; Casteel and Peek-Asa 2000; Faulkner, Landsittel, and Hendricks 2001; Hendricks et al. 1999; Vollaard and Van Ours 2011). However, these studies are generally cross-sectional and measure lock usage at - or after - the time of the crime. As prior victimization increases both the likelihood that a victim would purchase locks (Budd 1999; National Statistics 2019) and the chance of a future crimes against that victim (Ashton et al. 1998; Pease 1991), the lack of a proper time-order on the effect of locks on crime severely limits the accuracy of the research. In addition to methodological issues with much of the lock research, the vast majority of studies evaluate traditional key locks. As "smart locks" that are unlocked using a key card or a passcode are proliferating in businesses and residential areas, it is an increasingly important type of security device that is inadequately examined by criminologists (Ho et al. 2016). While locks seek to reduce crime by preventing offenders from accessing an area through physical restrictions, lighting seeks to improve the surveillance of an area, increasing the likelihood that offenders are detected and caught.

Increased surveillance is designed to reduce crime by making the risk of detection for an offender greater than in areas with more limited surveillance. Artificial lighting, generally through streetlights, has transformed nighttime activities in cities and has been found to improve public safety (Schivelbusch 1987; Welsh and Farrington 2008; Chalfin et al. 2019). Importantly, lights are a practical solution that both public (government) and private actors - such as businesses and homeowners - can take to reduce their risk of crime.

Studies on lighting, however, often face methodological issues, leading to relatively few rigorous studies on lighting and crime (Welsh and Farrington 2008). One such issue is that increased lighting through streetlights is not merely increased illumination in an area absent of all other elements. It can represent an investment in the community and can lead to increased street use in the area (Welsh and Farrington 2008). If this is so, then though streetlights were the instigator, it is the extra people on the street rather than the lighting that affected crime. That would mean that while large numbers of streetlights in an area may reduce crime, individual homeowners installing outdoor lights may not see the same benefit. Two recent studies that use experiments or natural experiments to avoid potential community effects find that increasing outdoor lighting decreases outdoor, nighttime crime (Doleac and Sanders 2015; Chalfin et al. 2019). The goal of this dissertation is to explore how the built environment affects behavior. This dissertation is composed of three papers that examine the effect of changes in the built environment on criminal activity and the likelihood that a crime results in an offender being arrested. The first paper measures whether the installation of smart locks on campus buildings on a major urban university campus affects crime within these buildings. The final two papers use natural experiments - changes in moonlight and changes in evening lighting due to daylight saving time - to better understand how the number of crimes and the likelihood that these crimes end in an arrest change as the level of outdoor lighting changes. As lights and locks are two of the most commonly used - yet inadequately studied

- mechanisms that people use to reduce crime, this dissertation improves our understanding of these crucial tools.

1.1 Paper 1 Summary

The first paper in this dissertation examines the effect of smart locks installed on the outer doors of campus buildings on an urban university campus. While traditional key locks are still the predominant type of lock in use today, businesses and individuals are increasingly turning to “smart locks” as a security-supplement (Ho et al. 2016). Whereas a traditional lock is always accessible to whomever has the key, smart locks provide additional flexibility by limiting access to certain buildings at specific times depending on the user’s needs. The locks evaluated in this study are opened using student or staff identification cards.

Though door locks are among the most common tools to prevent crime, research on the effect of locks on crime has been limited. While generally finding a positive effect of locks, a number of studies have methodological problems due to their cross-sectional design (Casteel and Peek-Asa 2000). A number of studies evaluate door locks on crime but count the locks after the crime occurred (Hunter 1988; Hendricks et al. 1999; Faulkner, Landsittel, and Hendricks 2001; Amandus et al. 1995). This makes it unclear whether the locks predate the crime or if people with past victimization are more likely to install locks. Additionally, nearly all past research on this subject has evaluated traditional key-locks or deadbolt locks.

Research on this technology has not kept pace with its implementation. Universities have been at the forefront of this technology, utilizing smart locks on campus buildings - particularly on student dorms - for decades (Barberet and Fisher 2009; Fisher 1995; Fisher et al. 1997; Rasmussen and Johnson 2008). However, to date there have been no studies that evaluate whether this technology reduces crime. This study attempts to bridge that gap by measuring if buildings that receive the card reader locks have a decline in crime relative to similar buildings that did not receive the locks.

The university studied is undergoing a safety initiative and installing card reader locks on the exterior doors of campus buildings. These locks are activated by students and staff swiping their school ID card on the card reader, which will unlock the door if the user has access to that particular building at that time.

This study uses data from the university's police department to create a monthly count of crimes within each building on campus for the period from June 2005 to November 2016. As over 90% of reported crimes were theft, a finding consistent with other research on university crime (Fisher 1995; Fisher et al. 1997; Fisher and Wilkes 2003; Fisher and Sloan 2003), the crime categories were summarized into two groups: theft and total crime. The non-theft crimes reported are primarily burglary, assault, and sexual offenses.

The university's police also provided data on which buildings received the card readers and when the card readers were activated. There were 16 buildings with card readers activated during the period studied. Each of 16 buildings that received the card reader locks were matched with two buildings based on similar location, size, visibility, and building type. To control for possible displacement in crime, all other buildings on campus are also added to the regression. This paper uses a difference-in-differences approach to examine how crime changes in card reader buildings after card readers are activated compared to a matched pair control group. Building and year-month fixed effects are included to control for differences between buildings that are time-stable and for changes in campus-wide crime trends over time. Standard errors are clustered to the pairs of card readers and comparison buildings.

Results indicate that the addition of card reader locks does not affect crime within the building. It may be that due to the already very low number of crimes within campus buildings, the additional security of the locks was not a sufficient boost in security to reduce crime further.

1.2 Paper 2 Summary

The second paper in this dissertation assesses whether a relatively small increase in outdoor lighting affects nighttime crime. A number of studies have found that increasing ambient lighting is related to a decrease in crime (Welsh and Farrington 2008; Doleac and Sanders 2015; Chalfin et al. 2019) However, this research is limited as improving lighting may affect the community in ways beyond the additional light, such as by improving social cohesion or informal social control of the area. These studies also measure large increases in lighting - the installation of outdoor lights (Welsh and Farrington 2008; Chalfin et al. 2019) or an extra hour of evening daylight from daylight saving time (Doleac and Sanders 2015) - leaving the effect of a small dosage increase in lighting largely unstudied. To build on this literature, this study uses moonlight as a natural experiment to measure the effect of changes in outdoor lighting on nighttime crime. As the percent of the moon illuminated is nearly identical for all cities in the United States on any given night, this study interacts the moonlight percentage with the proportion of the night which has clear skies, which generates substantial variability in the amount of actual moonlight a city experiences.

This study uses data from the National Incident-Based Reporting System (NIBRS), an FBI dataset that contains incident-level information for all crimes reported by an agency. NIBRS data provides detailed information on each incident reported; the variables included in this study are the type of crime, the location (in broad categories such as "sidewalk"), and the date and hour the crime occurred. Following past research on moonlight and crime, this study estimates the effect of moonlight on total crimes and on index crimes.[1]

[1]Index crimes are a collection of eight crimes categories by the FBI due to their frequency of occurrence and seriousness. These crimes can be categorized as violent or property crimes. The violent index crimes are murder, rape (including sodomy and sexual assault

Index crimes are also analyzed separately for violent index and property index crimes. To measure the percent of the moon illuminated, the proportion of the night with cloud coverage, and other weather variables included in the analysis, this study scraped data from the weather website Weather Underground.[2]

This study uses Poisson regression to estimate how the number of outdoor crimes in a night changes as moonlight changes.[3] The moonlight variable is created by interacting the percent of the moon illuminated on a given night with the proportion of the night without clouds. To control for differences in weather, variables for average nightly temperature, humidity, and rain (in inches) are included.[4] To control for differences between agencies, agency-level fixed effects are used. Year-month-day fixed effects are also used to control for crime trends that affect all agencies, such as the day of the week. Standard errors are clustered at the agency level and the models are weighted by the agency's population in the first year of data. As moonlight does not affect daytime lighting, this study uses crimes that occur between 10:00AM and

with an object), robbery, and aggravated assault. The property index crimes are burglary, theft, motor vehicle theft, and arson.

[2]Historical data on Weather Underground comes from weather stations located at airports. Each agency's data was matched to their closest airport using the agency's coordinates provided from the Law Enforcement Identifiers Crosswalk (LEAIC).

[3]A "night" is defined as 8PM to 2:59AM the following night. Due to data issues in NIBRS data that result in approximately 2.5 times as many crimes being reported in the 12:00AM to 12:59AM hour than any other hour, this hour is excluded.

[4]One concern with using cloud coverage is that nights with clouds are also more likely to have rain, which drastically decreases crime. Results are nearly identical when removing any night when it rained.

3:59PM as a robustness check.[5].

Results show that nights with a full moon and no cloud coverage have significantly more crime than nights without any moonlight. The robustness check examining daytime crimes had no significant results. Index crimes increased by approximately 6% while violent index crimes increased by nearly 8%. These results suggest that the dosage of outdoor lighting plays an important role in the effect of this light on crime. Past studies on lighting primarily study the effect of large changes in outdoor lighting, and in most cases result in a decrease in crime (Welsh and Farrington 2008; Doleac and Sanders 2015; Chalfin et al. 2019). As this study showed an increase in crime on nights with more moonlight, this indicates that a low-dosage increase in lighting may be criminogenic.

1.3 Paper 3 Summary

Research on the effect of lighting has found that increases in outdoor lighting can cause significant decreases in the number of outdoor, nighttime crimes that occur near these lights (Welsh and Farrington 2008; Chalfin et al. 2019; Doleac and Sanders 2015). In Welsh and Farrington (2008)'s meta-analysis on the effect of streetlights and crime, they offer two possible mechanisms

[5]There is an issue with NIBRS data during the hour from 12:00PM to 12:59PM where approximately 1.5 times as many crimes are reporting in this hour than in adjacent hours. As this indicates that some crimes where the time is unknown is reported during this time, the noon hour is removed from the data.

for the cause of light's effect on crime: (1) that it reduces opportunity and increases risk of detection; (2) that it improves social cohesion and control of the community. The final paper in this dissertation evaluates Welsh and Farrington (2008)'s first proposed mechanism by measuring whether the likelihood of an arrest increases as evening lighting changes.

To do so, this study uses the change in evening lighting cause by the transition to daylight saving time (DST) to measures how changes in lighting affect the likelihood that a crime results in an arrest. As daylight saving time affects all communities regardless of their amount of social cohesion or informal social control, this study can isolate the effect of lighting to just changes in possible risk. During the start of daylight saving time in spring, an hour of daylight is moved from the morning to the evening; in fall, an hour of evening light is moved to the morning. If light increases the risk of detection, the likelihood that a crime results in an arrest should increase during spring and decrease in fall.

This study uses data from the National Incident-Based Reporting System (NIBRS) for the years 2001-2016. For each crime incident, NIBRS data indicates if an arrest was made. This study examines three crime categories and one crime individually: total index crimes, violent index crimes, property index crimes, and robbery. Data is limited to only outdoor crimes as indoor lighting is not affected by DST. As DST's effect is largest during the evening, this study subsets the data to only the hours of 6:00pm-7:59pm, a period used in past research to evaluate DST's effect on sunset hours (Doleac and Sanders 2015).

This study uses logistic regression to measure how the change in evening lighting caused by DST affects the odds on an arrest for the crimes studied. The week following the transition in spring and fall (which are analyzed separately) are compared to the previous week. Similar to the robustness check in Paper 2, this study uses daytime crimes as a check as DST does not affect the amount of light during the day. This study also uses two additional checks. First, this study compares the week after the transition to or from DST to the following week. In 2005, the United States Congress changed the start and end dates of DST beginning in 2007. Following Umbach, Raine, and Ridgeway (2017), this study uses pre-2007 dates as the dates for post-2007 data and post-2007 dates for pre-2007 data as the final robustness check.

Results show that during daylight saving time in spring (when there is an additional hour of evening light), the odds that a crime results in an arrest increases significantly. This effect is driven by an increase in the odds of an arrest for violent crimes (27% increase), and for robbery (46% increase) in particular. These findings lend support to Welsh and Farrington (2008)'s first hypothesis, that crime decreases due to increased risk of detection when lighting increases and suggests. These findings suggest that one tool to improve clearance rates in an area is to increase the amount of nighttime, outdoor lighting in that area.

Chapter 2

The (In)Effectiveness of Campus Smart Locks for Reducing Crime

Abstract

Door locks are a ubiquitous form of security to control access to a building with the goal of reducing crime there. However, research on door locks is often limited by methodological issues and primarily focuses on residential or commercial locations. This paper assesses the impact of card reader door locks on school buildings on an urban university campus. Using a difference-in-differences approach, this paper estimates the effect of card reader locks on crime in buildings. The results indicate that the locks do not significantly affect crime within buildings on a university campus. While this study found no significant effect of card reader locks on crime, in the school context there are other outcomes that are important to measure, such as student fear. Avenues for future research, including suggestions of specific universities at which to conduct further studies, are discussed.

2.1 Introduction

Controlling access to a location as a means to reduce deviancy is an ancient practice. The gates of medieval castles, for example, ensured that only those permitted to enter may do so (Poyner 1983). In modern times, castles are no longer used, but the lessons of access control endure. Door locks are a modern replacement of the castle gate, permitting the owner to limit access to only those with keys. The use of door locks is ubiquitous. Dijk, Kesteren, and Smit (2007) examined the International Crime Victimization Survey and found similar trends of increasing deadbolt lock ownership worldwide including nearly 53% of households in the United States having deadbolt locks in 2005, approximately 10 percentage points above the global average. In England and Wales, which had the highest rate of deadbolt lock ownership, 69% of households used the device. By 2018, the number of households in England or Wales with a deadbolt lock reached 83% (National Statistics 2019). While the usage of locks is widespread, evidence of their effectiveness is less thorough.

While research generally finds that locks are associated with lower crime, the cross-sectional nature of these studies limits claims of causation (Amandus et al. 1995; Casteel and Peek-Asa 2000; Faulkner, Landsittel, and Hendricks 2001; Hendricks et al. 1999). Studies typically evaluate door locks' effect on crime but count the locks at the time the crime occurred. Additionally, nearly all past research on this subject has evaluated traditional key-locks. While key-locks are still the predominant type of lock in use today, businesses and individuals are increasingly turning to technology as a security-supplement. For example, “smart locks” that open to individuals with specialized access permission (often through an identity card or key-fob) are increasingly available (Ho et al. 2016).

As smart locks proliferate, the CPTED literature has not kept pace with research on the effect of these devices on crime. While research on traditional locks offer guidance towards the effects of smart locks, there have been no published research on this specific technology’s effect on crime to date. This study addresses this gap in the CPTED literature by seeking to answer the question: Do card reader locks reduce crime on an urban university campus? To do so, this study examines monthly theft and total crime before and after card reader locks are installed in buildings with the card readers against a comparison group of similar buildings that do not have card reader locks. The card readers are locks placed on the exterior of campus building doors which are activated by swiping a student or staff school identification card. The card readers selectively permit students and staff to enter during specific times and into specific buildings - offering a more flexible approach than traditional key locks. The results show no evidence that card reader locks affect crime in buildings. The null findings may be the result of the already low level of crime in campus buildings as the average campus building experiences fewer than two crimes per year.

This paper is organized as follows: Section 2.2 provides details of past research on access control. Section 2.3 explains the data used. Section 2.4 describes the empirical model and Section 2.5 shows the results. Section 2.6 discusses these results and notes avenues for future research, including which universities are good candidates for conducting similar studies.

2.2 Previous Research

Crime Prevention Through Environmental Design (CPTED) is an approach that seeks to alter the physical environment to reduce opportunities for crime (Cozens, Saville, and Hillier 2005; Cozens and Love 2015; Walsh 1999; Welsh and Farrington 2009). By limiting the chances an offender has to commit a crime, the total number of crimes should drop. Much of CPTED incorporates minor changes in a given area, which may vary from a single building (Minnery and Lim 2005) to wide sections of a city (Branas et al. 2011). Often this is done through the implementation of technology or physical alterations.

A core tenet of CPTED is that alterations in the environment can act as subtle nudges to affect behavior. This can reduce an offender's propensity towards criminal behavior or reduce victim vulnerability. Crowe and Zahm assert that "the elements that make a neighborhood safe are the same elements that make a 'good' neighborhood" (1994, 22). This "good neighborhood" is made so when opportunities for lawful behavior are maximized, and opportunities for unlawful behavior are minimized. Specifically, they suggest using "physical design elements" (1994, 22) to control access to the home, improve community members' ability to see who is nearby, and demarcate exactly where community land ends and private land begins. These ideas are the basis of CPTED.

To reduce crime, CPTED alters the environment to increase "territoriality, surveillance, [and] access control" (Cozens, Saville, and Hillier 2005, 330). An example of a subtle technique is a home with well-trimmed hedges which provides a view both into and out of the house. This increases the potential for passers-by on the street to observe if anyone unwelcome is in the home, and for the home resident to monitor for wrongdoers in the street (Cozens and Love 2009; Weisel 2002). Additionally, the trimmed hedges indicate that the owner takes pride in their home and would not tolerate disorderly activity in the community. A neighborhood where all homes are well-maintained signals that there is a norm of caring for the neighborhood and that each resident adheres to this norm.

Weisel's (2002) analysis of burglaries supports this notion, as she found that single-family homes with limited ties to the neighborhood are at greatest risk of burglary. These include homes that are "vacant for extended periods" of time, have new owners, have limited visibility due to high fences or hedges, or without (or with inadequate) security devices (2002, 8). The lengthy periods of vacancy and new ownership limit the effectiveness of natural surveillance by community members. In both cases, neighbors have limited knowledge about who are legitimate members of the community and who are strangers

- in essence, who belongs and who does not. This limits their ability to accurately identify a potential offender and alert the authorities. Tall hedges make it difficult for surveillance to occur even if the community knows who belongs there and may encourage offenders who wish to avoid detection. That elements of the physical environment signal a community's concern for crime - and willingness to combat it - is a core component of the influential Broken Windows Theory.

Kelling and Wilson's (1982) Broken Windows Theory suggests that vandalism increases in locations "that seem to signal that 'no one cares.'" A well-ordered home signals that someone does care, and that crime would not be tolerated there. A messier neighborhood, lacking the perceived personal pride and natural (informal) surveillance of an orderly neighborhood, would likely be an easier target for criminals. The signal that the community cares is more important than individual aspects of the environment. A well-kept hedge may offer minor visibility improvements compared to an unkempt one. But it can send a signal to offenders that the hedge's owner cares about their home - and may have made other investments (e.g. door locks) that increase the offender's risk of capture. However, for Broken Windows Theory to be accurate, offenders must be able to recognize these signals and respond accordingly.

There is evidence that offenders do in fact respond to visible security measures. A qualitative study by Carmel-Gilfilen (2011) conducted a walk-through of retail stores with self-admitted shoplifters and asked them to discuss store security and their willingness to shoplift there. Among the most cited store security measures were video cameras and security tags on clothes. “Expert” shoplifters, those with either 25 lifetime shoplifts or 10 shoplifts in the past year, were more deterred by physical security measures such as cameras than were novice shoplifters.

A similar study by Armitage (2018) showed 22 incarcerated “prolific burglars”, defined as having committed five burglaries per month, images of 16 residential houses and asked what factors would influence their decision to burglarize that property. All of the offenders identified physical security features as important factors in their decision, in particular the lock on the front door. Some offenders discussed the quality of the lock based on what they could see and whether they believed the lock would be capable of preventing them from entering. These studies indicate that CPTED may be more effective against experienced offenders who are aware of the security and its effect on their likelihood of detection.

There is good reason to believe that securing exterior doors and windows may reduce crime. In one third of burglaries, the offender “[enters] through unlocked or open windows or doors” (Weisel 2002, 14). Budd’s (1999) analysis of burglaries in the United Kingdom came to a similar conclusion, finding that 22% of burglaries occurred through unlocked doors or windows. Securing these entrances with locks would “greatly reduce the risk of being burgled”

(1999, 22). This trend continues today with an almost unchanged percent of burglaries - 23% - being committed through unlocked doors or windows in England or Wales in 2017 and 2018 (National Statistics 2019).

Physical obstructions to crime are a part of CPTED's access control, sometimes referred to as "target hardening" (Cozens, Saville, and Hillier 2005). Physical security measures should be seen, not as an impregnable fortress, but as a deterrent for crime. The majority of burglars are "easily deterred by dogs, alarms or locks" (Weisel 2002, 16). For those clever- or determined-enough to bypass these security measures, they serve to increase the risk that the offender is caught. Target hardening measures involve both making the vulnerable location harder to enter and limiting the scope of possible offenses if entry occurs.

2.2.1 External Target Hardening

The primary method for preventing an offender's entry is through the use of locks on doors or windows. Using locks is more important than just owning them. Weisel (2002) in the United States, and Budd (1999) in the United Kingdom, found that about one in four burglaries occurred through an unlocked door or window. Budd's seminal paper on burglary in the United Kingdom, using crime victimization data, found that the presence of security devices was associated with fewer burglaries. Door and window locks were the most effective devices. However, even for homes targeted by a burglar, these devices were protective. Burglaries against homes with door or window locks were more likely to be attempts rather than completed burglaries. The devices prevented the offender from entering the building.

Tseloni and colleagues also utilized national crime victimization surveys and attempted a cross-national analysis of burglary (2004). They used data from the United States, the United Kingdom (England and Wales), and the Netherlands to assess, among other factors, how target hardening affects burglary. In every country assessed, they found that hardened targets (those with locks, burglar alarms, and outdoor lighting) had increased odds of burglary. In the United Kingdom and the Netherlands, the odds more than doubled. In the United States the odds increased by 19% relative to homes without such devices. These analyses, however, are limited by the study design. As their study was cross-sectional, they were unable to assess if the security devices were acquired before or after the burglary. This is a common issue in target hardening research that will be discussed shortly.

One study that partially avoids this issue is Vollaard and van Ours' (2011) quasi-experimental study on the effect of burglary-resistant home doors and windows on residential burglary in the Netherlands. In 1999, the Netherlands changed its building codes to require all new homes to use these more secure features. The changes to the new homes were fairly inexpensive relative to the home cost (about $710 per home in 2019 dollars). Using victimization data, the authors compared burglaries in homes built before and after the changes, finding that new homes had a 26% lower burglary rate. They also found that the new homes had a protective effect on their neighbors. Older homes that were near the new homes had a lower rate of burglary compared to older homes without new neighbors. This indicates that burglars respond to changes in their opportunities. A neighborhood full of unsecured homes to burgle, after all, is a better target than a neighborhood with half as many opportunities.

2.2.2 Limitations of Prior Research

The use of target hardening to reduce crime is a technique far more widely utilized than adequately studied (Casteel and Peek-Asa 2000). Casteel and Peek-Asa's review of 26 studies on this topic contains only eight studies that used a control group or used experimental or quasi-experimental designs. Three of the studies with a control group used stores that declined to participate, allowing for selection bias. In fifteen of the reviewed studies, the research was "generated for an agency" and not subject to peer review; three studies were published in non-peer review journals (2000, 4). Amandus et al. (1995)'s review of 14 studies on CPTED and convenience store robberies contains only two experimental designs. Ten of these studies are cross-sectional, and thus unable to determine if the CPTED methods existed before the robbery took place. Their own study involved visiting stores 1-3 years *after* a robbery and assessing their CPTED factors at that later date. Hunter (1988) utilizes the same data as Amandus et al. (1995) and has similar results. Data on convenience store CPTED techniques in Virginia, which both Hendricks et al. (1999) and Faulkner, Landsittel, and Hendricks (2001) used for their studies, were collected only after that store reported a robbery. This lack of proper temporal ordering between procuring the security device and when the crime occurred makes determining the effect of target hardening devices, such as locks, on crime difficult.

This issue is exacerbated because while a crime victim would likely see security devices as a worthwhile investment, non-victims may see it as unnecessary. Therefore, it may be more likely that a crime victim had a security device than a non-victim, leading to the inaccurate belief that security devices cause crime. Budd (1999) offers evidence in support of this. Her analysis of security device ownership for burglary victims showed a substantial increase in ownership after victimization. For both burglary and attempted burglary victims, door deadbolt ownership increased by around 30% and window lock ownership increased by over 20% (1999, 40). In the 2017-2018 Crime Survey for England and Wales, nearly half of respondents who made security improvements to their home in the previous year did so in response to increased crime, their own burglary victimization, or their neighbor's victimization (National Statistics 2019).

Research on repeat victimization has found that merely being the victim of a crime "increases risk of further victimization" (Ashton et al. 1998, 271). These victims are often repeatedly targeted because some characteristic makes them more vulnerable. In cases of burglary, these characteristics involve building location, poor security, and occupation (Weisel 2002, 2005). The impact of a first victimization is substantial, with burglary victims being up to four times as likely to suffer another burglary in the weeks following the first incident than homes never victimized (Pease 1991). Ashton et al. (1998) interviewed convicted burglars and found that one-third of these burglars had in fact returned to past targets and burglarized them again.

These studies provide insight into the mechanisms of how lacking proper time-order on building security devices can affect research. A victim that suffers multiple burglaries may be highly motivated to acquire protective devices, even more so than a victim with a single burglary. Failing to control for other factors that motivate offending, may cause these victims to appear to *increase* their risk of burglary by investing in protective devices. The burglars interviewed by Ashton et al. (1998) noted that the procurement of security devices was a major catalyst for stopping their repeat victimization.

Access control is ubiquitous, ranging from security guards at building entrances to turnstiles in subway systems (La Vigne 1997). Access control has also benefited from advances in technology which allows flexibility in who can enter a building and during which times. For example, the Cochran Homes, a public housing complex built in 1953 in St. Louis, Missouri, utilized card readers to control entrance to the building (William Brill Associates and America 1977). In lieu of guards, the Cochran Homes required residents to swipe an identification card for entrance to the lobby and access to the elevators. This strategy was meant to balance the need to prevent unauthorized non-residents from entering the building with a desire to ensure that their home's entrance "did not suggest a prison" (1977, 18). The conflict between reducing crime and avoiding the creation of a "fortress society" is a recurrent theme in CPTED (Welsh and Farrington 2009, 7). In the half century since the Cochran Homes began using this access control technology, its adoption has been widespread, including on university campuses (Barberet and Fisher 2009; Fisher 1995; Fisher et al. 1997; Rasmussen and Johnson 2008). Yet little is known about its effect on crime. Unfortunately, neither the implementation of card readers in the Cochran Homes nor on university campuses were accompanied by an analysis of their effect on crime.

2.2.3 The Current Study

This paper examines the effect of card reader locks in building entrances on crime in buildings on an urban university campus. The university began utilizing card readers to limit access to certain buildings to only authorized students and staff. This paper analyzes how theft and total crime in buildings changed after that building received card readers compared to buildings that have yet to adopt them.

The university this study was conducted at is a private university located in the Northeast in a large, high-crime urban city. There are slightly over

20,000 students at the school with approximately half of the population being undergraduate and half being graduate students. While some buildings restrict access to only students and staff, primarily through security guards checking ID cards, the campus is freely accessible to the public. The card readers are activated by the school ID card already used by students, faculty, and staff and requires no additional equipment from the user. To access a building that has a card reader, users swipe their ID card through the reader and the building's doors unlock. Cards can be given selective access to certain buildings and only during certain times. For example, a person who is granted access to Building A can use their ID card to access that building, but the card will not unlock doors in Building B.

The card reader buildings activated their access control at different times. This study uses a matched comparison design to assess the effect of the card readers. Each of the card reader buildings (N = 16) was matched with two buildings based on similar location, size, visibility, and building type to enhance the quality of the comparison group. Building size involves both the number of floors and the square footage of the building. Comparison buildings are often on the same block as the treated building and are visible from the same location. If comparison buildings are not physically near their card reader match, they were chosen based on similar locations on campus. A card reader building on the peripheral of campus was matched with a comparison building likewise on the peripheral. Their similar visibility means that a criminal deciding which building to target would be aware of each building's presence. The building type is the main purpose of the building. A building with classrooms, for example, was matched with other classroom buildings. In this way both the building interior and its potential victims (e.g. students, administrative offices) are similar for both groups.

This study improves the research on access control in a number of ways. First, the use of a difference-in-differences design avoids the endogeneity problem that has limited prior research. A difference-in-differences design measures the effect of a treatment by comparing changes in the desired outcome over time in the treated group to a group similar to the one that was treated under the assumption that, but for the treatment, both groups would have parallel trends (Abadie 2005). This design ensures proper time-order and allows an evaluation of the lock's effect on crime. A benefit to this design is the two groups do not need identical crime counts, merely similar trends prior to treatment (Lechner 2011). Second, using theft rather than robbery or residential burglary offers a much larger sample of offenses than past research has used. Finally, whereas most previous studies assess access control on residential or commercial buildings, this study examines a university campus. University campus buildings often have higher foot traffic than either residential or commercial buildings, a factor that may affect the impact of access control devices.

2.3 Data

This study uses crime data from the university police for the period between June 2005 and November 2016. Each incident includes a record of which crime occurred, the date it happened, and in which building it occurred in. The university police also provided data on when card readers were installed in buildings. Non-card reader building security - guards and virtual concierge - data for each building also comes from the university police. Characteristics of the buildings come from the university's website.

2.3.1 Building Security

The focus of this study is to examine whether card readers reduce crime. For this, data available from the university police tells which buildings have card readers, when implementation began, and other security measures the building may have.

In addition to card readers, buildings may have security through guards or a virtual concierge. Though the data indicates whether what type of additional security a building may have, it does not say when that security was implemented. Security guards are private security hired by the university. They may be posted at specific locations - generally near main entrances - or mobile through the building. However, buildings with security guards can still have unsecured entrances, particularly if there are fewer guards than perimeter doors.

A virtual concierge is a call box outside a building that people can use to gain access. Either a building administrator or a university police employee will answer the call and, using a security camera in the callbox to look at the person's identification card, verify that the person is allowed to enter the building and grant them access. This is a similar tool to card readers in limiting access to a building but is far more labor intensive.

2.3.2 Building Characteristics

The physical features of a building may have an effect on victimization. This study considers three measures of building characteristics when selecting comparison buildings: the number of perimeter doors, the number of floors, and the square footage of the building. A building with many doors may be seen as less secure, as some doors may be unguarded or infrequently used (Weisel 2002). Buildings with a large number of perimeter doors may weaken the impact of security guards. Larger buildings may also be more populated and allow criminals to blend in with the crowd. The literature on the effect of building size (generally measured through the number of floors) has been mixed between no effect (Newman and Franck 1982) and weak effects (Holzman, Kudrick, and Voytek 1996; Newman and Franck 1982). Greenberg and Rohe's (1984) study found that most burglaries occurred on the first floor, indicating that ease of access, rather than building size, is an important predictor of burglary targets.

Table 2.1 shows summary statistics of these building features and average monthly and total crime experienced for each group. Row 1 shows the characteristics for the card reader buildings, while row 2 shows the characteristics for the comparison group. Row 3 includes all other buildings on campus.

Table 2.1: Design and security features for card reader, comparison, and other campus buildings. Values shown are the mean and (standard deviation).

	Perimeter Doors	Floors	Square Feet (in 1,000s of feet)	Guard/ Virtual Concierge	Monthly Crimes Before Card Readers	Monthly Crimes After Card Readers
Card Reader (N = 16)	7.25 (4.09)	5.77 (2.18)	89.81 (56.42)	0.75 (0.45)	0.17 (0.46), Total: 283	0.15 (0.46), Total: 74
Comparison (N = 32)	8.73 (6.26)	5.68 (2.35)	105.57 (90.34)	0.34 (0.48)	0.14 (0.43), Total: 505	0.13 (0.41), Total: 139
Other Campus Buildings (N = 74)	8 (9.77)	5.81 (5.22)	140.36 (138.19)	0.45 (0.5)		

The card reader and comparison buildings are relatively similar in terms of crime and building characteristics. Card reader buildings often have greater security than the comparison group. The card reader and comparison groups have similar monthly crime rates prior to installation of card readers. The average building experiences fewer than 2 crimes per year. The card reader buildings experienced a combined 357 crimes during the period studied while the comparison group had 644 total crimes. Comparison buildings are larger than card reader buildings. They have about 1.5 more perimeter doors and are 15,000 square feet larger than card reader buildings, but these differences are within one standard deviation. Among security features, card reader buildings are more likely to have guards or virtual concierges. This is most clear with virtual concierges, as card reader buildings are more than twice as likely to have them than the comparison group. This may be because buildings that are already concerned about security are more likely to request virtual concierges and card reader locks than other buildings.

Buildings with guards or virtual concierges are also more likely to have an entrance facing a major street. Studies on burglary targets found that buildings that are easier to quickly enter - those on the corner, on through streets, or near major streets - are more likely to be targeted (Cozens and Love 2009; Johnson and Bowers 2010; Weisel 2002). These types of buildings are easier for offenders to evaluate and then quickly enter and exit during the crime. Buildings with guards or virtual concierges are also more likely to contain well-funded departments (e.g. the business and law schools) that are able to pay for the security. However, average monthly crimes and security differences appear small and not statistically different.

The card readers are a supplement rather than a replacement to the other security. In most cases the card reader is only active during the night, so its effect is limited to only the night hours. Other building security, such as guards, are not replaced by the card readers but its presence may improve the guard's effectiveness. For example, a building with multiple doors and a single guard has many doors unguarded at any given time. With the addition of the card reader, all entrances are secured, and the guard can monitor the entry of persons through a single door of their choosing.

2.3.3 Crime

The university police respond to crime on campus and in the immediate surrounding area. A majority of crimes occur outside of buildings, generally in the streets around the campus. This study only considers the crimes that occur within campus buildings. Theft is by far the most common crime in buildings, a finding consistent with past studies on crime on university campuses (Fisher 1995; Fisher et al. 1997; Fisher and Wilkes 2003; Fisher and Sloan 2003). This category captures 90% of all crimes and contains offenses such as “theft from building” and “theft of a bicycle.” The other 10% of crimes are made up of 5% burglary, 2.5% assault, and 2.5% other crimes. This study examines theft and all reported crimes as the two outcomes.

Figure 2.1 shows the total number of total crimes for card reader and comparison buildings in the 10 months prior to and after the card readers were installed. Trends are similar before card readers were installed indicating that the comparison pairs were properly selected. The number of crimes each month was low; with both groups experiencing fewer than five total crimes in the majority of months. As crime is so uncommon in these buildings, a single building experiencing a higher than average month of crime can cause significant fluctuation in the number of crimes that group had in that month.

Table 2.1 also provides context of the frequency of crimes occurring in buildings by showing the average monthly thefts in both card reader and comparison buildings before and after the card reader was activated. In both

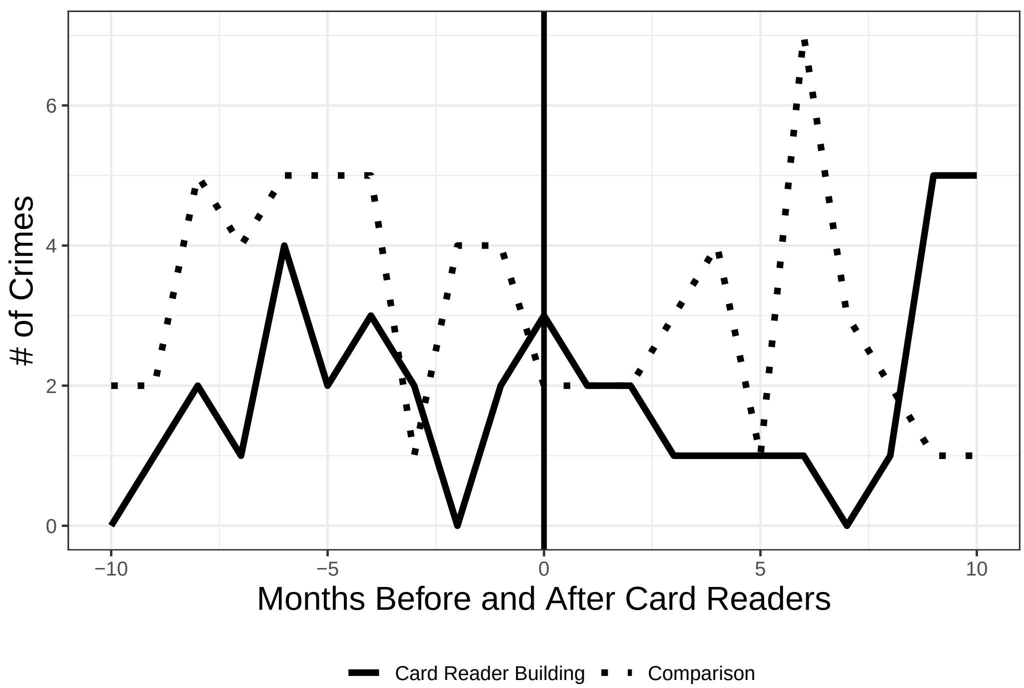

Figure 2.1: Crime trends for card reader (12 buildings) and non-card reader buildings (24 buildings) 10 months prior to and after card readers Four buildings (and their comparison matches) are excluded from this graph because they did not have ten months of post period.

groups, the average number of monthly crimes decreased after card readers, reflecting a campus-wide trend of decreasing crime. Figure 2.2 shows this downward trend in crime by showing the aggregate monthly sum of crimes in campus buildings for the entire period studied. The trend over time is downward, indicating that the campus is getting safer.

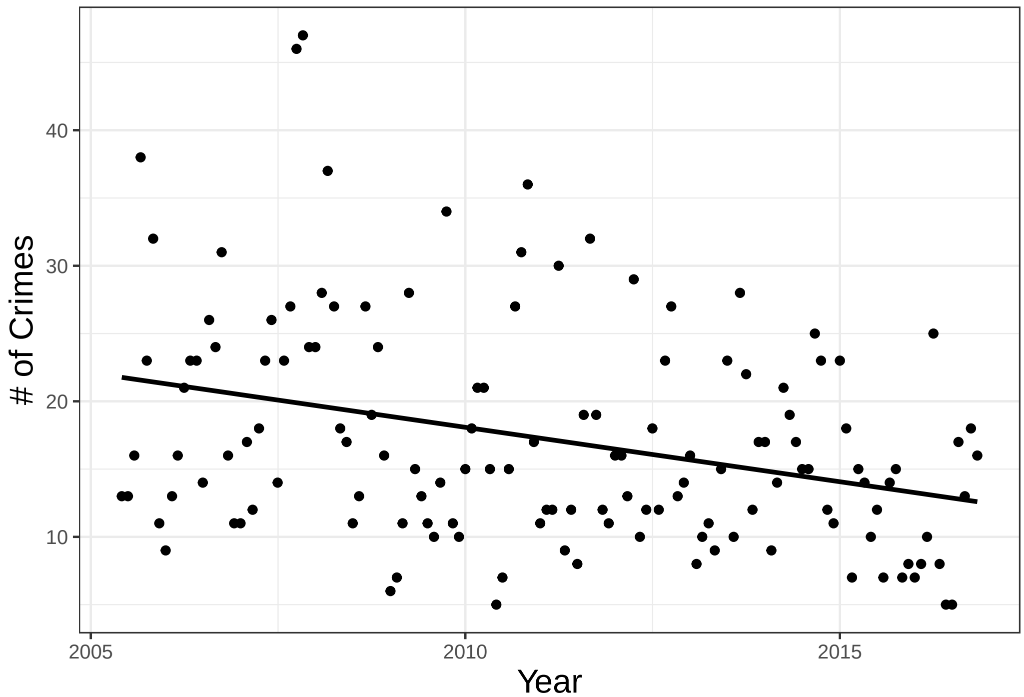

Figure 2.2: Total monthly crimes in campus buildings throughout the period studied.

2.4 Methods

This study estimates the effect of card readers on crime by comparing the change in crime after the card readers are installed to similar buildings without card readers. Each of the 16 card reader buildings were matched with two comparison buildings based on similar location, size, visibility, and type. To control for possible spillover to other buildings on campus, all other campus buildings are also included as a secondary comparison group.

The buildings which received card readers are predominantly those with large classrooms but include a small number of medical and research buildings. These buildings are often highly populated with students and openly accessible to the public with classrooms. In buildings with classrooms and faculty and graduate student offices, there exists a large number of potential victims and access for offenders. Installation of the card readers could reduce access to those buildings for potential offenders. While much of the past research has evaluated residential buildings, primarily single-family homes, no student dorms were included as a card reader or comparison building as all dorms had security guards on duty 24 hours per day to monitor people entering.

This study uses a Poisson regression model to estimate the effect of card readers on total crime and thefts in buildings according to the following form.

$$logE(Y_{it}) = \beta_0 + \beta CardReader_{it} + \lambda comparison_{it} + \alpha_i + \zeta_t \qquad (2.1)$$

where Y_{it} is the number of total crimes or thefts in building i and time t (year-month). CardReader is a dummy variable that takes the value of 1 for months when the card readers were active and 0 otherwise. The comparison takes a value of 1 when the building's treated pair has an active card reader and 0 otherwise. Buildings which are not part of a treated building's comparison pair will have a value of 0 for all months and serve as a reference group. Parameters β and λ estimate the effect of card readers and comparison buildings relative to each other and all other campus buildings. In Equation (2.1), α_i is the building fixed effect (N = 122), and ζ_t is the year-month (N = 138) fixed effect. Building fixed effects are used to control for differences between buildings that are time stable while year-month fixed effects control for crime trends across the campus that are common to all buildings. Standard errors are clustered at the building level.

2.5 Results

Table 2.2 shows the effect of card readers on total crime and theft. Column (1) estimates the effect of the card readers without including year-month fixed effects while column (2) includes them. The regression coefficients are exponentiated to show the incident rate-ratio (IRR) or the relative rate of change in the number of outcome variables for every one unit increase in the predictor variable. The effect of card readers is statistically significant for total crime and marginally significant for theft ($p<0.1$) when conditioning solely on building fixed effects. Both total crime and theft are estimated to have declined by about a third, with total crime decreasing by 28% and theft decreasing by 33%. However, this effect disappears upon the introduction of year-month fixed effects. This indicates that the effect of card readers in column (1) is an artifact of the campus getting safer in general.

When predicting total crime, the IRR in column (2), row 1, is 0.93 (95% CI: .65, 1.35), showing that buildings with card readers have about seven percent fewer crimes per month after card readers relative to all other campus buildings. Theft has an IRR of 1.01 (95% CI: .70, 1.45) or a 1% increase in the number of thefts. However, for both categories these differences are not statistically significant from no difference. The standards errors for both these categories are quite large, making the results imprecise. The results also show no significant change in comparison buildings.

2.6 Discussion

Technology-assisted locks, such card reader or key-fob locks, are increasingly being used for building security. These tools allow more individualized control than key locks and are an attractive solution to the problem of limiting access control to specific people during set times. This highly specialized form of access control is commonly used in environments where access must be controlled for a large number of doors and people. This study is the first that assesses if card reader locks reduce crime in buildings.

Table 2.2: Effect of building security on crime in campus buildings.

Variable	**(1)**	**(2)**
Total Crime		
Card Reader	0.72* (0.12)	0.93 (0.18)
Comparison	0.67** (0.10)	0.85 (0.15)
Year-Month Fixed Effects	No	Yes
Building Fixed Effects	Yes	Yes
Theft		
Card Reader	0.74 (0.11)	1.01 (0.19)
Comparison	0.68** (0.10)	0.89 (0.15)
Year-Month Fixed Effects	No	Yes
Building Fixed Effects	Yes	Yes

Each cell shows exponentiated regression coefficients, robust standard errors are in parentheses.
* p<0.05
** p<0.01

Using administrative crime data from the university police department, this study found that card readers do not reduce crimes in buildings relative to comparison buildings or the campus-wide decline in crime in all buildings. The null effect may be due to the low baseline of crime in campus buildings. On average, each building reports under two crimes per year. One element of the low and declining crime rate may be the security system already in place across campus. The vast majority of campus buildings have some form of security, generally security guards or traditional key locks after hours. Card readers, therefore, are an incremental increase to an already robust security system. These findings, however, are limited to crimes within campus buildings on the campus studied. The increase in security through card readers may have driven some offenders off-campus towards easier targets or to nearby universities.

The additional security to the exterior of buildings may also inadvertently increase crime if inhabitants respond to the additional security by taking fewer precautions inside the building. If the new locks on the outside of the building make professors, for example, less likely to lock their offices, offenders who do gain access may have easier access to targets inside the building, negating the crime-reducing goal of the locks. A survey asking people who regularly use buildings which receive the locks if they changed their security precautions because of the locks could ascertain whether this possibility has occurred.

Card reader locks are designed to reduce unauthorized access to buildings and reduce crime by keeping potential offenders out of the buildings. However, for offenders who are granted access, such as students who also commit crime, the card reader locks would not prevent these crimes. For crimes in which an offender was arrested, the data used for this study does not indicate whether they were permitted in the building where the crime occurred. As the locks are designed only to prevent crime among those not allowed in the building, this limits the internal validity of the study as it includes crime that are not affected by the locks. Future studies should use data that includes information on whether the offender is a person who would be prevented from accessing the building if it had a card reader lock. This is likely to be an issue in all studies on this topic as the vast majority of property crimes do not end in an arrest, rendering even data which does identify the offender to be largely incomplete. In 2017, approximately 86% of burglaries and 80% of thefts did not result in an arrest (United States Department of Justice 2018).

In certain campus buildings, the card reader locks are only activated at night and permit public access during the day. While the crime data does include the time the crime was reported, there are significant issues in the measure of the time of property crime. During household burglaries, approximately one-third of victims who were not present during the crime did not know when the crime occurred (Catalano 2010). According to the National Crime Victimization Survey, the majority of property crimes occur between 6PM and 6AM or the victim does not know when it occurred (Rand and Robinson 2011). As many campus buildings are unoccupied during the weekend and at night, this number is likely higher on university campuses, severely limiting the accuracy of the data.

The usage of official police crime data rather than victim reports may also be a factor in the low crime rate. Using official police data under counts the number of thefts. Crime that goes unreported cannot be analyzed. It is likely, however, that the more severe the theft (i.e. the costlier the financial loss), the more likely the victim is to report. A 2008 report by the Bureau of Justice Statistics using National Crime Victimization Data found that the amount lost in a theft is strongly related to the likelihood of the police being notified (Rand and Robinson 2011). Thefts with a loss of under $50 are reported to police less than 20% of the time while more than half of thefts costing the victim $250 or more are reported. Therefore, this study may better evaluate the effect on serious crime than on more minor crime.

Most research on access control focuses on serious crimes such as burglary and robbery. As these crimes are relatively rare, the number of crimes included in the studies is often low. This study reduces this problem by using theft, a far more common crime, as its primary crime of analysis. This study does evaluate serious crimes - primarily assault and burglary - as part of the total crimes category. However, the number of these crimes is too low to evaluate separately from theft. Future research should use schools with a higher crime rate or combine a number of schools until the count of serious crimes is acceptable for analysis.

Figure 2.3 offers guidance on which universities and colleges are good targets for study. This graph shows the 452 public or private 2- and 4-year universities with between 10,000 and 30,000 students that have reported crime data to the Department of Education during 2016. In particular, this graph shows the difference in the rate of burglaries per student across these schools. While the data does not have the numbers of thefts, burglary is a good proxy for the types of crimes that card readers can impact. The university studied here represents a typical case, with only slightly more burglaries (9 during 2016) than the average school (mean = 7.14). The relatively low numbers of burglaries across campuses lends support that this study may be generalizable across many schools. It also limits the number of viable schools for study as many schools have fewer burglaries than the one studied. Only 12 schools reported 40 or more burglaries during 2016. These schools, in particular the ones with ample resources to devote on increasing security such as Harvard (70 burglaries) and Stanford (54 burglaries), may be excellent locations to further this research.

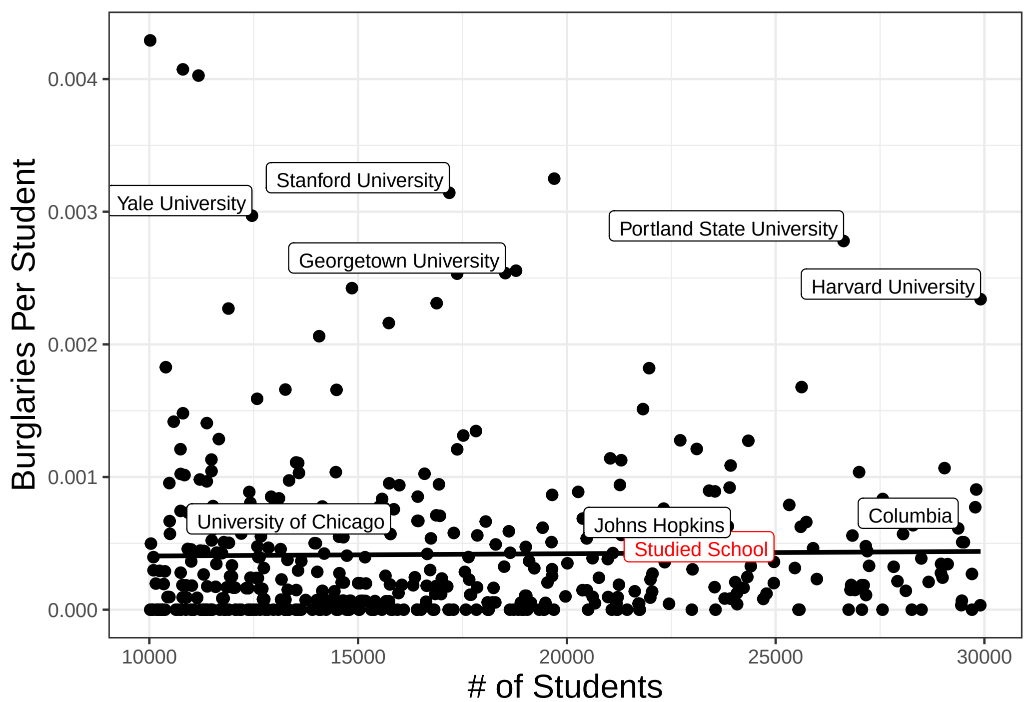

Figure 2.3: Burglaries in Public and Private University Campus Buildings - 2016 (N = 452 Universities).

This study differs from previous studies of access control as it was conducted on a university campus - a location where student safety, fear, and ability to learn are often prioritized above material loss. This study directly evaluates student safety through the limited number of non-theft crimes in the total crime category. However, it does not evaluate student fear of victimization. A reduction in theft may, in fact, have no impact on fear. If students are unaware of the ongoing crimes, or consider them insufficiently threatening, a reduction in crime may not reduce fear of it.

McCreedy and Dennis (1996) surveyed 760 college students about their own victimization, fear of crime, and willingness to take night classes. They found that victims of sexual offenses or stalking, and those who received a “lewd or threatening phone call” are less likely to attend night classes than non-victims (1996, 76). This indicates that crime victims change their behaviors as a result of being victimized, potentially to their educational detriment. The reduction in attendance on campus at night can be tested. If card readers lead to a safer campus, enrollment in night classes could increase if students feel safer going into buildings during the evening. While victims of traumatic crimes are unlikely to change their behavior simply due to improved locks, it could alter the behavior of students who have not been the victim of a crime but nonetheless feel unsafe in campus buildings at night. Future studies on access control, particularly ones in educational settings, should focus on potential softer effects alongside crime reduction. Ensuring that students feel safe may be reason enough to utilize card readers.

There remains a number of questions about card readers that are unanswered by the present study. The ubiquity of card readers, and similar technology-based locks, and the dearth of research on them make this a ripe field for study. These tools are used with growing popularity; to provide users with information regarding their effectiveness on a variety of crime- and non-crime-related issues, more research is needed.

Chapter 3

The Effect of Moonlight on Outdoor Nighttime Crime

Abstract: The use of outdoor lighting, particularly through streetlights, is a common tool for policy makers attempting to reduce crime. Research on the effect of lights on crime, however, is limited as installing or improving street lighting may affect the community in ways beyond merely increasing outdoor lighting. Welsh and Farrington's (2008) study suggested that improving street lighting may also improve informal social control in the area as it reflects improved street usage and investments in the community. This paper uses moonlight as a unique measure of outdoor ambient lighting that avoids the issue of community cohesion and examines the effect of lighting directly. The amount of actual moonlight a city receives each night is measured using the interaction between the percent of the moon illuminated and the proportion of the night without clouds. This interaction creates significant variation in moonlight between cities and across nights in the same city. Contrary to past research on lighting, this study finds that brighter nights, those with a full moon and no clouds, have significantly more crime than nights without any moonlight. These results suggest that there are heterogeneous effects of outdoor lighting by dosage and that more research on possible criminogenic effects of low dosages of outdoor lights is needed.

3.1 Introduction

The moon has a long history in popular culture as affecting people's propensity towards violence. Within the realm of science, the moon has been studied as a potential influence on a number of factors including crime (Lieber and Sherin 1972; Lieber 1978; Schafer et al. 2010; Stolzenberg, D'Alessio, and Flexon 2017; Thakur and Sharma 1984), violent behavior (Coates, Jehle, and Cottington 1989; Núñez, Méndez, and Aguirre-Jaime 2002; Owen et al. 1998), animal behavior (Bhattacharjee et al. 2000; Chapman and Morrell 2000; Zimecki 2006), suicide (Eisenbach et al. 2008; Mathew et al. 1991; Voracek et al. 2008), and mental illness, (Amaddeo et al. 1997; McLay, Daylo, and Hammer 2006; Raison, Klein, and Steckler 1999; Rotton and Kelly 1985; Wilkinson et al. 1997) with many of these studies finding no effect.

Despite the numerous studies evaluating the moon's effect on human behavior, a consistent logical mechanism by which the moon can affect people has not been proposed. The myriad of mechanisms proposed include the moon's gravitational pull on human brains (Lieber and Sherin 1972; Thakur and Sharma 1984; Zimecki 2006), its effect on human sleep patterns (Cajochen et al. 2013; Raison, Klein, and Steckler 1999), emotional distress (Ju, Sunmola, and Ewhirujakpor 1992), and a number of difficult to detect mediums including "tidal force, geomagnetism, electromagnetism, weather, ions, and ELF waves" (Culver, Rotton, and Kelly 1988, 683). This inconsistency across research on explanations for why the moon might affect people, or even what behaviors it does affect, has limited the creation of a consistent literature on the effect of the moon on human behavior.

In addition to the absence of a consistent mechanism explaining the supposed effect the moon has on human behavior, most studies have been plagued by methodological issues. The vast majority of studies assess lunar phase, in particular the full moon, on a number of outcomes such as animal attacks, violence, and crime. A meta-analysis of 37 studies on the effect of the moon asserted that studies that found a significant effect suffered from "inappropriate analyses ... and a willingness to accept any departure from chance as evidence for a lunar effect" (Rotton and Kelly 1985, 286).

Yet the bulk of the research on this topic ignores the one aspect of the moon which has a plausible effect on human behavior: the increased illumination caused by moonlight. When controlling for cloud coverage, the moon provides an exogenous shock to the amount of outdoor nighttime light in an area - a concept that is largely passed over in the dozens of studies conducted about the moon.

The idea that increased lighting has a crime-reducing effect on an illuminated area is well-supported within the Crime Prevention Through Environmental Design (CPTED) literature (Chalfin et al. 2019; Cozens and Love 2015; Welsh and Farrington 2008). During the night, surveillance opportunities are often limited by the available light. Areas that are well lit are considered riskier for offenders - who might be brightly illuminated and thus more identifiable or detectable to any witnesses when committing a crime - and will consequently invite fewer criminals.

Research on targets of burglary supports the notion that limited visibility increases crime in that area. Homes with limited visibility due to overgrown bushes or the lack of lighting are targeted more frequently than homes without obstructed visibility (Weisel 2002). An analysis of crime victimization in Britain found that burglary victims were more than 55% less likely to have outdoor lighting at the time of the burglary than non-victims (Budd 1999). Attempted burglary victims were almost half as likely to own outdoor lighting than non-victims. Lighting impacts offender decisions on where to target, and their likelihood of success. A burglar may be willing to target a home with outdoor lights, but will spend less time attempting to break in, likely due to recognizing that the extra lighting makes it more likely that they will be detected. The ability of members of the public to informally monitor an area as a deterrent to crime is an important component of Routine Activities Theory.

According to Routine Activities Theory, crime requires three elements to interact: a likely offender, a suitable target, and the absence of a capable guardian (Cohen and Felson 1979). Outdoor lighting can affect all three elements. Increased lighting at night may encourage more outdoor activities, increasing the number of potential victims, offenders, and guardians on the street. Crucially, as outdoor lighting changes, so too does the capability of guardians to detect or deter crime. A dark area offers far less visibility than a well-lit one, limiting one's capability as a guardian for observation. It could also affect the number or type of victims available as people may opt for brightly lit areas over darker ones that they perceive as more threatening, leaving fewer capable guardians in the darker areas where victims and offenders may still interact. Research on the timing of crime has found that crime is most prevalent during the night (Ceccato and Uittenbogaard 2014; Felson and Poulsen 2003; Glasner and Leitner 2016; LeBeau 1994; Lister et al. 2000; Tompson and Townsley 2010; Tompson and Bowers 2013; Van Koppen and Jansen 1999). These studies often cite the reduced capability of guardians to affect crime due to limited visibility as a contributing factor to the large number of crimes at night, yet studies directly assessing whether lighting affects crime are sparse.

The majority of lighting studies treat light as binary - primarily whether streetlights are on or off - often due to limitations in the available data. Yet there is evidence that the dosage of light plays an important role on its effect on crime. A recent experiment by Chalfin et al. (2019) found that areas that were assigned higher dosages of light from mobile light towers deployed in New York City experienced greater declines in crime than control areas. Interestingly, they found that there are diminishing returns of lighting; after a certain threshold, extra light does not help. As the majority of lighting studies examine streetlights, there is a gap in the literature on the effect of low levels of lighting on crime. This study contributes to the literature on lighting by attempting close that gap by answering the following research question: What is the effect of low dosage lighting on outdoor, nighttime crime? To address this question, this paper uses moonlight as a measure of ambient nighttime lighting and measures how the number of outdoor crimes change as cities experience different amounts of moonlight. As cities are limited in their crime control measures due to budgetary restraints, it is important to improve our understanding of how dosage of lighting affects crime to optimize outdoor lighting to the brightness that most effectively decreases crime.

The remainder of this paper is as follows: The remainder of Section 3.1 details the literature on the effect of light on crime broadly and the effect of moonlight on crime specifically. Section 3.2 discusses the data used and Section 3.3 explains the methodology. Section 3.4 summarizes the results found. Section 3.5 details a robustness check used and the results of that check. Finally, Section 3.6 discusses these results and concludes.

3.1.1 Lighting and Crime

Studying lighting presents difficulties. The vast majority of studies assessing lighting involve installing or improving streetlights. However, installing outdoor lighting is often a costly endeavor, necessitating expensive infrastructure investments which limits the number of experiments or quasi-experiments of lighting available. Indeed, to date only one randomized controlled trial has been conducted on the effect of outdoor lighting and crime. Chalfin et al.

(2019) randomly assigned housing developments in New York City to receive light towers in public outdoor areas, significantly increasing the illumination of those areas, and measured crime over a six-month period. They found that housing developments that received the light towers had significant declines in crime relative to the comparison housing developments. Total felony outdoor nighttime crimes declined by 30%, while violent outdoor nighttime crimes declined by 12%.

While Chalfin et al. (2019)'s experiment allows for a causal measure of lighting on crime, the majority of studies on street lighting are limited due to their research design. A meta-analysis by Welsh and Farrington (2008) found only 13 studies on street lighting which included a suitable comparison group to the area that had improvements in its street lighting. Their analysis found that "improved street lighting significantly reduces crime" (3). Intriguingly, they found that crimes decreased during daytime as well as at night, which suggests that the improvement in the streetlights had an effect beyond simply the change in nighttime illumination. The process of improving - or in some cases installing - street lighting may reflect a reinvestment in the community that could improve informal social control and signal to offenders that deviant behavior is unwelcome. Community behavioral changes as a result of increased night lighting, such as a more active community, may also affect crime during the day. The reduction in daytime crime may reflect changes in the community's economic situation or social cohesion that led to both more investment in community infrastructure and lighting. These possibilities make it difficult to parse out the direct impact of illumination on crime.

In recent years, researchers have sought to address this limitation by using daylight saving time (DST) as a natural experiment where only the amount of sunlight during the evening changes, and everything else is held constant. Daylight saving time provides a shock to how many hours of daylight an evening has by shifting an hour of daylight from the morning to the evening. A recent study using this technique examined robbery in the weeks following the shift to DST (when the evening gains an hour of daylight) and found a 7% decline in the number of robberies that occurred (Doleac and Sanders 2015). Their findings are driven primarily by a drop in crime during the sunset hours where robbery declined by as much as 27%, indicating that their results are caused by changes in outdoor lighting. The sunset hours are important as they are the times when DST causes an increase in lighting. These results show that substantial increases in lighting can have a large effect on crime.

A major benefit to DST studies is that evenings in the week after DST begins are substantially lighter than evenings on the same day in the previous week with everything else held constant. For example, if a person drives home from work at 6:00 pm each day, DST would cause their commute to be better lit compared to the previous week. The lack of investment into communities can reduce the likelihood that Doleac and Sanders (2015)'s results are due to changes into the community rather than simply the extra lighting reducing crime through increasing risk of detection.

However, such a jolt in the amount of evening daylight may also cause enough changes in behavior to alter the balance of victims, offenders, and capable guardians. If the increase in lighting causes the person who, for example, normally drives to the grocery store to instead walk to the store, that could increase the number of capable guardians in the area and make offenders less likely to commit a crime. Alternatively, this could change the number of potential targets or offenders in the area, increasing crime. This is a limitation to many studies of lighting, as it is not entirely clear by what mechanism the change in lighting affects crime.

Studies of DST, as well as studies on streetlights, measure the effect of large increases in the amount of lighting in an area. Yet the effect of low dosage lights is inadequately addressed in the CPTED literature given that local jurisdictions, limited by resource constraints, must decide how much to invest in improving lighting throughout the city.

3.1.2 The Effect of Moonlight

Studies of moonlight offer some of these answers as they measure the effect of a dim source of nighttime light. A recent paper by Stolzenberg, D'Alessio, and Flexon (2017) used moon illumination to assess moonlight's effect on the aggregate sum of index crimes for 13 states and Washington D.C. during the 2014 calendar year. Their approach found that outdoor index crimes increased on nights with more moonlight, a finding at odds with much of the literature on lighting and crime. However, an important limitation to their study was that, because they aggregated crimes from each of the police agency that was studied into a single count per night, they could not include cloud coverage data, which is related to the actual amount of moonlight a city receives on any given night.

Schafer and his colleagues (2010) studied the effect of moonlight on crime in San Antonio, Texas and controlled for some weather conditions. Their study found a null effect of moonlight on total crime and on most of the other crime categories studied. Their moonlight measure was based only on the percent of the moon illuminated that night "on the presumption of a clear sky and did not take into account any weather conditions that might have obstructed the actual visibility of the moon" (362). The use of a measure of cloud coverage is a crucial component for any study of moonlight; without it, there exists major measurement error in how much moonlight a city receives.

The percent of the moon illuminated changes in a predictable pattern over time and is nearly identical for cities on the same night in the continental United States. The lack of variability between cities makes it difficult to assess the effect of moonlight on nighttime crime - all cities receive effectively the same treatment. This study uses cloud coverage to introduce variation into moonlight across cities on the same night. As a cloudy night is no brighter than a moonless one, the use of cloud coverage creates substantial variability in the amount of actual moonlight between cities.

As an example, Table 3.1 shows the percent of the moon illuminated and the proportion of the night with clear skies for two example cities on the same night. Both cities have identical moon illumination that night. Row two of this table shows the proportion of the night with clear skies.[1] In this measure, each city's moonlight is vastly different. City A is covered by clouds all night, reducing its moon visibility to zero while City B maintained 75% moon illumination.

Table 3.1: Percent of the moon illuminated and proportion of the night with clear skies in two example cities for the same night.

	City A	City B
Moon Illuminated	75%	75%
Proportion Clear Skies	1.00	0.00
Real Moon Visibility	75%	0%

The lack of cloud coverage in past studies of moonlight is a major limitation as moonlight cannot be properly measured without considering cloud coverage. This study expands CPTED research in the field of lighting by using moonlight as a quasi-experiment for light on outdoor, nighttime crime. In particular, it builds on Stolzenberg, D'Alessio, and Flexon (2017)'s, and Schafer et al. (2010)'s research by using cloud coverage to produce variability in moon illumination and analyzing crime from 299 agencies rather than looking at a single city or aggregating crime nationally.

[1] i.e. without any clouds.

3.2 Data

To measure the effect of moonlight on outdoor nighttime crime, this study creates an agency-night panel data set for each night over the years 2010 through 2016. Crime data comes from the National Incident-Based Reporting System (NIBRS) while moonlight and weather data come from the website Weather Underground.[2] To control for differences in weather that may affect crime, this study includes average temperature, average humidity, and rainfall (in inches) during the night.[3]

As the effect of ambient light will be strongest during dark hours, this study examines crime occurring between 8:00 pm and 2:59 am, the same hours analyzed by Schafer et al. (2010).[4] [5] Crime that occurs between 1:00 am and 2:59 am are included in the crime count for the previous night. For example, a robbery that happens at 1:00 am on October 31st will be counted towards crime for October 30th. As the percent of the moon illuminated measure is a single value per night, this ensures that crimes that occur in the early morning are not counted with the moonlight for that night.

[2]www.wunderground.com

[3]Data for the weather uses the same hours as crime data from NIBRS.

[4]The hour of 12:00 am to 12:59 am has about 2.5 times as many crimes reported as adjacent hours have, and significantly more crimes than any other hour. This suggests that some crimes where the incident time is unknown are reported to have occurred at midnight or that the time reflects the start of a work shift rather than when the crime happened (Jarvis 2015). As a result, crimes occurring within that hour are excluded from this study.

[5]These hours were used to improve comparability with Schafer et al. (2010), however this introduces some inaccuracies in measuring moonlight as the moon is not always fully risen by 8:00 pm. As this will affect all agencies consistency, the results are unlikely to change when controlling for the precise time of moon rise.

3.2.1 Crime data

The National Incident-Based Reporting Program (NIBRS) is an FBI data set that provides detailed information for each crime reported to the agency.[6] This study uses the offense-level data which includes information for each crime committed during an incident. In incidents where more than one crime was committed, the offense-level data contains one row of data for each crime.[7] This study uses the date and hour the crime occurred to determine if the crime occurred at night, and the crime location to determine whether the crime happened outdoors.[8]

Reporting to NIBRS is voluntary and most agencies choose not to report.[9] Few major cities report to NIBRS, with only one quarter of agencies that serve a population of 250,000 people or greater reporting.[10] There are also geographic limitations to using NIBRS with reporting agencies tending to be in the southern or eastern portion of the country. Figure 3.1 shows the location of each agency included in this study.

[6]For a detailed overview of NIBRS and discussions of its limitations please see Maxfield (1999) and Jarvis (2015). For an overview of the organizational structure of NIBRS data please see Akiyama and Nolan (1999).

[7]Unlike the FBI's Uniform Crime Reporting (UCR) Program Data which utilizes the Hierarchy Rule to report only the most serious crime in an incident, NIBRS reports every crime that occurred.

[8]Outdoor locations are those in the following NIBRS location categories: ATM separate from bank, camp/campground, construction site, dock/wharf/freight/modal, terminal, field/woods, highway/road/alley, lake/waterway, park/playground, parking lot/garage, rest area, and tribal lands. As Jarvis (2015) notes, some of these locations are imprecise causing some degree of imprecision in measuring whether the crime occurred inside or outside.

[9]According to the FBI's 2017 NIBRS report, 42% of law enforcement agencies, covering under one-third of the United States population, submitted data to NIBRS.

[10]https://ucr.fbi.gov/nibrs/2017

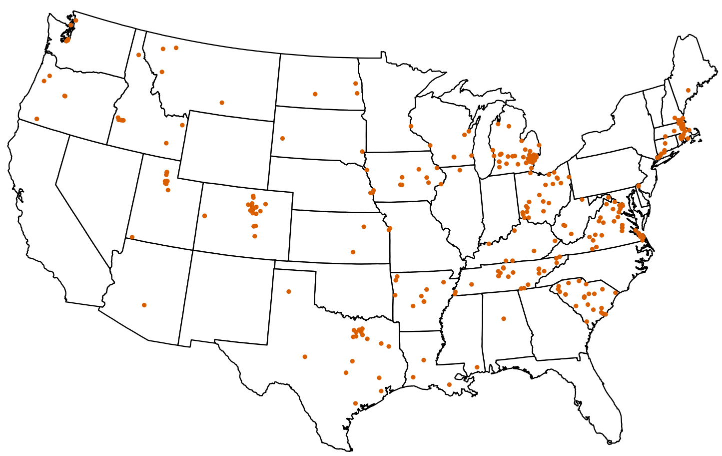

Figure 3.1: Agencies included in this study, n = 299.

Following Stolzenberg, D'Alessio, and Flexon (2017), crime is measured as both the number of total crimes and the number of index crimes.[11] [12] In addition, index crimes are subdivided into violent index crimes (murder, rape, robbery, and aggravated assault) and property index crimes (burglary, motor vehicle theft, theft, and arson).[13]

One concern with NIBRS' measure of the hour in which the crime occurred is that uncertainty about when the crime actually happened can lead to inaccurate hours being reported. For example, if a home is burglarized during the day, the residents may not know of the crime until they return home that evening. This can lead to substantial inaccuracies in the measurement of when a crime occurs. This is far more prevalent in property crime, when a victim need not be present during the crime, than in violent crime when the victim will, in most cases, know exactly when the crime occurred. A Bureau of Justice Statistics study found that only 1% of violent crime victims did not know when the crime occurred, while 12% of property crime victims did not know when their crime happened (Rand and Robinson 2011). A separate Bureau of Justice Statistics study found that for burglaries where the victim

[11]Index crimes are a collection of eight crimes chosen by the FBI as their measure of crime in their Uniform Crime Reporting (UCR) Program due to their seriousness, frequency of occurrence, and high level of reporting throughout the country. The eight index crimes are murder, rape, robbery, aggravated assault, burglary, theft, motor vehicle theft, and arson.

[12]Unlike the UCR which only provides crime counts for the eight index crimes (non-index crimes are only reported when an arrest is made), NIBRS provides detailed information on broader collection of 46 crimes referred to a Group A offenses.

[13]The index crime of rape is defined using the FBI's revised definition which includes sodomy and sexual assault with an object.

was not present, which make up the majority of burglaries, 31% of victims did not know when the crime occurred (Catalano 2010). Due to this limitation, the NIBRS variable for the hour the crime occurred is likely to contain some measurement error. However, as these inaccuracies are unlikely to be because of changes in moonlight, this issue will not bias this study's results.[14]

Table 3.2 provides descriptive statistics for the crime variables included. The number of total crimes that occur is fairly low with about two crimes reported outside per agency each night, though a small number of larger agencies reported significantly more crimes with one agency reporting 84 crimes in a single night. These crimes are primarily non-index crimes with these less severe crimes making up approximately two-thirds of all crimes. Among index crimes, property crimes compose nearly 75% of crimes reported.

Table 3.2: Descriptive statistics for agency-level outdoor nightly crimes.

	Mean	Std. Dev.	Min.	Max.
Total Crime	1.94	3.86	0	84
Total index Crime	0.75	1.93	0	43
Violent index Crime	0.20	0.72	0	20
Property index Crime	0.55	1.49	0	41
Moon Illuminated*Clear Sky	0.24	0.31	0	1
Temperature (F)	52.50	18.42	-30	101
Humidity	72.56	17.12	4	100
Rain (in inches)	0.00	0.03	0	10

[14]The imprecision of when the crime occurred is likely related to the issue of midnight and noon hours having significantly more crime reported than any other hour. If the crime time was in a broad range or unknown entirely, it may have been reported at one of those hours as a placeholder.

This study limits NIBRS agencies to only local police or sheriff's departments in jurisdictions of at least 50,000 people and which report 12 months of the year for all years studied. Agencies are limited to those with 50,000 or greater population to ensure that the agencies have enough crimes to be measured. As weather data comes from the nearest airport to the agency, this also greatly improves the accuracy of that data as smaller cities are more likely to be located further from airports than larger cities. 299 agencies meet these criteria and are included in this study.

3.2.2 Moonlight and Weather Data

To address limitations in proper measurement of moonlight that past studies have had, this study uses weather data to control for cloud coverage that could obscure the moon's light. The website Weather Underground provided information on weather conditions and the percent of the moon that is illuminated for each night.[15] Approximately 4% of agency-nights did not have weather data available, as a result of issues with the website during webscraping, and these agency-nights were dropped from the analysis.

For the measure of moonlight, this study created a variable from the

[15] Data from Weather Underground is sourced from weather stations at airports. For example, San Francisco's weather data is based on the weather at the San Francisco International Airport. As such, weather data is noisier than would be ideal - particularly for agencies far from the airport - but has been used reliably in previous research (Tompson and Bowers 2013). Each agency studied was matched with their nearest airport using the website's API which returns the nearest airport for a pair of coordinates. The coordinates for each agency are from the Law Enforcement Identifiers Crosswalk 2012 which was matched with the NIBRS data using the agency's ORI code.

interaction between the percent of the moon illuminated and the proportion of the night with clear skies (i.e. without clouds).[16] The resulting variable is continuous between 0 (new moon or constant clouds) and 1 (full moon and no clouds).

Rows 5-8 of Table 3.2 describes the weather variables included. The average amount of the moon illuminated in each agency per night, after interacting with the proportion of the night with clear skies, was 24%. When not considering the effect of clouds, the average amount of the moon illuminated is 50%, showing that cloud coverage makes a substantial difference in the measurement of moonlight. Nights were on average 52°F with humidity at 73%. Most nights do not experience any rain though this varied by location and time of year.

3.3 Empirical Strategy

The differences in the amount of cloud coverage cities receive generates substantial variation in the amount of moon illumination that a city receives. Therefore, the moonlight-clear skies interaction offers a natural experiment to measure the effect of lighting on outdoor nighttime crime. This study estimates the effect of moonlight on crime using a Poisson regression model.

[16]Weather data is available hourly or, for some airports, more frequently. To determine the proportion of the night that is clear of cloud coverage this study divides the time units reported (hours in most cases) that have clear skies by the total number of time units. A clear period is one with any weather that is "clear." Cloudy periods include all periods that are not labeled as "clear."

The model this study estimates is:

$$logE(Y_{it}) = \beta_0 + \beta_1 moonlight_{it} + weather'_{it}\lambda + \alpha_i + \zeta_t \quad (3.1)$$

where Y_{it}) is the number of crimes in agency i (n = 299) in time t (year-month-day, n = 2,555 days). *moonlight* is a continuous variable (0 to 1) measuring moonlight that is created by the interaction between the percent of the moon illuminated and the proportion of the night with clear skies. As each agency has the same share of moonlight prior to controlling for cloud coverage, the interacted moonlight-clear skies variable is the only measure of moonlight necessary. X' is a vector of time- and agency-varying control variables that include the agency's population and weather conditions for each agency-night. The weather conditions included are average temperature, average humidity, and rainfall in inches. The parameter α_i is the agency fixed effect to control for differences between agencies, and the parameter ζ_t is the year-month-day fixed effect to control for crime trends consistent across all agencies such as seasonality or the day of the week. Standard errors are clustered at the agency level. Models are weighed by the agency's population in 2010, the first year of data.

3.4 Results

Table 3.3 presents results from the main analysis with Row 1 reporting the incident rate ratio which indicates that nights with 100% moon illumination (a full moon and clear skies all night) have significantly more outdoor crimes compared with nights without any moonlight (either a new moon or cloud coverage throughout the entire night).[17] Column 1 estimates the effect of moonlight on total crime while Column 2 estimates the effect only for index crimes. Columns 3 and 4 estimate the effect for index violent and index property crimes, respectively. For total index crime there is a 5.7% increase in crime on nights with a full moon and no clouds compared to a night without any moonlight. Most of this effect is the result of violent crime which is 7.9% higher. Moonlight does not have a significant effect on property crime.

Table 3.3: Main Results: The effect of moonlight on nighttime outdoor crime

	Total Crimes	Index Crimes	Violent Index	Property Index
exp(B)	1.066***	1.057***	1.079***	1.040
Se(B)	0.012	0.017	0.017	0.022
[CI]	[1.044, 1.089]	[1.025, 1.091]	[1.046, 1.112]	[0.997, 1.085]
p-value	0.000	0.001	0.000	0.067

Note:
Number of observations: 734,321. Approximately 4% of agency-nights have one or more weather variables missing, these nights were dropped from the analysis. ***p<0.01, **p<0.05

While statistically significant, Columns 1-3 each have large standard

[17] One concern with this measure is that nights with more clouds are also more likely to have rain which significantly decreases the number of crimes. Models run excluding nights with any amount of rain provide nearly identical results.

errors causing wide confidence intervals. Violent index crimes, for example, are estimated to be 7.9% higher on a night with full moonlight compared to a night without any moonlight, but the 95% confidence interval stretches from a 4.7% increase to an 11.2% increase. Though past studies on moonlight have been conducted, their measurement of moonlight was inaccurate because they did not control for cloud coverage.

3.5 Robustness Check

Moonlight's effect on crime is hypothesized to be purely due to changes in outdoor lighting. To check the robustness of the findings, this study uses crimes that occur during the day as a falsification test. The same analyses as in the main results are conducted with the hours examined now being 10:00 am to 3:59 pm.[18] All results for these tests should be non-significant as it is for a time when the sun is out, and the moon provides no additional light.

Table 3.4 shows the results for this check and all crime categorizes analyzed show non-significant results. As moonlight cannot affect daytime illumination, these results provide evidence that the moonlight variable is measured accurately and that its effect at night is likely due to illumination. As many past studies on the moon posit that its effect is through non-

[18]Similar to the issue at 12:00 am - 12:59 am, the hour 12:00 - 12:59 pm has approximately 150% the number of crimes reported as adjacent hours, indicating that some crimes where the time is unknown are reported to have occurred at noon. As such, that hour is excluded from the data.

illumination mechanisms such as the moon's gravitational pull on one's brain (Lieber and Sherin 1972), these results also serve to provide further evidence against the moon's purported mystical properties.

Table 3.4: Robustness Check Results: The effect of moonlight on daytime outdoor crime.

	Total Crimes	Index Crimes	Violent Index	Property Index
exp(B)	1.004	0.983	0.976	0.981
Se(B)	0.017	0.023	0.026	0.029
[CI]	[0.972, 1.037]	[0.939, 1.029]	[0.927, 1.028]	[0.926, 1.039]
p-value	0.817	0.455	0.367	0.508

Note:
Number of observations: 734,321. Approximately 4% of agency-nights have one or more weather variables missing, these nights were dropped from the analysis. ***p<0.01, **p<0.05

A reasonable second robustness check would be to examine crimes that occur indoors. As most indoor locations are equipped with electrical lights, moonlight should not affect criminal behavior indoors. Due to serious limitations in NIBRS' measurement of indoor locations, this robustness check is not used. Crimes that happen outside but in the immediate vicinity of an indoor location are considered to have occurred in that indoor location. For example, if a crime happened on the front lawn of the victim's residence, NIBRS would record that crime as occurring in the "Residence/Home" category, an indoor location.[19] The exact number of crimes reported in indoor locations that actually occurred outside is unknown and unable to be ascertained in this

[19] Personal communication with Bradley Zoladz, Training Instructor for the FBI's CJIS Division, on March 18th, 2019.

data set. This issue makes any measure of indoor crime inaccurate as the true number of these crimes actually occurring within a structure is unknown.

3.6 Discussion and Limitations

Past studies on the relationship between lighting and crime primarily focus on crime in a small geographic location close to a newly installed or improved streetlight. These changes cause a substantial increase in the amount of lighting in that area - in some cases a change from no light at all. This study, however, examined crime across the city and with far dimmer illumination than that produced by a streetlight. The findings indicate that a small amount of light can increase crime. The mechanisms for why this is so are unclear.

The finding that violent crime significantly increased while property crime had no significant difference suggests that the increase in lighting altered either the risk or opportunity only for interpersonal crimes. Welsh and Farrington (2008) hypothesized that in some circumstances better lighting could increase crime by increasing the number of potential victims and offenders in an area or that the better illumination of victims "may allow better judgments of their vulnerability and attractiveness [as a robbery target]" (5). The brighter night may encourage individuals to walk along a dark area that, were it entirely dark, they would normally avoid. The impact that changes in lighting has on people's behavior in outcomes other than crime, for example willingness to walk rather than use public transportation, could offer guidance as to whether risk or opportunity for crime changes. These changes may also reduce a capable guardian's ability to determine who belongs in the area by limiting their ability to identify people. Offenders likely need lower illumination to be able to identify suitable victims; they only need to tell if the victim has material goods worth stealing or is capable of resisting.

While it is beyond human capabilities to alter the moon, these results offer further evidence that the effect of outdoor lighting exists on a spectrum where the dosage of light generated can alter its effect on crime. That more moonlight is related to increased violent crime shows that low dosages of lighting may be criminogenic. The idea that higher dosages of light are an important crime-fighting tool is already supported among policy makers who are increasingly replacing the bulbs in streetlights with LED lights for both cost savings and to increase the brightness of the lights for supposed safety benefits (Hendrickson 2018; Hurd 2019; Staff 2019; Trickey 2017b). Research on lighting dosage will be able to inform policy makers of the optimal amount of lighting to install to improve public safety. If further evidence supports the notion that low dosage of lights are criminogenic - especially if at levels caused by dim streetlights - it could help policy makers prioritize areas of their city where the level of light is contributing to crime.

Though this study used clouds to control for differences in moonlight visibility between cities, it treated light as a constant for all locations *within* the city for any given night. That lighting from the moon affects one part of a city differently than another is clear. Physical features such as trees and tall buildings can drastically diminish, even eliminate, light from the moon. Electrical lights, from streetlights, vehicle headlights, and buildings can also reduce illumination from the moon. If these features vary within a city, this study's estimates may be moderated by moonlight having a strong effect in parts of the city alongside a weak effect in other parts. Moonlight's effect is also likely heterogeneous among cities as cities with differing levels of mechanical lighting will be affected to different degrees by moonlight. For example, a high crime area that also has few streetlights may be more affected by moonlight than a high crime area with ample lighting.

Variations in the ways that neighborhoods in a city can handle extreme weather demonstrate that a city's reaction to environmental factors are not homogeneous. A study on aggravated assault and temperature in Dallas found that while higher temperature increased aggravated assaults throughout the city, the increases were most pronounced in lower socioeconomic status neighborhoods (Harries, Stadler, and Zdorkowski 1984). The authors hypothesized that this was due to poorer communities being unable to mitigate the effect of high temperatures because they could not afford air conditioning. Likewise, the effect of ambient light may vary based on other sources of lighting or barriers that reduce lighting's effectiveness. A recent study analyzing the impact of shadows in New York City found that even in the nation's largest metropolis, there were substantial variations in the amount of *daylight* that city blocks received due to the placement of buildings (Miranda et al. 2019).

While NIBRS data does not contain the precise location of crimes, local police data sets are available with the coordinates of crimes. Future studies should use these local data sets to control for light within a city which may cloud the effect of moonlight.

Chapter 4

Ambient Lighting and Arrests: Evidence from a Natural Experiment

Abstract
Objectives The purpose of this study is to assess if 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 likelihood that a crime results in an arrest in the week after the transition to and from 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 increases 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 arrests.

4.1 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

[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.

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 by 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 opportunity 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 increas-

[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).

ing 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

[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.

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 this 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.

4.1.1 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.

$$E[Benefit_{crime}] > E[Detection] * E[Punishment] \tag{4.1}$$

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

[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.

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 increasing 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

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

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 also 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

[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.

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.

4.1.2 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]

[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.

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

[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)

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 experience 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

[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.

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

[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.

and Farrington (2008)'s proposed mechanisms: that increased lighting alters 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

4.2 Data

The data used in this study comes from the FBI's National Incident-Based Reporting System (NIBRS) for the years 2001 to 2016. 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.[16] 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 4.2 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

[16]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.

country's population reported to NIBRS.[17] 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.[18] 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

[17]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

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

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.[19] To avoid double-counting arrests when multiple offenses are committed in the same incident, only the most serious offense per incident is kept.[20]

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), property index crimes (burglary, motor vehicle theft, theft, and arson).[21] In addition, robbery is examined by itself, as well as part of the violent crime category, as past studied have found robbery to be particularly responsive to changes in outdoor lighting (Doleac and Sanders 2015)

Table 4.1 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

[19]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.

[20]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).

[21]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.

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 result in an arrest. During spring, the proportion 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 4.3 and 4.4 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 4.3 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 changed 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 4.4 shows this same visualization for the end of DST in the fall. As seen in Figure 4.3, 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.

4.3 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.[22] 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.[23]

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

$$log\frac{p(arrest)}{1-p(arrest)} = \beta_0 + \beta_1 DST + \eta i + \zeta year + \lambda DayOfWeek_i \qquad (4.2)$$

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

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

[23]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.

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.

4.3.1 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.[24] This analysis seeks to estimate the following model:

$$log\frac{p(arrest)}{1-p(arrest)} = \beta_0 + \beta_1 DST + \beta_2 days + \beta_3 DST * days + \zeta year + \lambda DayOfWeek \quad (4.3)$$

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 (4.2) 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

[24] 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.

between the DST indicator variable (DST) and the number of days from DST ($days$). As in Equation (4.2), this model uses agency and time fixed effects (year and day of week) represented by ηi, $\zeta year$, and $\lambda DayOfWeek$, respectively.

4.4 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.[25]

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.[26] However, there was not a sufficient number of offenses in the agencies from these states that report to NIBRS to analyze.

4.5 Results

4.5.1 Spring: More evening lighting

Table 4.2 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

[25]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.

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

increases the likelihood that a crime ends in an arrest.[27] This effect is driven by violent crime, particularly robbery. Column 1 shows the effect on total index crime, 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 4.1, 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 4.2 and follow the same layout as in Table 4.2. 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

[27]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.

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 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 4.3 shows results for the regression discontinuity design shown in Equation (4.3). This table presents results for the spring analysis and follows the organization of Table 4.2 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 4.2, their findings support the model from Section 4.1.1 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 is 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 4.2, 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.

4.5.2 Fall: Less evening lighting

Table 4.4 follows the same organization as Table 4.2 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 likelihood 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 crime 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 4.5 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.

4.6 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. Another possible mechanism is that the increases in lighting reduces the number of opportunities to offender with a low risk of being caught, reducing the window in which offenders can comfortable 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 (2008)'s 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 that quandary that while crime has declined significantly since the 1990s, the arrest rate for crimes have been largely stagnant. Figure 4.5 shows national arrest rates for violent and property crimes in the United States from 1980-2017. During eacj year since 1980 approximately 40% of violent crimes and under 20% of property crimes cleared. 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.

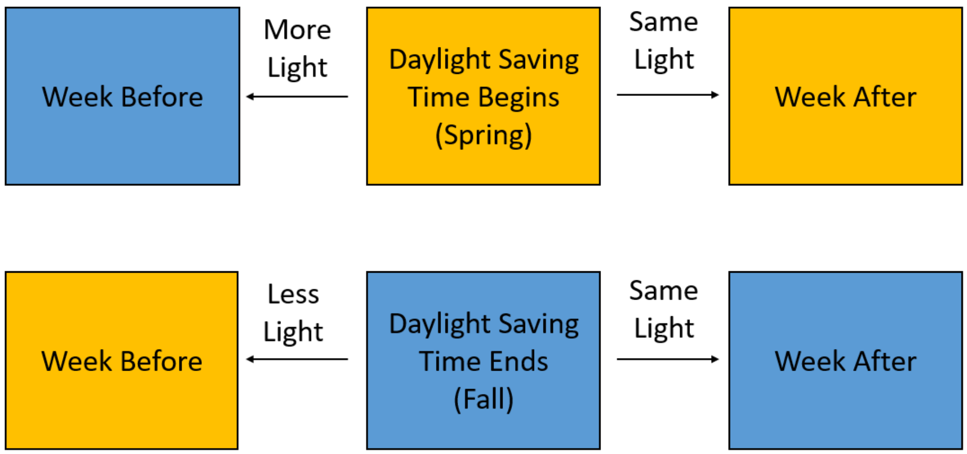

Figure 4.1: The change in the amount of evening light caused by the start (end) of DST in spring (fall) compared to the week before and after.

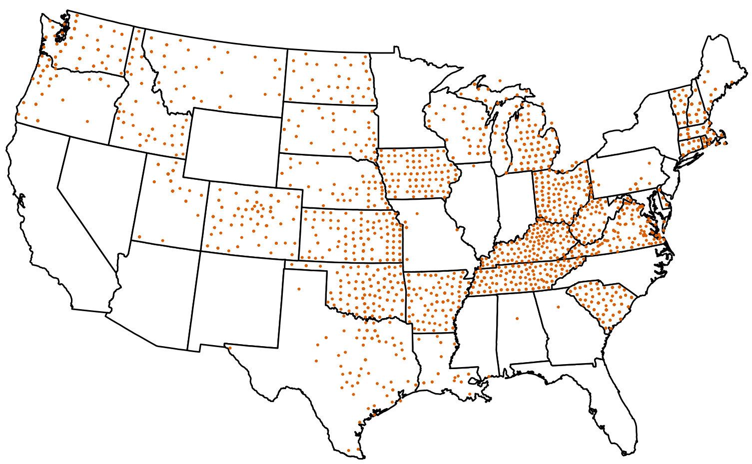

Figure 4.2: Agencies included in this study, n = 3985.

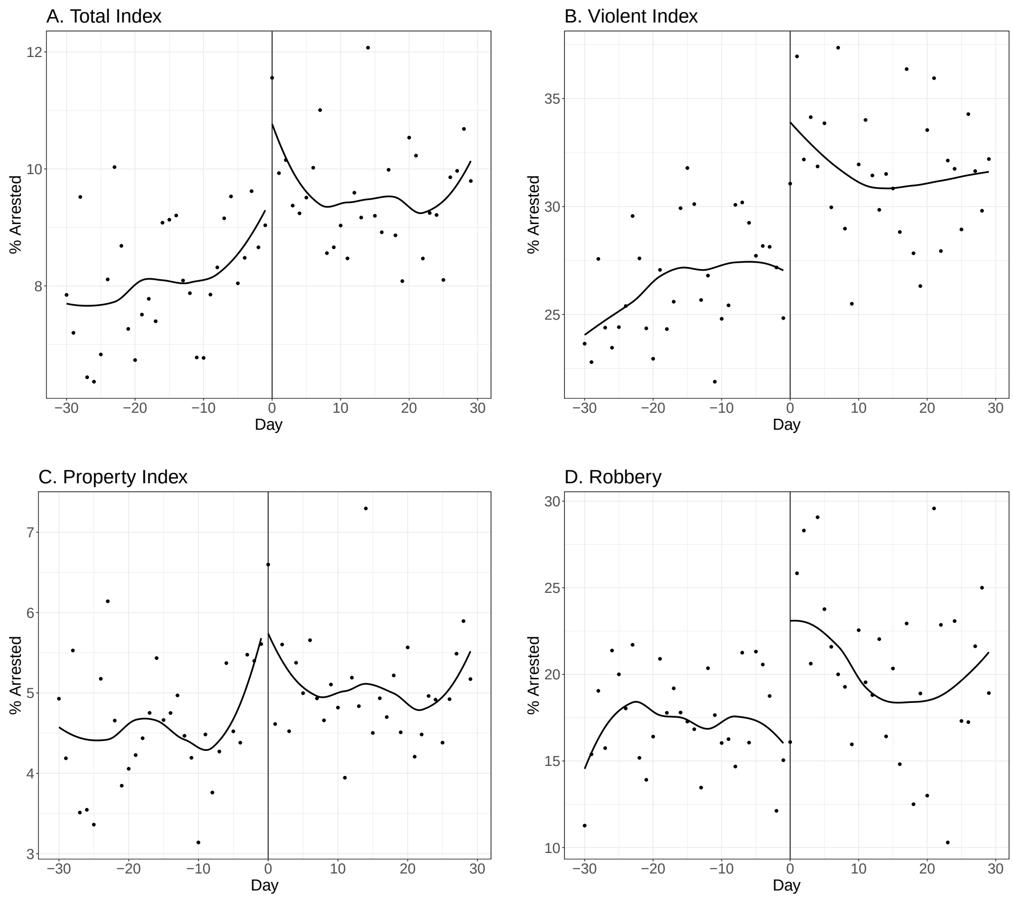

Figure 4.3: Daily percent of crimes where the perpetrator is arrested during spring (more evening light) around the day that daylight saving time begins (Day 0).

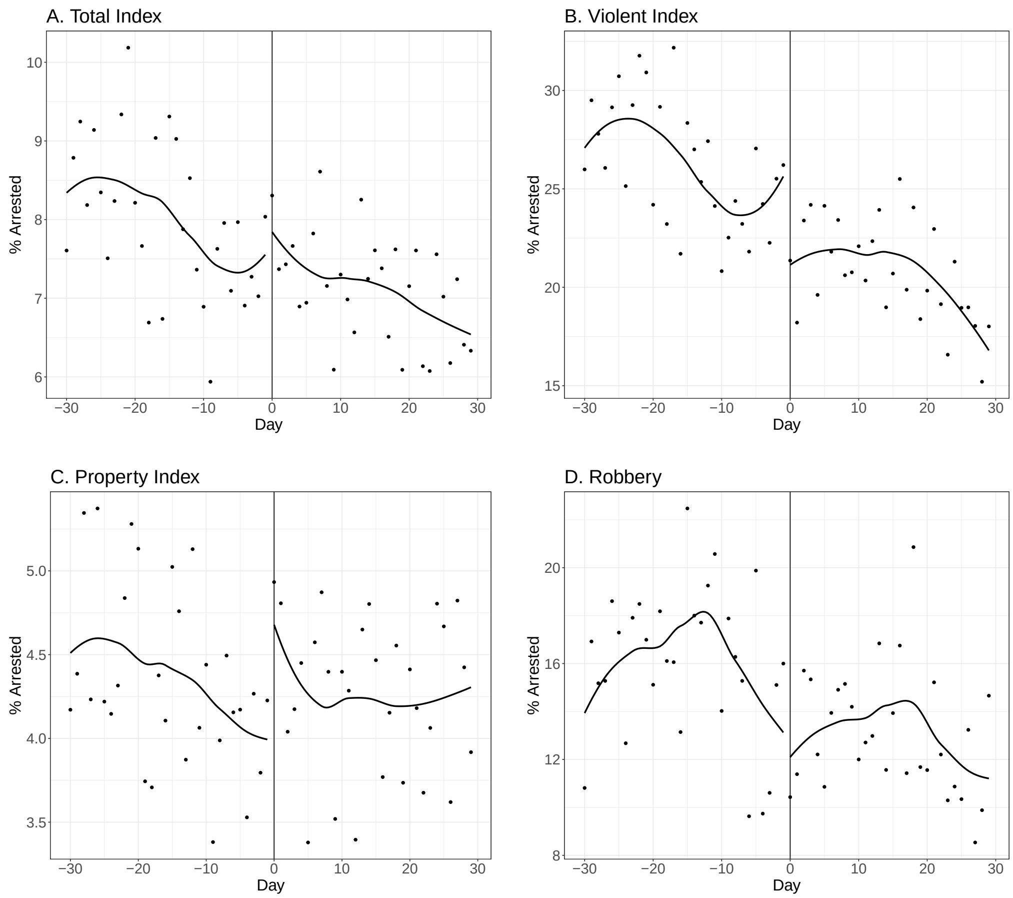

Figure 4.4: Daily percent of crimes where the perpetrator is arrested during fall (less evening light) around the day the daylight saving time ends (Day 0).

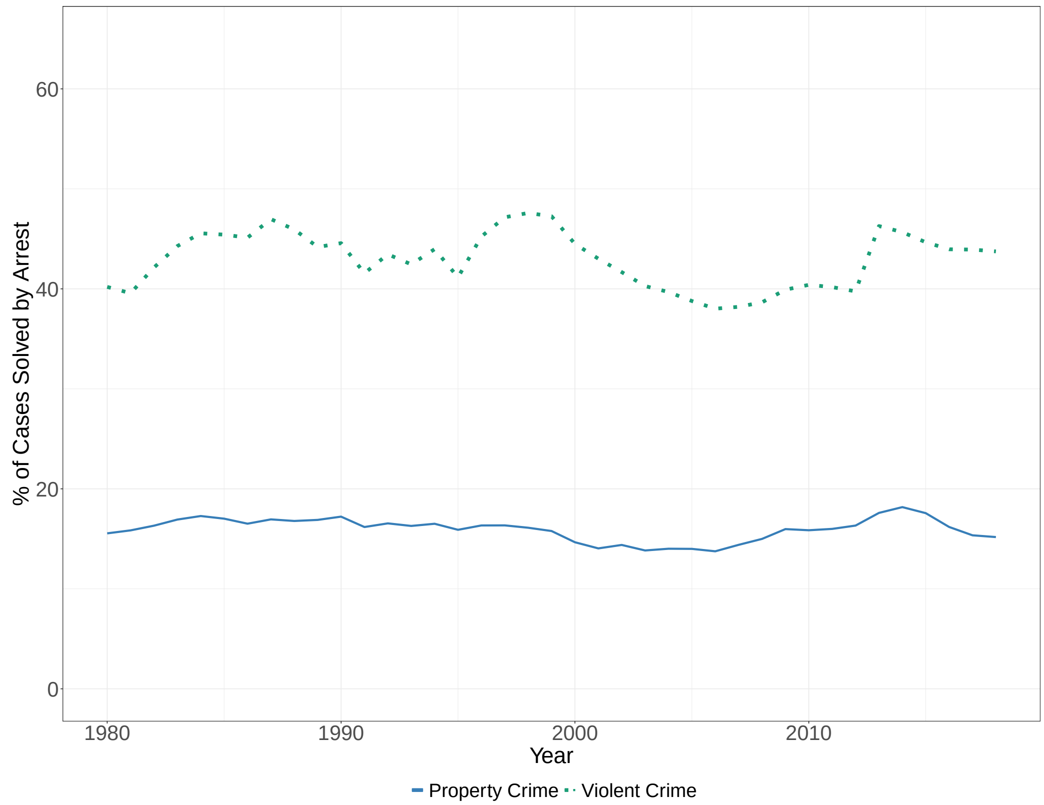

Figure 4.5: The percent of violent crimes (murder, rape, robbery, and aggravated assault) and property crimes (burglary, motor vehicle theft, and theft) that result in at least one offender being arrested. This figure shows national data using all agencies that have reported to the FBI's Uniform Crime Reporting (UCR) Program data for 12 months of the year for every year shown.

Table 4.1: 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 4.2: 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 4.3: 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 4.4: 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 4.5: 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

Chapter 5

General Discussion

This dissertation sought to contribute to the Crime Prevention Through Environmental Design (CPTED) literature by examining two common tools used to reduce crime: door locks and outdoor lights. The first paper examined the effect of “smart locks” install on campus buildings on crime in an urban university setting. Results found no significant effect of the locks, however the already low rate of crime on campus means that the locks were only a small increase in the already ample amount of security on campus. The remaining two papers studied the effect of outdoor lighting on crime and arrests. The second paper used moonlight to measure the effect of a small increase in outdoor lighting on outdoor, nighttime crime. This paper found that nights with a full moon and no cloud coverage have significantly more crime than nights without any moonlight. As most previous studies measure much brighter sources of lighting than moonlight - primarily streetlights - this provides evidence that a small increase in lighting may be criminogenic. The final paper used daylight saving time (DST) to examine how the likelihood that a crime results in an arrest changes when the amount of evening daylight is altered by the transition to and from DST. Results showed a significant increase in the likelihood of an arrest, in particularly for robbery.

In total, this dissertation advances the criminology field by improving our understanding of how door locks and outdoor lighting affect crime. As major cities in the United States are increasingly investing on improvements to current streetlights (Trickey 2017a; Bliss 2019; Wisniewski 2019; Jaramillo 2020), this dissertation can provide guidance to policy makers as to how to make these changes to most effectively reduce crime and improve arrest rates. Results from the three papers in this dissertation suggest that the effect of door locks and outdoor lighting are complex - they depend on the context and situation in which they are used, as well as the dosage of light intensity. Overall, these findings advanced the research on these tools and provide avenues to explore for future research.

Chapter 6

References

Abadie, Alberto. 2005. "Semiparametric Difference-in-Differences Estimators." *The Review of Economic Studies* 72 (1): 1–19.

Akiyama, Yoshio, and James Nolan. 1999. "Methods for Understanding and Analyzing Nibrs Data." *Journal of Quantitative Criminology* 15 (2): 225–38.

Amaddeo, F, G Bisoffi, R Micciolo, M Piccinelli, and M Tansella. 1997. "Frequency of Contact with Community-Based Psychiatric Services and the Lunar Cycle: A 10-Year Case-Register Study." *Social Psychiatry and Psychiatric Epidemiology* 32 (6): 323–26.

Amandus, Harlan E, RD Hunter, E James, and S Hendricks. 1995. "Reevaluation of the Effectiveness of Environmental Designs to Reduce Robbery Risk in Florida Convenience Stores." *Journal of Occupational and Environmental Medicine* 37 (6): 711–17.

Armitage, Rachel. 2018. "Burglars' Take on Crime Prevention Through Environmental Design (Cpted): Reconsidering the Relevance from an Offender Perspective." *Security Journal* 31 (1): 285–304.

Ashton, Julie, Imogen Brown, Barbara Senior, and Ken Pease. 1998. "Repeat Victimisation: Offenders Accounts."

Avdija, Avdi S. 2019. "Police Response to Homicide Crime Scenes: Testing the Effect of the Number of Police Officers and Investigators Responding to an Active Crime Scene on the Arrest Success Rate." *Journal of Criminal Justice and Security*, no. 2: 101–14.

Barberet, Rosemary, and Bonnie S Fisher. 2009. "Can Security Beget Insecurity? Security and Crime Prevention Awareness and Fear of Burglary Among University Students in the East Midlands." *Security Journal* 22

(1): 3–23.

Barnes, Christopher M, and David T Wagner. 2009. "Changing to Daylight Saving Time Cuts into Sleep and Increases Workplace Injuries." *Journal of Applied Psychology* 94 (5): 1305.

Beer, ES de. 1941. "The Early History of London Street-Lighting." *History* 25 (100): 311–24.

Berument, M Hakan, Nukhet Dogan, and Bahar Onar. 2010. "Effects of Daylight Savings Time Changes on Stock Market Volatility." *Psychological Reports* 106 (2): 632–40.

Bhattacharjee, Chanchal, Peter Bradley, Matt Smith, Andrew J Scally, and Bradley J Wilson. 2000. "Do Animals Bite More During a Full Moon? Retrospective Observational Analysis." *BMJ* 321 (7276): 1559–61.

Blanes Vidal, Jordi, and Tom Kirchmaier. 2018. "The Effect of Police Response Time on Crime Clearance Rates." *The Review of Economic Studies* 85 (2): 855–91.

Bliss, Laura. 2019. "The Future of the Streetlight Might Be in the Past." *Politico*. https://www.citylab.com/design/2019/11/street-light-los-angeles-history-lighting-design-lamp-safety/602218/.

Braga, Anthony A, and Desiree Dusseault. 2018. "Can Homicide Detectives Improve Homicide Clearance Rates?" *Crime & Delinquency* 64 (3): 283–315.

Branas, Charles C, Rose A Cheney, John M MacDonald, Vicky W Tam, Tara D Jackson, and Thomas R Ten Have. 2011. "A Difference-in-Differences Analysis of Health, Safety, and Greening Vacant Urban Space." *American Journal of Epidemiology* 174 (11): 1296–1306.

Budd, Tracey. 1999. "Burglary of Domestic Dwellings: Findings from the British Crime Survey."

Cajochen, Christian, Songül Altanay-Ekici, Mirjam Münch, Sylvia Frey, Vera Knoblauch, and Anna Wirz-Justice. 2013. "Evidence That the Lunar Cycle Influences Human Sleep." *Current Biology* 23 (15): 1485–8.

Carmel-Gilfilen, Candy. 2011. "Advancing Retail Security Design: Uncovering Shoplifter Perceptions of the Physical Environment." *Journal of Interior*

Design 36 (2): 21–38.

Casteel, Carri, and Corinne Peek-Asa. 2000. "Effectiveness of Crime Prevention Through Environmental Design (Cpted) in Reducing Robberies." *American Journal of Preventive Medicine* 18 (4): 99–115.

Catalano, Shannan M. 2010. *Victimization During Household Burglary*. US Department of Justice, Office of Justice Programs, Bureau of Justice Statistics.

Ceccato, Vania, and Adriaan Cornelis Uittenbogaard. 2014. "Space–Time Dynamics of Crime in Transport Nodes." *Annals of the Association of American Geographers* 104 (1): 131–50.

Chalfin, Aaron, Benjamin Hansen, Jason Lerner, and Lucie Parker. 2019. "Reducing Crime Through Environmental Design: Evidence from a Randomized Experiment of Street Lighting in New York City." National Bureau of Economic Research.

Chapman, Simon, and Stephen Morrell. 2000. "Barking Mad? Another Lunatic Hypothesis Bites the Dust." *BMJ* 321 (7276): 1561–3.

Coate, Douglas, and Sara Markowitz. 2004. "The Effects of Daylight and Daylight Saving Time on Us Pedestrian Fatalities and Motor Vehicle Occupant Fatalities." *Accident Analysis & Prevention* 36 (3): 351–57.

Coates, Wendy, Dietrich Jehle, and Eric Cottington. 1989. "Trauma and the Full Moon: A Waning Theory." *Annals of Emergency Medicine* 18 (7): 763–65.

Cohen, Lawrence E, and Marcus Felson. 1979. "Social Change and Crime Rate Trends: A Routine Activity Approach." *American Sociological Review*, 588–608.

Cook, Philip J, Anthony A Braga, Brandon S Turchan, and Lisa M Barao. 2019. "Why Do Gun Murders Have a Higher Clearance Rate Than Gunshot Assaults?" *Criminology & Public Policy* 18 (3): 525–51.

Cozens, Paul, and Terence Love. 2009. "Manipulating Permeability as a Process for Controlling Crime: Balancing Security and Sustainability in Local Contexts." *Built Environment* 35 (3): 346–65.

———. 2015. "A Review and Current Status of Crime Prevention Through

Environmental Design (Cpted)." *Journal of Planning Literature* 30 (4): 393–412.

Cozens, Paul Michael, Greg Saville, and David Hillier. 2005. "Crime Prevention Through Environmental Design (Cpted): A Review and Modern Bibliography." *Property Management* 23 (5): 328–56.

Crowe, TD, and DL Zahm. 1994. "Crime Prevention Through Environmental Design: NAHB Land Development Magazine." *National Association of Home Builders*.

Culver, Roger, James Rotton, and IW Kelly. 1988. "Geophysical Variables and Behavior: XLIX. Moon Mechanisms and Myths: A Critical Appraisal of Explanations of Purported Lunar Effects on Human Behavior." *Psychological Reports* 62 (3): 683–710.

Dijk, J van, J van Kesteren, and Paul Smit. 2007. *Criminal Victimisation in International Perspective*. Boom Juridische Uitgevers.

Doleac, Jennifer L, and Nicholas J Sanders. 2015. "Under the Cover of Darkness: How Ambient Light Influences Criminal Activity." *Review of Economics and Statistics* 97 (5): 1093–1103.

Dominguez, Patricio, and Kenzo Asahi. 2017. "Crime Time: How Ambient Light Affect Criminal Activity." *Available at SSRN 2752629*.

Eisenbach, Christoph, Alexander Lavinius Ungur, Joerg Unger, Wolfgang Stremmel, and Jens Encke. 2008. "Admission to Intensive Care for Parasuicide by Self-Poisoning: Variation by Time Cycles, Climate and the Lunar Cycle." *Psychiatry Research* 161 (2): 177–84.

Faulkner, Kimberly A, Douglas P Landsittel, and Scott A Hendricks. 2001. "Robbery Characteristics and Employee Injuries in Convenience Stores*." *American Journal of Industrial Medicine* 40 (6): 703–9.

Felson, Marcus, and Erika Poulsen. 2003. "Simple Indicators of Crime by Time of Day." *International Journal of Forecasting* 19 (4): 595–601.

Ferguson, Susan A, David F Preusser, Adrian K Lund, Paul L Zador, and Robert G Ulmer. 1995. "Daylight Saving Time and Motor Vehicle Crashes: The Reduction in Pedestrian and Vehicle Occupant Fatalities." *American Journal of Public Health* 85 (1): 92–95.

Fisher, Bonnie S. 1995. “Crime and Fear on Campus.” *The Annals of the American Academy of Political and Social Science* 539 (1): 85–101.

Fisher, Bonnie S, and John J Sloan. 2003. “Unraveling the Fear of Victimization Among College Women: Is the "Shadow of Sexual Assault Hypothesis" Supported?” *Justice Quarterly* 20 (3): 633–59.

Fisher, Bonnie S, John J Sloan, Francis T Cullen, and Chunmeng Lu. 1997. “The on-Campus Victimization Patterns of Students: Implications for Crime Prevention by Students and Post-Secondary Institutions.” *Crime Prevention at a Crossroads*, 101–23.

Fisher, Bonnie S, and Andrew RP Wilkes. 2003. “A Tale of Two Ivory Towers. A Comparative Analysis of Victimization Rates and Risks Between University Students in the United States and England.” *British Journal of Criminology* 43 (3): 526–45.

Gaski, John F, and Jeff Sagarin. 2011. “Detrimental Effects of Daylight-Saving Time on Sat Scores.” *Journal of Neuroscience, Psychology, and Economics* 4 (1): 44.

Glasner, Philip, and Michael Leitner. 2016. “Evaluating the Impact the Weekday Has on Near-Repeat Victimization: A Spatio-Temporal Analysis of Street Robberies in the City of Vienna, Austria.” *ISPRS International Journal of Geo-Information* 6 (1): 3.

Greenberg, Stephanie W, and William M Rohe. 1984. “Neighborhood Design and Crime a Test of Two Perspectives.” *Journal of the American Planning Association* 50 (1): 48–61.

Gregory-Allen, Russell, Ben Jacobsen, and Wessel Marquering. 2010. “The Daylight Saving Time Anomaly in Stock Returns: Fact or Fiction?” *Journal of Financial Research* 33 (4): 403–27.

Grogger, Jeffrey, and Greg Ridgeway. 2006. “Testing for Racial Profiling in Traffic Stops from Behind a Veil of Darkness.” *Journal of the American Statistical Association* 101 (475): 878–87.

Gurevitz, Mark. 2005. “Daylight Saving Time.” In. Congressional Research Service, Library of Congress.

Harries, Keith D, Stephen J Stadler, and R Todd Zdorkowski. 1984. “Seasonality and Assault: Explorations in Inter-Neighborhood Variation, Dallas

1980." *Annals of the Association of American Geographers* 74 (4): 590–604.

Harrison, Yvonne. 2013. "The Impact of Daylight Saving Time on Sleep and Related Behaviours." *Sleep Medicine Reviews* 17 (4): 285–92.

Heboyan, Vahé, Scott Stevens, and William V McCall. 2018. "Effects of Seasonality and Daylight Savings Time on Emergency Department Visits for Mental Health Disorders." *The American Journal of Emergency Medicine*.

Hendricks, Scott, Douglas Landsittel, Harlan Amandus, Jay Malcan, and Jennifer Bell. 1999. "A Matched Case-Control Study of Convenience Store Robbery Risk Factors." *Journal of Occupational and Environmental Medicine* 41 (11): 995–1004.

Hendrickson, Matthew. 2018. "Streetlight Replacement Program Heads Back to South Side in Project's Next Phase." *Chicago Sun Times*. Chicago Sun Times. https://chicago.suntimes.com/news/streetlight-replacement-program-heads-back-to-south-side-in-projects-next-phase/.

Herber, Stefanie P, Johanna Sophie Quis, and Guido Heineck. 2017. "Does the Transition into Daylight Saving Time Affect Students' Performance?" *Economics of Education Review* 61: 130–39.

Ho, Grant, Derek Leung, Pratyush Mishra, Ashkan Hosseini, Dawn Song, and David Wagner. 2016. "Smart Locks: Lessons for Securing Commodity Internet of Things Devices." In *Proceedings of the 11th Acm on Asia Conference on Computer and Communications Security*, 461–72. ACM.

Holland, Nancy, and Jimmie Hinze. 2000. "Daylight Savings Time Changes and Construction Accidents." *Journal of Construction Engineering and Management* 126 (5): 404–6.

Holzman, Harold R, Tarl Roger Kudrick, and Kenneth P Voytek. 1996. "Revisiting the Relationship Between Crime and Architectural Design: An Analysis of Hud's 1994 Survey of Public Housing Residents. Cityscape: A." In *Journal of Policy Development and Research*. Citeseer.

Horrace, William C, and Shawn M Rohlin. 2016. "How Dark Is Dark? Bright Lights, Big City, Racial Profiling." *Review of Economics and Statistics* 98 (2): 226–32.

Huang, Arthur, and David Levinson. 2010. "The Effects of Daylight Saving

Time on Vehicle Crashes in Minnesota." *Journal of Safety Research* 41 (6): 513–20.

Hunter, Ronald David. 1988. "The Relationships of Selected Environmental Characteristics to the Incidence of Convenience Store Robbery Within the State of Florida." PhD thesis, Florida State University.

Hurd, Cheryl. 2019. "City of Berkeley to Fix Dimly-Lit Street Lights." *NBC Bay Area*. NBC Bay Area. https://www.nbcbayarea.com/news/local/City-of-Berkeley-to-Fix-Dimly-Lit-Street-Lights-506257361.html.

Investigation, Federal Bureau of. 2015. *Effects of Nibrs on Crime Statistics*.

Jaramillo, Catalina. 2020. "Philly Just Took a Step Toward Getting Led Streetlights Citywide." *WHYY*. https://whyy.org/articles/philly-just-took-a-step-toward-getting-led-streetlights-citywide/.

Jarvis, John P. 2015. "Examining National Incident-Based Reporting System (Nibrs) Data: Perspectives from a Quarter Century of Analysis Efforts." *Justice of Research and Policy* 16 (2): 195–210.

Johnson, Shane D, and Kate J Bowers. 2010. "Permeability and Burglary Risk: Are Cul-de-Sacs Safer?" *Journal of Quantitative Criminology* 26 (1): 89–111.

Ju, Ohaeri, Am Sunmola, and C Ewhirujakpor. 1992. "A Study of the Relationship Between African Myths About the Phases of the Moon and Emotional Distress." *Journal of the Nigeria Medical Association* 23 (2).

Kamstra, Mark J, Lisa A Kramer, and Maurice D Levi. 2000. "Losing Sleep at the Market: The Daylight Saving Anomaly." *American Economic Review* 90 (4): 1005–11.

Kantermann, Thomas, Myriam Juda, Martha Merrow, and Till Roenneberg. 2007. "The Human Circadian Clock's Seasonal Adjustment Is Disrupted by Daylight Saving Time." *Current Biology* 17 (22): 1996–2000.

Kingshott, Brian F, and Robert T Meesig. 2019. "Does Community Policing Help to Solve Crime? A Look at Its Relationships with Crime Clearance Rates." *Journal of Applied Security Research* 14 (1): 3–31.

Koslofsky, Craig. 2002. "Court Culture and Street Lighting in Seventeenth-Century Europe." *Journal of Urban History* 28 (6): 743–68.

Kountouris, Yiannis, and Kyriaki Remoundou. 2014. "About Time: Daylight Saving Time Transition and Individual Well-Being." *Economics Letters* 122 (1): 100–103.

La Vigne, Nancy Gladys. 1997. *Visibility and Vigilance: Metro's Situational Approach to Preventing Subway Crime.* US Department of Justice, Office of Justice Programs, National Institute of Justice Washington, DC.

LeBeau, James L. 1994. "The Oscillation of Police Calls to Domestic Disputes with Time and the Temperature Humidity Index." *Journal of Crime and Justice* 17 (1): 149–61.

Lechner, Michael. 2011. "The Estimation of Causal Effects by Difference-in-Difference Methods." *Foundations and Trends in Econometrics* 4 (3): 165–224.

Lieber, Arnold L. 1978. "Human Aggression and the Lunar Synodic Cycle." *Journal of Clinical Psychiatry.*

Lieber, Arnold L, and Carolyn R Sherin. 1972. "Homicides and the Lunar Cycle: Toward a Theory of Lunar Influence on Human Emotional Disturbance." *American Journal of Psychiatry* 129 (1): 69–74.

Lister, Stuart, Dick Hobbs, Steve Hall, and Simon Winlow. 2000. "Violence in the Night-Time Economy; Bouncers: The Reporting, Recording and Prosecution of Assaults1." *Policing and Society: An International Journal* 10 (4): 383–402.

MacDonald, John, Charles Branas, and Robert Stokes. 2019. *Changing Places: The Science and Art of New Urban Planning.* Princeton University Press.

Manfredini, R, F Fabbian, A De Giorgi, B Zucchi, R Cappadona, F Signani, N Katsiki, DP Mikhailidis, and others. 2018. "Daylight Saving Time and Myocardial Infarction: Should We Be Worried? A Review of the Evidence." *European Review for Medical and Pharmacological Sciences* 22 (3): 750–55.

Mathew, VM, J Lindesay, N Shanmuganathan, and V Eapen. 1991. "Attempted Suicide and the Lunar Cycle." *Psychological Reports* 68 (3): 927–30.

Maxfield, Michael G. 1999. "The National Incident-Based Reporting System: Research and Policy Applications." *Journal of Quantitative Criminology*

15 (2): 119–49.

McCreedy, Kenneth R, and Brent G Dennis. 1996. "Sex-Related Offenses and Fear of Crime on Campus." *Journal of Contemporary Criminal Justice* 12 (1): 69–80.

McLay, Robert N, Amado A Daylo, and Paul S Hammer. 2006. "No Effect of Lunar Cycle on Psychiatric Admissions or Emergency Evaluations." *Military Medicine* 171 (12): 1239.

Minnery, John R, and Bill Lim. 2005. "Measuring Crime Prevention Through Environmental Design." *Journal of Architectural and Planning Research*, 330–41.

Miranda, Fabio, Harish Doraiswamy, Marcos Lage, Luc Wilson, Mondrian Hsieh, and Cláudio T Silva. 2019. "Shadow Accrual Maps: Efficient Accumulation of City-Scale Shadows over Time." *IEEE Transactions on Visualization and Computer Graphics* 25 (3): 1559–74.

Monk, Timothy H, and Simon Folkard. 1976. "Adjusting to the Changes to and from Daylight Saving Time." *Nature* 261 (5562): 688.

Morgan, Anthony, and Christopher Dowling. 2019. "Does Cctv Help Police Solve Crime?"

National Statistics, Office for. 2019. "Crime Survey for England and Wales 2017-2018." *Available at Http://Doi.org/10.5255/UKDA-SN-8464-1*.

Newman, Oscar, and Karen A Franck. 1982. "The Effects of Building Size on Personal Crime and Fear of Crime." *Population and Environment* 5 (4): 203–20.

Núñez, S, L Pérez Méndez, and A Aguirre-Jaime. 2002. "Moon Cycles and Violent Behaviours: Myth or Fact?" *European Journal of Emergency Medicine* 9 (2): 127–30.

Owen, Cathy, Concetta Tarantello, Michael Jones, and Christopher Tennant. 1998. "Lunar Cycles and Violent Behaviour." *Australian and New Zealand Journal of Psychiatry* 32 (4): 496–99.

Painter, Kate. 1996. "The Influence of Street Lighting Improvements on Crime, Fear and Pedestrian Street Use, After Dark." *Landscape and Urban Planning* 35 (2-3): 193–201.

Pease, Ken. 1991. "The Kirkholt Project: Preventing Burglary on a British Public Housing Estate." *Security Journal* 2 (2): 73–77.

Pierson, Emma, Camelia Simoiu, Jan Overgoor, Sam Corbett-Davies, Vignesh Ramachandran, Cheryl Phillips, and Sharad Goel. 2017. "A Large-Scale Analysis of Racial Disparities in Police Stops Across the United States." *arXiv Preprint arXiv:1706.05678*.

Pizarro, Jesenia M, William Terrill, and Charles A LoFaso. 2018. "The Impact of Investigation Strategies and Tactics on Homicide Clearance." *Homicide Studies*.

Poyner, Barry. 1983. *Design Against Crime: Beyond Defensible Space*. Butterworths London.

Raison, Charles L, Haven M Klein, and Morgan Steckler. 1999. "The Moon and Madness Reconsidered." *Journal of Affective Disorders* 53 (1): 99–106.

Rand, Michael R, and Jayne E Robinson. 2011. "Criminal Victimization in the United States, 2008-Statistical Tables." *US Department of Justice*.

Raphael, Steven. 2016. "Optimal Policing, Crime, and Clearance Rates." *Criminology & Public Policy* 15: 791.

Rasmussen, Chris, and Gina Johnson. 2008. "The Ripple Effect of Virginia Tech: Assessing the Nationwide Impact on Campus Safety and Security Policy and Practice." *Midwestern Higher Education Compact*.

Reppetto, Thomas A. 1974. *Residential Crime*. Ballinger Publishing Company Cambridge, MA.

Ridgeway, Greg. 2019. "Experiments in Criminology: Improving Our Understanding of Crime and the Criminal Justice System." *Annual Review of Statistics and Its Application* 6: 37–61.

Robb, David, and Thomas Barnes. 2018. "Accident Rates and the Impact of Daylight Saving Time Transitions." *Accident Analysis & Prevention* 111: 193–201.

Rotton, James, and Ivan W Kelly. 1985. "Much Ado About the Full Moon: A Meta-Analysis of Lunar-Lunacy Research." American Psychological Association.

Schafer, Joseph A, Sean P Varano, John P Jarvis, and Jeffrey M Cancino. 2010. "Bad Moon on the Rise? Lunar Cycles and Incidents of Crime." *Journal of Criminal Justice* 38 (4): 359–67.

Schivelbusch, Wolfgang. 1987. "The Policing of Street Lighting." *Yale French Studies*, no. 73: 61–74.

Scott, Thomas L, Charles Wellford, Cynthia Lum, and Heather Vovak. 2019. "Variability of Crime Clearance Among Police Agencies." *Police Quarterly* 22 (1): 82–111.

Sexton, Alison L, and Timothy KM Beatty. 2014. "Behavioral Responses to Daylight Savings Time." *Journal of Economic Behavior & Organization* 107: 290–307.

Smith, Austin C. 2016. "Spring Forward at Your Own Risk: Daylight Saving Time and Fatal Vehicle Crashes." *American Economic Journal: Applied Economics* 8 (2): 65–91.

Sood, Neeraj, and Arkadipta Ghosh. 2007. "The Short and Long Run Effects of Daylight Saving Time on Fatal Automobile Crashes." *The BE Journal of Economic Analysis & Policy* 7 (1).

Staff, HNN. 2019. "Maui County Faces a Lawsuit over Bright Streetlights." *Hawaii News Now*. http://www.hawaiinewsnow.com/2019/02/14/maui-county-faces-lawsuit-over-bright-streetlights/.

Stevens Jr, Charles R, and Dominique Lord. 2006. "Evaluating Safety Effects of Daylight Savings Time on Fatal and Nonfatal Injury Crashes in Texas." *Transportation Research Record* 1953 (1): 147–55.

Stolzenberg, Lisa, Stewart J D'Alessio, and Jamie L Flexon. 2017. "A Hunters Moon: The Effect of Moon Illumination on Outdoor Crime." *American Journal of Criminal Justice* 42 (1): 188–97.

Sullivan, John M, and Michael J Flannagan. 2002. "The Role of Ambient Light Level in Fatal Crashes: Inferences from Daylight Saving Time Transitions." *Accident Analysis & Prevention* 34 (4): 487–98.

Thakur, CP, and Dilip Sharma. 1984. "Full Moon and Crime." *British Medical Journal* 289 (6460): 1789–91.

Tompson, Lisa, and Kate Bowers. 2013. "A Stab in the Dark? A Research

Note on Temporal Patterns of Street Robbery." *Journal of Research in Crime and Delinquency* 50 (4): 616–31.

Tompson, Lisa, and Michael Townsley. 2010. "(Looking) Back to the Future: Using Space—Time Patterns to Better Predict the Location of Street Crime." *International Journal of Police Science & Management* 12 (1): 23–40.

Trickey, Erick. 2017a. "The Detroit Success Story Visible from Space." *Politico*. https://www.politico.com/magazine/story/2017/05/18/detroit-led-streetlights-infrastructure-project-215159.

———. 2017b. "The Detroit Success Story Visible from Space." https://www.politico.com/magazine/story/2017/05/18/detroit-led-streetlights-infrastructure-project-215159.

Tseloni, Andromachi, Karin Wittebrood, Graham Farrell, and Ken Pease. 2004. "Burglary Victimization in England and Wales, the United States and the Netherlands a Cross-National Comparative Test of Routine Activities and Lifestyle Theories." *British Journal of Criminology* 44 (1): 66–91.

Umbach, Rebecca, Adrian Raine, and Greg Ridgeway. 2017. "Aggression and Sleep: A Daylight Saving Time Natural Experiment on the Effect of Mild Sleep Loss and Gain on Assaults." *Journal of Experimental Criminology* 13 (4): 439–53.

United States Department of Justice, Federal Bureau of Investigation. 2018. "Crime in the United States, 2017." *Available at SSRN 2752629.*

Van Koppen, Peter J, and Robert WJ Jansen. 1999. "The Time to Rob: Variations in Time of Number of Commercial Robberies." *Journal of Research in Crime and Delinquency* 36 (1): 7–29.

Varughese, Jason, and Richard P Allen. 2001. "Fatal Accidents Following Changes in Daylight Savings Time: The American Experience." *Sleep Medicine* 2 (1): 31–36.

Vollaard, Ben, and Jan C Van Ours. 2011. "Does Regulation of Built-in Security Reduce Crime? Evidence from a Natural Experiment." *The Economic Journal* 121 (552): 485–504.

Voracek, Martin, Lisa Mariella Loibl, Nestor D Kapusta, Thomas Niederkrotenthaler, Kanita Dervic, and Gernot Sonneck. 2008. "Not Carried Away by a Moonlight Shadow: No Evidence for Associations Between Suicide Occurrence and Lunar Phase Among More Than 65,000 Suicide Cases in Austria, 1970–2006." *Wiener Klinische Wochenschrift* 120 (11): 343–49.

Walsh, E. 1999. "Crime Prevention Through Environmental Design: Explores the Use of Structure as a Means of Discouraging Criminal Activity." *Journal of Housing and Community Development* 56: 42–44.

Weisel, Deborah Lamm. 2002. *Burglary of Single-Family Houses*. US Department of Justice, Office of Community Oriented Policing Services Washington, DC.

———. 2005. *Analyzing Repeat Victimization*. US Department of Justice, Office of Community Oriented Policing Services Washington, DC.

Welsh, Brandon C, and David P Farrington. 2008. "Effects of Improved Street Lighting on Crime." *Campbell Systematic Reviews* 13: 1–51.

———. 2009. *Making Public Places Safer: Surveillance and Crime Prevention*. Oxford University Press.

Wilkinson, Greg, Marco Piccinelli, Stephen Roberts, Rocco Micciolo, and John Fry. 1997. "Lunar Cycle and Consultations for Anxiety and Depression in General Practice." *International Journal of Social Psychiatry* 43 (1): 29–34.

William Brill Associates, Inc, and United States of America. 1977. "Controlling Access in Highrise Buildings - Approaches and Guidelines."

Wilson, James Q, and George L Kelling. 1982. "The Police and Neighborhood Safety: Broken Windows." *Atlantic Monthly* 127 (2).

Wisniewski, Mary. 2019. "Chicago's Night Sky Is About to Become an Orange Memory, as the City Nears End of Led Streetlight Replacement. But Are the New Lights Better?" *Chicago Tribune*. https://www.chicagotribune.com/business/transportation/ct-biz-chicago-light-replacement-leds-20191231-wvzghgxvrrhv5fktzod6cnytn4-story.html.

Zimecki, Michał. 2006. "The Lunar Cycle: Effects on Human and Animal Behavior and Physiology." *Postepy Hig Med Dosw.* 60: 1–7.