The Effect of Moonlight on Outdoor Nighttime Crime

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Abstract: The use of outdoor lighting, particularly through street lights, 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.

Keywords: CPTED, lighting, outdoor crime

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1 Introduction

The moon has a long history in popular culture as affecting people's propensity towards violence and insanity. 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 (Raison, Klein, and Steckler 1999; Cajochen et al. 2013), 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 (Cozens and Love 2015; Welsh and Farrington 2008; Chalfin et al. 2017). 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 (Felson and Poulsen 2003; Tompson and Townsley 2010; Ceccato and Uittenbogaard 2014; Van Koppen and Jansen 1999; Lister et al. 2000; Glasner and Leitner 2016; Tompson and Bowers 2013; LeBeau 1994). 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 street lights 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 and his colleagues' (2017) 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 street lights, 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 1 details the literature on the effect of light on crime broadly and the effect of moonlight on crime specifically. Section 2 discusses the data used and Section 3 explains the methodology. Section 4 summarizes the results found. Section 5 details a robustness check used and the results of that check. Finally, Section 6 discusses these results and concludes.

1.1 Lighting and Crime

Studying lighting presents difficulties. The vast majority of studies assessing lighting involve installing or improving street lights. 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. (2017) 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. (2017)'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 street lights 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 savings time (DST) as a natural experiment where only the amount of sunlight during the evening changes, and everything else is held constant. Daylight savings 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 drastic effect on crime.

A major benefit to DST studies is that evenings in the week after DST begins have substantially more light 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) 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 normally drives home at 6:00 pm to instead go for a jog, 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 offender 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 street lights, 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.

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 all agencies 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 1 shows the percent of the moon illuminated and the proportion of the night with clear skies for Los Angeles and San Francisco on October 31st, 2015. Both cities have nearly 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. San Francisco is covered by clouds all night, reducing its moon visibility to zero while Los Angeles maintained 78% moon illumination.

INSERT TABLE 1 ABOUT HERE

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), and Schafer et al. (2010) research by using cloud coverage to produce variability in moon illumination and analyzing crime from 299 agencies rather than looking in a single city or aggregating crime nationally.

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.

2.1 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] NIBRS data includes files organized at multiple levels of analysis including the victim-level, offender-level, and offense-level.[7] 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.[8]. 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.[9]

Reporting to NIBRS is voluntary and most agencies choose not to report. 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. 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 1 shows the location of each agency included in this study.

INSERT FIGURE 1 AROUND HERE

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.[14] 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 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.[15]

Table 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.

INSERT TABLE 2 AROUND HERE

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 are. 299 agencies meet these criteria and are included in this study.

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.[16] Approximately 4% of agency-nights did not have weather data available and these nights were dropped from the analysis.

For the measure of moonlight, this study created a variable from the interaction between the percent of the moon illuminated and the proportion of the night with clear skies (i.e. without clouds).[17] The resulting variable is continuous between 0 (new moon or constant clouds) and 1 (full moon and no clouds).

Rows 5-8 of Table 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 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. The model this study estimates is:

$$logE(Y_{it}) = \beta_0 + \beta moonlight + X'\beta_{it} + \alpha_i + \zeta_t \tag{1}$$

where $logE(Y_{it})$ is the number of crimes in agency i (n = 299) in time t (year-month-day, n = 2,555 days). The parameter $\beta moonlight$ 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. $X'\beta_{it}$ 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.

4 Results

Table 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).[18] 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.

INSERT TABLE 3 AROUND HERE

While statistically significant, Columns 1-3 each have large standard 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 substantial 4.7% increase to an enormous 11.2% increase. Though past studies on moonlight have been conducted, the lack of controlling for cloud coverage in these studies makes their measure of moonlight inaccurate and thus their results non-comparable.

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.[19] 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 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-illumination mechanisms such as the moon's gravitational pull on one's brain, these results also serve to provide further evidence against the moon's purported mystical properties.

INSERT TABLE 4 AROUND HERE

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.[20] The exact number of crimes reported in indoor locations that actually occurred outside is unknown and unable to be ascertained in this 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.

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 street light. 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 street light. 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 street lights 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 2017). 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 street lights - 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. Mechanical lights, from street lights, 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 street lights 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.

Notes

[1]i.e. without any clouds.

[2]www.wunderground.com

[3]Data for the weather uses the same hours as crime data from NIBRS: 8:00 pm - 2:59 am excluding 12:00-12:59 am.

[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.

[6]For a detailed overview of NIBRS and discussions of its limitations please see Maxfield (1999) and Jarvis (2015).

[7]For an overview of the organizational structure of NIBRS data please see Akiyama and Nolan (1999).

[8]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.

[9]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 @jarvis2015examining notes, some of these locations are imprecise causing some degree of imprecision in measuring whether the crime occurred inside or outside.

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

[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.

[14]Notable exceptions to this are cases of rape when the victim is incapacitated or for murder when there are no witnesses.

[15]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.

[16]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 is from the Law Enforcement Identifiers Crosswalk 2012 which was matched with the NIBRS data using the agency's ORI code.

[17]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."

[18]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.

[19]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.

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

7 References

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.

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.

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.

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, Aaaron, Benjamin Hansen, Lucie Parker, and Jason Lerner. 2017. "The Impact of Street Lighting on Crime in New York City Public Housing."

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

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.

Cozens, Paul, and Terence Love. 2015. "A Review and Current Status of Crime Prevention Through Environmental Design (Cpted)." *CPL Bibliography* 30 (4): 393–412.

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.

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.

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.

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

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.

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.

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/.

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-html.

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

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." *Niger Med. J* 23 (2).

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.

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.

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.

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.

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.

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.

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*.

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.

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/.

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.

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

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.

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.

Weisel, Deborah Lamm. 2002. *Burglary of Single-Family Houses.* 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.

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.

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

Table 1: Percent of the moon illuminated and proportion of the night with clear skies in Los Angeles and San Francisco for the night of October 31st and early morning of November 1st, 2015.

	Los Angeles	San Francisco
Moon Illuminated	78%	77%
Proportion Clear Skies	1.00	0.00
Real Moon Visibility	78%	0%

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Table 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

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Table 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	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

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Table 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	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

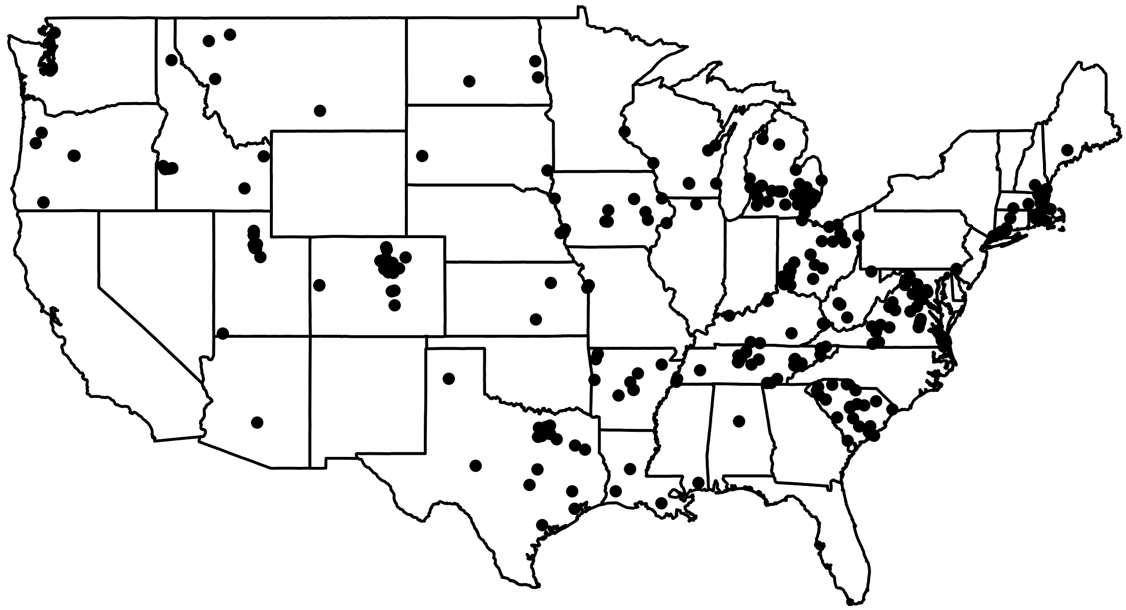

Figure 1: Agencies included in this study, n = 299.

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