BRINGING LIGHT TO THE DARK — CAN SOLAR PUBLIC LIGHTING IMPROVE NIGHTTIME LIFE FOR THE URBAN POOR?

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1. INTRODUCTION

In rapidly growing cities throughout the developing world, lack of public service provision disproportionately affects residents in poor, mostly informal neighborhoods, typically called informal settlements or "slums." Although they are home to approximately a billion urban residents (UN Habitat, 2018), i.e., about 14% of the world population, these areas are often disconnected from public urban infrastructure, such as water, sewage, electricity networks, and even more often: streetlights.

While experimental research (as well as international policy attention) has focused on access to water, sanitation, electricity, and other forms of upgrading in informal settlements (e.g., Devoto et al., 2012; Galiani et al., 2013; Gonzalez-Navarro & Quintana-Domeque, 2012; Günther & Horst, 2014), very few studies have analyzed public lighting (Gulyani and Bassett, 2007; Jaitman, 2012). One reason why there are so few studies might be that doing research in poor, informal neighborhoods at night is often difficult and requires extensive community engagement. Concerns about crime and the challenges of working in the dark likely discourage the sort of in-depth research that is afforded to other basic services in informal settlements, for which all field research can be done during daylight. Furthermore, no data exists on access to public lighting in informal settlements. While the UN Sustainable Development Goal 11 is focused on making "cities and human settlements, inclusive, safe, resilient, and sustainable," none of the targets mention access to streetlighting, despite the fact that access to public light in informal settlements falls under the purview of Goal 11 (United Nations, 2021). This omission likely also means that researchers seeking to make their research SDG-relevant do not realize that public lighting is an important avenue where research is needed.

Importantly, research from high-income countries on streetlights cannot easily be transferred to poor informal settlements. First, the density of many informal settlements makes it impossible to install standard streetlights without demolishing existing houses or taking up limited space

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in pathways. In addition, those living in poor informal settlements engage with public space at night in ways that are fundamentally different than those living in formal urban areas (Kamalipour, 2020). Moreover, basic services like water and sanitation are usually shared and difficult to access when it is dark (Boyce, 2019). The choice for many households is either to go outside at night to use the toilet or use a bucket inside their home, which is emptied in the morning. In addition, houses are often small and typically shared by many family members, meaning that many activities that might otherwise be done indoors happen in public areas, like laundry and food preparation. This more intensive use of public space, even to meet basic needs, set against the reality of high crime rates in many informal settlements raises questions about how public lighting can improve the quality of life at night (Matzopoulos et al., 2020; UN-Habitat, 2011, 2007).

To improve our understanding of how public light can be effectively implemented in these neighborhoods and what impact better lighting might have, we apply a cluster-randomized controlled trial to test the effectiveness of a public lighting technology developed specifically for informal settlements. To our knowledge, it is the first quantitative study to test the impact of public lighting in an informal settlement and only the second RCT studying the impact of public lighting anywhere. Studying one informal settlement in Khayelitsha, Cape Town with about 800 households, we systematically select 49 paths and randomly allocate 24 compounds to receive outdoor solar lighting mounted on each house. There are 65 paths and 26 compounds, with their respective houses, that serve as the control group.

Despite the fact that high-mast lights were already installed in this informal settlement (see Appendix D Figure 1), we find that the intervention leads to a large improvement in nighttime lux[3] levels, with a more than six-fold increase in average lux measured at the path level and a more than eight-fold increase in compounds (semi-private cul-de-sacs). This effect can be partially attributed to the fact that theft and vandalism were relatively minor. Satisfaction with the lights across both treatment groups was high and about 50% of residents say they would be willing to pay at least half the price of a replacement light. We also find that the intervention leads to a higher perception of safety among households living on lit paths, compared to those living on control paths, though we do not find any effects on safety in compounds. Greater perceptions of safety do not translate to broad-based changes in behavior. Despite reporting that they feel safer, people living in treated paths do not report that they engage in more nighttime activities overall, however, we find that both treatment and control respondents are more willing to use shared sanitation at night. In compounds, we find weak evidence that engagement in nighttime activities declined. Respondents in both paths and compounds do not report significantly fewer experiences of crime on their streets.

[3] What human perceive as brightness, is referred to as illuminance. Illuminance is defined as the amount of light falling per unit area of the surface. Illuminance can be measured in units of lux (CIE 2007).

As the finding on shared sanitation indicates, these results require consideration of spillovers. Because anyone in the neighborhood can use a lit path even if they do not live on it, null effects could indicate that all residents are somewhat treated rather than that there is no effect. To address this, we use difference-in-differences to check for changes over time, instrumental variables to check for differences linked to non-compliance, and we analyze households separately who live adjacent to a path or compound of the opposite treatment status (varying treatment intensity), however, we do not find evidence that spillovers are large for any outcome other than the use of shared sanitation at night.

To our knowledge, no public lighting intervention in a developing country context, particularly not in informal settlements, has yet been studied using an experimental approach, therefore our study advances our understanding of the impact of public lighting in two dimensions. First, we contribute to the literature on the impact of public lighting in a new context. There is a large body of mostly observational evidence — primarily from formal cities in high-income countries — to suggest that public lighting influences and improves various aspects of nighttime life, from visibility (Boyce, 2019; Fotios, Yang, et al., 2015; Fotios & Cheal, 2009; Fotios & Uttley, 2018) to perceptions of safety and confidence at night (Atkins et al., 1991; Blöbaum & Hunecke, 2005; Boyce et al., 2000; Fotios, Yang, et al., 2015; Fotios & Uttley, 2018; Fotios & Castleton, 2016; Kaplan, 2019; Kaplan & Chalfin, 2020; Nair et al., 1997; Nasar & Bokharaei, 2017b; Nasar & Jones, 1997; Peña-García et al., 2015; Svechkina et al., 2020; Vrij & Winkel, 1991; Wu & Kim, 2018) to pedestrian activity (Fotios, Unwin, et al., 2015; Fotios & Castleton, 2016; Uttley & Fotios, 2017) to crime (Chalfin et al., 2021, 2020; Welsh and Farrington, 2008). Whereas the literature has had relatively little to say about public lighting in informal settlements (Auerbach, 2020; Gulyani and Bassett, 2007; Kretzer, 2020). We provide quantitative evidence on the impact of public lighting in a different setting — an informal settlement in a middle-income country. Although our results show that public lighting has a positive effect on perceptions of safety, similar to the literature, we find that this may not lead to widespread changes in nighttime behavior. The only other randomized controlled trial which studies the impact of public lighting focuses on public housing developments in New York City (Chalfin et al., 2021).

Second, we contribute to the nascent, but growing field of development engineering, which focuses on testing alternative approaches to technology deployment in low-income settings. By using a distributed, solar-powered public light, we test a hybrid model for what is usually a more centralized public service. In reviewing the few alternative public lighting technologies tried in informal settlements elsewhere, many embrace some form of pole-mounted lights, but imagine decentralized delivery approaches. For example, in some informal settlements in Bogotá, Colombia, residents build their own streetlights to fill gaps in light availability (Kretzer and Walczak, 2020). The NGO Liter of Light, which teaches communities to build solar-powered streetlights made from a water bottle, a solar panel, PVC pipe, and a lead acid battery, implemented these lights in an informal settlement in Chikkaballapur district, Bangalore called

Kundwara (Venkat, 2016). Zonke Energy, based in Cape Town, aims to provide off-grid informal settlements with solar-powered mini-grids and affixes outdoor lights to its electricity distribution poles (Zonke Energy, 2021).[4] Wall-mounted, outdoor solar lights, which we test in this study, represent the opposite approach. The city can still play the role of service provider, but the infrastructure is installed at the structure level to suit the urban form and to draw on local stewards — the residents themselves. Thus, we also quantitatively test a new model of public lighting delivery. This new lighting solution would also fit within the climate resilience goals of many cities to expand the use of renewable energy (e.g., City of Cape Town, 2019).[5] The dramatic decline in the cost of solar photovoltaic (PV) technology, from approximately US $2/Watt in 2010 to US $0.38 in 2019, makes a distributed solar public lighting solution not only feasible, but likely also cost effective (IRENA, 2019; Our World in Data, 2019).[6]

2. CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

Outside of poor informal settlements, there is a large body of mostly observational evidence — primarily from formal cities in high-income countries — to suggest that public lighting improves various aspects of nighttime life. Inadequate nighttime lighting hinders visibility, increasing the likelihood of tripping (Boyce, 2019; Fotios & Cheal, 2009; Fotios & Uttley, 2018) and making it hard to recognize the faces of others (Fotios, Yang, et al., 2015). A relatively large body of literature also links light levels to a perception or feeling of safety (Atkins et al., 1991; Blöbaum and Hunecke, 2005; Boyce et al., 2000; Kaplan, 2019; Kaplan and Chalfin, 2020; Nair et al., 1997; Nasar and Jones, 1997; Peña-García et al., 2015; Svechkina et al., 2020; Vrij and Winkel, 1991; Wu and Kim, 2018) and reassurance or confidence walking alone at night (Fotios, Unwin, et al., 2015; Nasar & Bokharaei, 2017a). There are also some studies on nighttime walking behavior (Fotios, Yang, et al., 2015; Fotios & Castleton, 2016; Painter, 1996; Uttley & Fotios, 2017). For example, Uttley and Fotios (2017) use pedestrian counters to study the impact of Daylight Savings Time (DST) in Virginia to show that an additional hour of ambient light in the evenings is associated with a significant 62% increase in pedestrians on the street.

Another strand of empirical literature, again mostly observational and with small sample sizes in cities in high-income countries, suggests public lighting reduces crime and fear at night (Farrington and Welsh, 2002; Welsh and Farrington, 2008). Chalfin et al. (2021) provide the first experimental evidence from a public housing development project in New York City suggesting that public lighting (in comparison to no lighting) reduces nighttime outdoor crimes

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[4] Zonke Energy is a modular solar mini-grid company based in Cape Town, South Africa.

[5] For example, the City of Cape Town has articulated its own climate resilience strategy.

[6] In 2019, the City of Cape Town budgeted approximately US $67,000 for two high-mast lights vs. approximately US $30,000 to provide the entire informal settlement with solar public lighting. For a more detailed discussion of cost estimates see Section 3.3. Source: City of Cape Town. 2019. Almost 2500 public lights installed in Khayelitsha, work continues. Accessed Jan 27, 2021. http://www.capetown.gov.za/Media-and-news/Almost%202%20500%20public%20lights%20installed%20in%20Khayelitsha,%20work%20continues

by about 35%.[7] Another recent study by Kaplan & Chalfin (2020) makes use of a natural experiment in Chicago – citywide public lighting outages – providing evidence that short-term outages have little impact on crimes on affected streets, but that crime in nearby streets increases alongside pedestrian activity. Moreover, Doleac and Sanders (2015) and Domínguez and Asahi (2019) both use DST in the US and Chile, respectively, to show that additional ambient light in the evenings is associated with a decrease in crime. Domínguez and Asahi (2019) also show that residential areas, which tend to have fewer streetlights, show the largest effects suggesting that more ambient light may have a larger effect in areas with less streetlighting. Kaplan (2019), however, finds the opposite, using moonlight as the exogenous light source to show that nights with brighter moonlight are associated with significantly higher crime than nights with none.

To explain how public light influences nighttime behavior, the theoretical literature broadly focuses on crime, however, two channels can also explain other aspects of nighttime life, such as access to public infrastructure, or social life after sunset, which have been so far mostly ignored. Most theory emphasizes crime because crime prevention is of critical interest to policymakers and the general public with more easily quantifiable costs to society (Chalfin, 2015) than lack of outdoor activities and increased levels of perceived safety. In addition, the theory is largely driven by empirical work in high-income countries. Although we study nighttime activity in a low-income setting, these two theories for crime in high-income settings can still usefully inform our research. The first theory, *prospect-refuge theory*, is that light directly influences nighttime outdoor activity and reduces the likelihood and fear of crime by creating opportunities for surveillance (Cozens et al., 2005; Fisher and Nasar, 1992). Under good lighting conditions, a pedestrian can more easily identify a threat and thus, feels more at ease in the space. In contrast, under poorly lit conditions, resulting shadows could give an offender the chance to watch potential victims while remaining hidden.[8] The second theory argues that it is not just illumination that influences crime and fear of crime in public space, but also the community investment that the infrastructure symbolizes (Chalfin et al., 2021; Cozens et al., 2005; Kaplan, 2019; Welsh & Farrington, 2008). Both of these theories fit within the broader theory of *Crime Prevention through Environmental Design* (CPTED), which focuses on how design interventions in the built environment can deter crime (Cozens et al., 2005). Determining which of these two channels is dominant has proven challenging, especially since they are not mutually exclusive. Researchers point to reductions in daytime crime in addition to reductions in nighttime crime, as an indicator of the community investment channel (e.g., Chalfin et al., 2021), while effects only on nighttime outcomes indicate the direct effect of illumination at night (Cozens et al., 2005; Farrington and

[7] Specifically, they study nighttime index crimes, which include: murder and non-negligent manslaughter, robbery, felony assault, burglary, grand larceny, and motor vehicle theft.

[8] It has also been argued that the opposite is possible: more light makes it easier for a potential criminal to identify a victim (Fisher and Nasar, 1992).

Welsh, 2002), but empirical studies remain inconclusive (Chalfin et al., 2021; Doleac and Sanders, 2015; Domínguez and Asahi, 2019; Kaplan, 2019; Uttley and Fotios, 2017).

From these theoretical and empirical studies, it is probable that public light also has a significant effect on perceived safety, nighttime behavior, and crime in cities of low- and middle-income countries. However, both the magnitude and the mechanism remain unclear, given that the cities in these countries are radically different than most geographies represented in previous literature. Poor informal settlements are often substantially different, both in their urban form (i.e., frequently characterized by low-rise, small, but high-density housing) as well as in their urban dynamics (i.e., people may spend more time outside). The density common to many informal settlements not only changes the dynamics of life at night, but also changes which lighting technologies are feasible. Furthermore, the need to enter public space to access basic sanitation services as well as conduct otherwise private activities, like laundry, suggest the scope for impact may differ. For example, Chalfin et al. (2021) study NYC public housing developments, which are characterized by large multi-story buildings with open public spaces where residents otherwise have private access to basic infrastructure and likely have a different relationship with public space compared to residents of informal settlements.

These contextual differences suggest that more research is needed to understand the effect of public lighting on life in informal settlements. Therefore, we not only explore whether an alternative to both high-mast lights and standard streetlights is effective in informal settlements, but also what the impact is of greater light availability on perception of safety and risk of crime, nighttime activities, and experience of crime.

3. RESEARCH DESIGN AND SETTING

3.1 STUDY SETTING

Cape Town, South Africa is home to more than 400 informal settlements and that number is always growing (Ndifuna et al., n.d.; Obose, 2021).[9] Existing policies predominantly support the continued deployment of high-mast lights for public lighting in informal settlements (City of Cape Town, 2019b; de Lille, 2012) (see Appendix D Figure 1). These are 30-40-meter-tall floodlights (also called stadium lights) that are typically installed on public land on the perimeter of informal settlements. The City of Cape Town maintains that high-mast lights are the best available solution, given the maze of property laws that affect informal settlements and the physical limitations on space. High-mast lights are also said to be more resistant to vandalism and easier to maintain in informal settlements because they can be placed in locations accessible to a service vehicle.

[9] At least 17 new informal settlements have been established in Khayelitsha, alone, since the onset of the COVID-19 pandemic in March 2020 (Obose, 2021).

On the other hand, residents of Cape Town's informal settlements, local NGOs, and our own baseline measurements (see Section 4.1 and Article 3) suggest that despite these advantages, high-mast lights do not provide bright, uniform light at night (Mtembu, 2017; Ramphele, 2017; Weyers and Notywala, 2017). In informal settlements, light from high-mast lights can create sharp contrasts and dark shadows (Kretzer, 2020). This type of lighting might not necessarily be better than none at all, since drastic changes between bright light and shadows make it even more difficult to navigate and detect potential threats (Wu and Kim, 2018). Furthermore, South Africa's electricity grid is unreliable (Kumo et al., 2021). Scheduled black-outs, called "load shedding," are common, plunging large areas of the city into complete darkness. Even when the electricity comes back, the high-mast lights are often left damaged by the outage, meaning weak or no public lighting is available until they are repaired. Finally, high-mast lights are linked to a history of racial and economic inequality in South Africa — in Cape Town, these lights are only used for residential public lighting in townships that were previously zoned as Black African under apartheid (O'Regan et al., 2014).

As in other countries, many informal settlements in South Africa are not mapped.[10] A Google Maps search will often show an empty patch of land in the shape of the informal settlement, obscuring the fact that thousands of people may live there and that an extensive pedestrian path network may exist. While it may be that informal settlements go unmapped as a result of their informality or because governments specifically do not want to acknowledge these unplanned urban neighborhoods, they also go unmapped because it is not easy to do. Houses are often built out of short-lived building materials and it is common for residents to renovate, expand, or change the orientation of their home, which can substantially alter walking paths. In addition, in South Africa's informal settlements a group of residents often decides to block a path, turning it into a compound, or cul-de-sac, to limit through traffic and enhance their sense of security. In other words, informal settlements are constantly changing, making any maps quickly outdated.

The informal settlement we selected for this study is an approximately 30-year-old, 38,200-square-meter neighborhood (Ndifuna et al., n.d.), whose path network was unmapped before we started this research. The site was selected with guidance from our local partner, a Cape Town-based NGO called the Social Justice Coalition (SJC),[11] which provided us a list of three informal settlements around Cape Town where they had contact with the leadership and that

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[10] Non-governmental organizations like Slum Dwellers International and Violence Prevention through Urban Upgrading (VPUU), and others, are working in South Africa to address the dearth of informal settlement maps. Both the Western Cape Government's Informal Settlement Support Programme, as well as the City of Cape Town have been supporting informal settlement enumerations and mapping efforts.

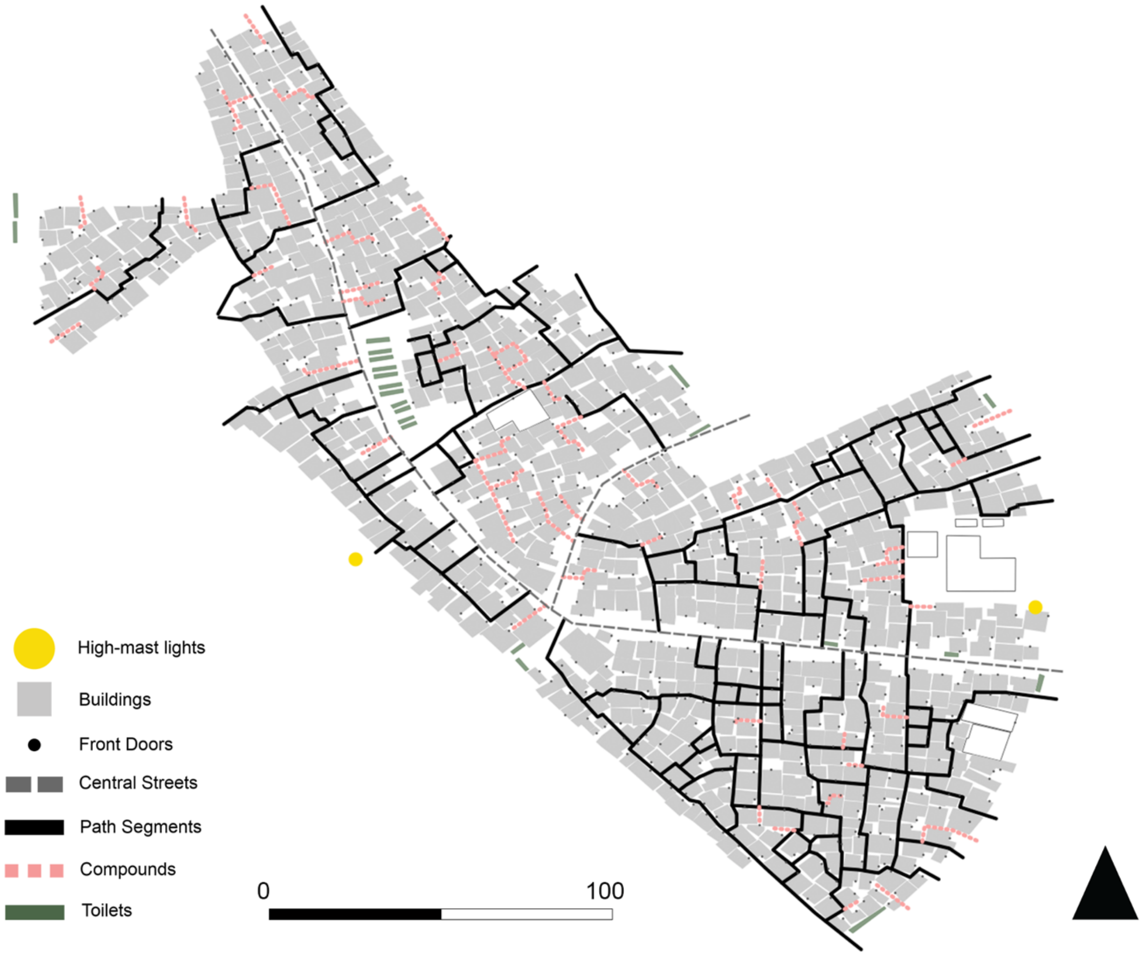
[11] The Social Justice Coalition (SJC) is a non-governmental organization based in Khayelitsha, Cape Town that primarily focuses on organizing legal action and grassroots activism to secure the rights of residents of informal settlements. In 2017, SJC began a campaign focused on public lighting and agreed to collaborate with us by (a) helping us identify an informal settlement and (b) providing us with Visiting Researcher status, which enabled us to make use of SJC's office space for meetings and storage. They are not directly involved in the implementation of the intervention, but rather aim to learn from the results at the end of the study.

were not included in governmental plans for upgrading in the immediate future. Along with our research partners, we ultimately selected one particular site for this study because (a) it is a manageable size to conduct a field test of a technology, (b) it is a very dense informal settlement with dark paths, making lighting particularly beneficial, and (c) it is a "contiguous" informal settlement that is not interrupted by any formal structures. Last, finding a community leadership that is willing to let a research team in without a clear promise of what the outcome of the research will be is challenging in South Africa. In this neighborhood, however, the leadership's willingness to engage in the research process enabled the field study to take shape and made data collection at night possible.

In collaboration with a research partner from architecture and local residents, we mapped and labeled the houses and the network of walkways throughout the informal settlement.[12] Based on the most up to date version of the map in August 2019, we classified the path network into three categories for the field study (Figure 1).

[12] This impact evaluation is part of a broader project, which was developed as part of the ETH Zurich Institute for Science, Technology, and Policy's Urban Research Incubator and is described in this dissertation as well as in Briers (2021). We collaborated on the coordination and implementation of the project, though we had separate research questions. For more information, see the Introduction of this dissertation.

Figure 1. Path network map of the informal settlement



Mapping done in collaboration with Stephanie Briers, Xolelwa Maha, Thabisa Mfubesi, Frans Mafilika, Noliyema Swartbooi, Tembinkosi Mositata, Thanduxolo Jubati, Pumeza Wanga, Nomsa Siyo, Yamkela Rongwana, Sibongile Mvumvu, and Jennifer Qongo.

Central streets refer to the two major arteries that bisect the informal settlement and are passable with a car or truck. They are wide enough for city service vehicles to service the waste collection point, sewerage, and toilet blocks in the neighborhood. These paths are excluded from the experiment because they are outliers in terms of length, width, and usage.[13]

Path segments are components of paths (a route to get from point A to point B). In a study of crime hot spots, Weisburd et al. (2012) define path segments by intersection and Blattman et al. (2019) draw from this, defining a path segment as the "length of street between two intersections." In defining path segments, we try to follow this approach as much as possible by adopting turning decision as our rule to define the beginning and end of a path segment. A path

[13] Initially, we also excluded them because we thought they would be brighter than narrower paths, however, the light measurements revealed that the lighting on these paths is not uniform (see Article 3).

segment begins either upon entrance from a formal street or after someone makes a decision to turn right or left from another path segment. Since informal settlements are not planned according to top-down urban planning guidelines, path segments vary in length and width.

Compounds can be thought of as cul-de-sacs within the path network. They emerge when a group of households agree to block off all other entryways to their houses except one shared entrance. That entrance is often demarcated by a gate that may or may not be locked during the day and is frequently locked at night. The space in front of the houses participating in a given compound is semi-private, as the residents typically all share it for activities like doing washing, hanging clothes to dry, preparing food, and socializing, but it is not open at all times to people who do not live in the compound.

3.2 EXPERIMENTAL DESIGN AND SAMPLE SELECTION

We use a randomized controlled trial (RCT) to study the impact of an alternative public lighting technology that is intended to provide brighter lighting on the thin pathways in informal settlements. In the case of informal settlements in Cape Town, the existing high-mast lights provide bright lighting on wider paths and to those households that live close to the high-mast lights, but they cast strong shadows in narrower paths and provide dim or no lighting in path segments and compounds that are farther away. Until now, the impact of public lighting has rarely been evaluated quantitatively in low-income settings. The randomization allows us to test both the efficacy of a new technology and service delivery option for public lighting as well as the impact of public lighting on life at night.

We chose a cluster-randomized controlled trial, randomizing at the path and compound level with the unit of observation being the household. By randomizing at the path segment and compound level, instead of at the household level, we ensure that the treatment is distributed in a way that would make logical sense to a pedestrian at night. In other words, the intervention results in lit routes, rather than randomly lit houses that might create patchy, non-uniform lighting that does not enable residents to pass from one part of the neighborhood to another on a lit route. Moreover, randomizing at the household level would have made it nearly impossible to create a viable control group, since one household could be in the control group, but live on the same path segment or compound next to several households in the treatment group, thereby experiencing almost all of the treatment effect (except direct lighting of the entryway to their house). On the other hand, clustering by area, which would have led to even fewer possible spillovers (see Section 7.2), was not possible given that the neighborhood was too small to create a sufficient number of area clusters. Including additional neighborhoods was not feasible due to the high time investment and security issues associated with working in these neighborhoods at night.

We stratify the informal settlement's path network into pedestrian path segments and compounds (see Figure 1 and Section 3.1) — on which about 800 households live. We randomized the 50 total compounds into 24 treatment and 26 control compounds using a standard randomization procedure on the computer. We used a systematic randomization approach to assign 114 path segments[14] into 49 treatment and 65 control path segments (see Figure 2 and Appendix D Figure 2). A purely random selection of path segments could easily result in a set of disparate path segments that have no practical pedestrian logic or, by chance, be clustered in one area of the settlement. Therefore, we used a systematic sampling protocol to select treatment path segments. The informal settlement we study is split by two central streets that run north-south and east-west (see Figure 1). It is also surrounded by formal, paved vehicular roads. Beginning in the northwest corner of the settlement, we selected roughly[15] every other path segment, from north to south and from west to east until the next intersection, to be a treatment path segment. At the intersection, one of the next possible segments was selected until reaching one of the central streets. When there was no intersection, the next path segment was also selected into the treatment group (see Figure 2). This approach ensures that the treatment resulted in lit paths that a person could logically walk, while avoiding giving preference to any one path into the settlement over another.

All households with a front door facing onto these treatment path segments or compounds received a free light (see Section 3.3) for the six-month study period (October 2020-March 2021), which they could keep after the study ended. Households in the control group were offered a free light at the end of the study. See Section 4.1, Table 1 for a study timeline.

The unit of analysis is the household, except for light measurements, for which we use the cluster-level average. All houses in the neighborhood — approximately 793[16] — were eligible to participate in both survey rounds, however, any household which was not randomized into an experimental group will not be included in the analysis.[17] To estimate effects, we compare outcomes in households living on treated path segments/compounds with outcomes in households on path segments/compounds that did not receive solar public lights. We are interested both in the efficacy of the solar public lighting technology and the impact of light, in general, on our outcomes of interest.

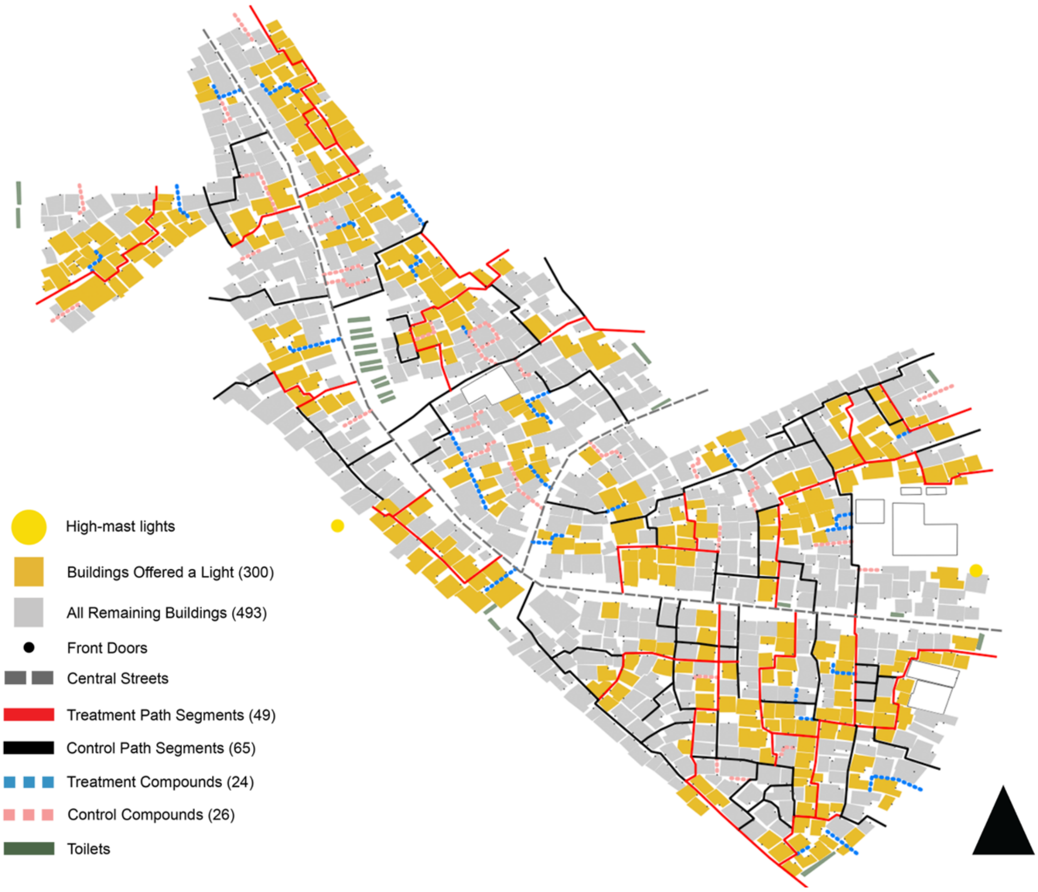
[14] Out of 133 path segments. In addition to the two central streets (see Figure 1 and Section 2.1), we exclude 17 path segments that have no front doors of houses facing them (and hence no option for a lighting intervention).

[15] We say "roughly" because there are situations where three routes all originate from the same entrance into the settlement. In cases like this, only one of the three possible routes was selected into the treatment.

[16] Based on our mapping exercise and baseline survey, we identified 793 households, but informal settlements are highly dynamic places and therefore we say approximately to account for what may be a difference in the reality today on the ground.

[17] If a household's front door did not face a path or a compound, it is not included in the experimental analysis.

Figure 2. Treatment assignment in the informal settlement



The map shows the randomization at the path segment and compound level as well as all structures that were offered a light during the implementation of the intervention.

3.3 TECHNOLOGICAL INTERVENTION

Due to the density of this informal settlement, standard pole-mounted streetlights were not a viable option. Instead, wall-mounted lights installed on the front façade of each house, usually above the front door, have the following advantages: first, they can be installed low enough that the illumination reaches the ground; second, they provide lighting in public space while also lighting the private area in front of each home; third, household members can easily keep an eye on the lights to help ensure that they are safe from theft and vandalism.[18] In addition, the advantage of a solar-powered light is that it is not vulnerable to grid reliability problems, such as planned power outages, which are common in Cape Town.

The outdoor solar light selected for this intervention is a slightly modified version of one that can be purchased "off the shelf" at many hardware stores throughout Cape Town, or anywhere

[18] The concept for wall-mounted outdoor public lighting was developed by former ETH PhD student Stephanie Briers as part of her doctoral research.

in the world (Appendix D Figure 3). The light is a 10-watt, outdoor, solar light that is equipped with a larger battery to ensure it stays illuminated during all dark hours (except, perhaps, in extreme weather conditions) and fitted with hardware that is resilient (though not impervious) to inclement weather, vandalism, and theft. The light automatically turns on at sunset and off at sunrise. It is powered by a 15-watt solar panel, with a fixed arm to secure the angle of orientation and make theft more difficult. In addition, there is a laser-printed logo and the following text "Property of Ward [Redacted]. Not for Resale" printed on the front glass. The City of Cape Town inspired the logo and text, since they also mark infrastructure that is easy to steal (e.g., water taps) to make it identifiable. The logo is also intended to signal that the light is owned and monitored by the community.

Costs for outdoor solar lights vary substantially depending on the quality of the light. These particular solar lights cost approximately US $26, including shipping from China to South Africa. In comparison, the City of Cape Town budgeted approximately US $3000 (46,192.31 ZAR) per standard streetlight in Khayelitsha in 2019/2020 and budgeted US $33,000 (32,739.56 ZAR) per high-mast light. Since standard streetlights are hardly ever used in informal settlements in Cape Town it is hard to estimate a per household cost, however, since one streetlight only provides light in a relatively small area around the light it is still clear that solar public lights are much cheaper. The two high-mast lights that provide light to this informal settlement also provide light to the areas that neighbor it, however, if we roughly calculate that these two lights serve approximately 800 households inside the informal settlement and approximately 200 less densely packed households outside, the cost is approximately US $66 per household. Since it is not clear if these budgets also account for installation and maintenance, if we add in our own installation and maintenance costs, we arrive at a cost per household of approximately US $70 for solar public lights, suggesting wall-mounted lights are cost competitive (City of Cape Town, 2019b).[19]

In September 2020, a local field team installed 281 lights above or near the front door of houses on the selected treatment path segments and compounds (see Section 3.2), such that the light beams into the public space (path or shared compound). Before installing the light, a field worker provided the household with a pamphlet containing information about the light and its purpose, then asked the homeowner for consent to install it (see Section 4.1, Table 1 for a timeline).

In addition to a distributed, solar-powered public lighting technology, we also test a hybrid public service model by hiring a local maintenance team to monitor and repair the lights. The

[19] We spent approximately US $8,000 on installation of all lights in the informal settlement and about US $2400 on maintenance during the six-month intervention. We use these numbers to arrive at the per unit cost.

approach is loosely modeled on South Africa's Expanded Public Works Programme (EPWP), which provides temporary employment to local residents to maintain public infrastructure.[20]

4. DATA

4.1 DATA COLLECTION

We collected two main types of data — a household survey (census) and lux measurements — in order to measure five main outcomes of interest: light, perception of safety, perception of crime risk, nighttime activity, and experience of crime.[21]

We surveyed one household member, preferably the household head, in each household (N = 599) in March 2019 for the baseline survey and in May/June 2021 with (N = 579) for a follow up survey after the intervention (see Section 3.3). The survey was done by field officers using tablets with questions in both English and isiXhosa, both official languages in South Africa and the two most frequently spoken languages in this neighborhood. In addition, field supervisors conducted back checks. Data was downloaded from the tablets and stored on a secure server at the end of each workday, after which the surveys were cleared from the tablets. High frequency checks were run after each day of data collection to ensure data quality.

The survey contained modules on socio-economic characteristics, housing, employment, services and infrastructure, daily activities and time use, perception of safety and risk, experience of crime, and organization capacities and political engagement. At baseline, we had three refusals and 17 empty houses, largely due to residents being away during the three-week period when we conducted the survey.

The field officers were all residents of the informal settlement, which is a common requirement for working in South African informal settlements. This approach is not without its drawbacks, particularly with respect to potential bias in survey measurements. We find this trade-off worthwhile, since it made work at night possible (one reason why so far very few quantitative studies on life at night in informal settlements exist).

An endline survey was carried out in May and June 2021, about seven months after the intervention began. Again, field officers were selected and trained, with additional training days focused on developing proficiency with reading the informal settlement map. This training enabled additional questions about where experienced crimes occurred within the informal

[20] More information about the City of Cape Town's EPWP is available here: http://www.capetown.gov.za/work%20and%20business/jobs-and-skills-development/youth-careers/find-an-opportunity-with-epwp

[21] We also intended to collect pedestrian motion sensor data to measure whether lit path segments and compounds were used more frequently at night. Unfortunately, due to theft/vandalism and the unforeseen extension of the project due to the COVID-19 pandemic, we only had about 30 sensors working at endline for less than two weeks, therefore we could not collect sufficient data for the analysis.

settlement and which areas respondents identify as dangerous. We made several changes to the questions in the endline survey, reflecting lessons learned from baseline and knowledge gained throughout the study. To better understand safety perceptions, we asked additional questions about perception of safety linked to different locations within the settlement. We also added physical attacks and vandalisms to our list of perceived risk of crime questions. Rather than asking about activities at specific locations (e.g., a specific church) we asked whether people engaged in certain activities at night (e.g., at any church). For experiences of crime, we made several changes. First, we added burglary to the list of crimes. Second, we reduced the time period we asked about from 12 months to six months. This change was necessary because we originally intended to run the intervention for 12 months, however, due to project delays, mostly caused by COVID-19, we reduced the intervention time to six months. Third, we asked respondents who experienced a robbery or physical attack to specify whether it happened during the day or at night, whether it happened inside the informal settlement or elsewhere, and, if it happened in the informal settlement, to point out on a map where the crime occurred. In addition to these changes, we also added questions about perceived quality of lighting in different areas of the neighborhood, which we did not ask at baseline to avoid priming respondents. Finally, we added a series of questions about satisfaction with the solar public lights, some of which were asked to all respondents and some of which were only asked to respondents who accepted a solar public light. For a summary of changes made to the questions that contribute to our outcomes of interest see Appendix D Table 1.

At endline, we reached a total of 579 respondents in the experimental sample. We could not reach 31 respondents that were included at baseline, but we found 13 respondents who were not available at baseline. In total, we have both a baseline and follow-up from 566 respondents. See Section 4.3 for additional details about attrition.[22]

In addition to the household surveys, we measured light brightness in lux (i.e., point horizontal illuminance) using a device called a light meter or luxmeter.[23] A team of trained residents collected lux measurements in teams of two using the light meter.[24] Again, it was necessary for residents to do this work since it would be too difficult and dangerous to send an outsider into the neighborhood at night. The teams received a detailed path network map of the informal settlement and were asked to (a) take a measurement at every front door (or gate if they could not enter a locked compound) and (b) take measurements at additional marked points on path

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[22] We dropped 13 surveyors from the sample to minimize bias because they were also the only available respondent in their household and thus, responded to the survey.

[23] One lux is equal to one lumen per square meter or 0.0929 foot-candles, the American customary unit used to measure the same phenomenon.

[24] Urceri MT-912 Light Meter

segments. This procedure allows us to calculate an average lux value per path segment or per compound.

To take a measurement, the team member holding the light meter stood with their back to the front door, ensured that no roof covering was overhead, and then took a measurement while holding the light meter at the height of their belly button. To take a measurement at a marked point on a path segment, they followed the same procedure except instead of standing with their back to the door, they stood with their back to a wall on either side of the path. Since the average path width in this informal settlement is just under two meters, choosing one side of the path over the other is unlikely to have a substantial influence on the measurements.[25]

Staff recorded both the maximum and minimum lux levels at each data collection point on a paper checklist, so that the resulting data indicates the measurement point identifier (either the structure ID or the marked point ID), the date, the maximum lux measurement, the minimum lux measurement, and whether the measurement was taken at a door, a locked gate, or a marked point. It took approximately seven nights to collect a complete set of lux measurement data covering the entire informal settlement, with staff working between one to two hours per night. The team never collected data on days when load shedding (scheduled electricity outages) occurred, although it was unavoidable to collect data on days when the high-mast lights were not completely functional. A complete round of baseline lux measurements, including path points was collected in June 2020.[26]

Table 1 shows a high-level timeline of the project, including the planned and actual timing of the key activities.

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[25] This approach was developed in consultation with a light engineer and verified by other light engineers.

[26] We took a first set of light measurements in February 2020, without path points, and then conducted a second baseline in June 2020. We use the measurements from June 2020 for the analysis.

Table 1. Study timeline

Activity	Planned	Actual
Baseline Household Survey	March 2019	March 2019
Baseline Sensor Measurement	Oct.-Dec. 2019	Oct.-Dec. 2019
Baseline Lux Measurement	February 2020	Feb. & June 2020
Intervention Start	March 2020	**October 2020**
Endline Lux Measurement	February 2021	**Mar./April 2021**
Endline Household Survey	March 2021	**May/June 2021**
Second Phase Light Installation	April 2021	**Aug./Sep. 2021**

A study timeline showing the planned and actual timing of major activities because of COVID-19.

4.2 BALANCE AND STATISTICAL POWER

Baseline data collection was used to better understand the existing lighting situation in the informal settlement and how people feel and act in public space at night (Table 2). The lighting levels in this informal settlement before the intervention in September 2020 were low. The average measured lux level was low at 2.6 lux for paths and 1.5 lux for compounds. These averages are lower than the minimum average requirement for wholly pedestrian streets in the city center according to City of Cape Town guidelines (Sustainable Energy Africa, 2012).[27] Based on conversations with local lighting professionals including those in the City of Cape Town's Public Lighting Development department, the minimum value for any single measurement on a pedestrian path should be 1 lux: we have 587 (66%) spot lux measurements below 1 lux (N = 889, including path points).[28]

The baseline survey also provided us with a better understanding of the basic characteristics of the neighborhood, what residents do after sunset, and how safe they feel. In March 2019, the settlement had about 2,280 residents living in 793 residential structures, each with an average of 2.5 rooms and an average household size of about three people. About 22% of respondents reported living on a household income of 400 ZAR/US $26 or less per month (though many also receive grants through South Africa's social safety net), while the median income range is between 1500 – 3500 ZAR/US $97 - 225.[29] About 70% of residents have completed at least Grade 10 (half of high school, mandatory in South Africa). Almost every resident relied on shared public toilets, though some residents report that they have family living in the formal area

[27] Note that there are no specific regulations for informal areas.

[28] Due to the quality of our device, we probably measure more zeroes when the lux level is below 1 lux than a professional lighting engineer with a much more expensive device might, who might measure more values between 0 and 1.

[29] Currency conversions were done on Nov. 17, 2021 when USD $1 = 0.064 ZAR and values are rounded to the nearest US dollar.

nearby and go there to use a private toilet. During the baseline survey period, sunset was between 7:00-7:30 pm and sunrise at 6:30-7:00 am. Fewer than half of respondents said they went outside at night to use the public toilets, many report that they use a bucket inside their house at night or avoid the toilet altogether. About 50% of respondents report that they did not leave their house after 8:00 pm the night before. In comparison, only 6% say they never left the house during the daytime the day before. Approximately 75% of respondents report going to sleep between 8:00 pm and 11:00 pm, while about 51% report waking up between 5:00 am and 8:00 am. These times indicate that there is need for public lighting very early in the morning and until quite late at night, at least for visibility.

When it comes to safety, 55% of respondents report that they do not feel safe in the informal settlement during the day and about 80% report that they do not feel safe at night, thus nighttime is associated with higher levels of fear. In addition, about 25% of respondents report that they or someone in their household had been robbed, 16% report that their house was vandalized, and 11% report that they or someone in their household was physically attacked in the previous 12 months, indicating both a lack of perceived and actual safety.

As explained in Section 3.2, we stratified the path network into path segment and compound clusters and randomized at this level (see Appendix D Figure 2). On average, there are 3.75 households on each of the 114 path segments and 50 compounds in this study. Based on a *t*-test of means, the random assignment of the lighting intervention led to treatment and control paths and compounds that are not significantly different from each other (see Table 2).

Table 2. Balance at baseline

	Paths					Compounds				
Variable	**Obs**	**Mean**	**Control**	**Treat**	**p-value**	**Obs**	**Mean**	**Control**	**Treat**	**p-value**
Panel A										
Female	442	0.55	0.56	0.54	0.71	157	0.62	0.64	0.61	0.67
Age	442	38.82	38.40	39.39	0.38	157	39.28	39.31	39.25	0.97
Attained education level[a]	440	5.40	5.45	5.32	0.47	156	5.42	5.48	5.35	0.65
Monthly Income[b]	414	3.16	2.99	2.71	0.06	145	3.26	3.18	3.34	0.59
Household members	442	3.03	2.94	3.16	0.23	157	2.99	2.91	3.06	0.60
Rooms in house	442	2.52	2.54	2.49	0.60	157	2.31	2.29	2.33	0.82
Length of residence	441	16.57	16.35	16.86	0.63	157	17.80	18.26	17.35	0.63
Risk Index (max: 15)	442	10.92	11.17	10.59	0.03	157	10.91	11.08	10.75	0.43
Panel B										
Avg. lux (path-level)	112	2.57	2.33	2.87	0.27	50	1.52	1.70	1.35	0.41
Safety Perception Index (max: 5)	442	1.25	1.22	1.29	0.40	157	1.15	1.23	1.08	0.29
Feels safe in this informal settlement during day	442	0.47	0.45	0.49	0.45	157	0.44	0.50	0.38	0.13
Feels safe in this informal settlement at night	442	0.22	0.23	0.21	0.73	157	0.20	0.26	0.15	0.11
Carries no private light outside at night	442	0.56	0.54	0.59	0.28	157	0.51	0.47	0.54	0.38
Night Activities Index (max: 8)	442	3.36	3.40	3.32	0.59	157	3.25	3.19	3.30	0.63
Time wake up	440	7.14	7.28	6.96	0.09	157	7.29	7.43	7.15	0.44
Time go to sleep	434	19.99	20.00	19.98	0.96	157	19.82	20.21	19.46	0.29
Go outside to use toilet at night	429	0.49	0.52	0.44	0.09	153	0.40	0.41	0.39	0.79
Out with friends/family at night	442	0.49	0.51	0.46	0.34	150	0.46	0.49	0.43	0.48
Leave house at night	435	0.50	0.47	0.54	0.14	150	0.42	0.41	0.43	0.81
Time kids come in at night	250	19.23	19.38	19.07	0.05	157	19.49	19.64	19.35	0.35
Time women come in at night	314	19.71	19.88	19.50	0.13	152	19.72	20.07	19.42	0.11
Time men come in at night	302	20.71	20.81	20.58	0.32	90	20.57	20.97	20.27	0.09
Exp. of Crime Index (max: 3)	442	0.53	0.55	0.50	0.58	157	0.47	0.59	0.34	0.04
Someone in household robbed in last 12 months	435	0.26	0.29	0.23	0.17	156	0.22	0.29	0.16	0.07
Someone in hh physically attacked in last 12 mon.	438	0.11	0.12	0.10	0.44	157	0.11	0.13	0.09	0.43
House vandalized in last 12 months	435	0.16	0.14	0.18	0.29	156	0.14	0.18	0.09	0.09
Risk of Crime Variables										
Risk of robbery (max: 5)	435	4.27	4.32	4.21	0.34	156	4.49	4.50	4.47	0.86
Risk of burglary (max: 5)	438	4.41	4.41	4.42	0.85	155	4.56	4.67	4.45	0.10

Notes: The table reports a t-test of means for respondent characteristics in Panel A and for the outcomes of interest measured at baseline in Panel B. The sample includes all respondents at baseline assigned to an experimental group. [a]For attained education level, the mean is consistent with an educational attainment between Grade 10 and 11. [b]For monthly income, the mean is associated with a range between 801 - 1,500 ZAR. For all risk questions, respondents could choose a response from a from a six-point scale, with 0 indicating no risk and 5 indicating a very big risk (and not applicable). The Risk Index is a count index measuring perception of risk in the next 12 months. Inputs include: risk of injury from a taxi or vehicle, risk of gender-based violence, risk of a house fire. The risk of crime variables are not grouped into a count index.

Based on these baseline survey measurements, we estimate with a power of 0.8 and statistical significance of alpha 0.05 that we are powered to detect an effect on average lux, our primary indicator of efficacy, of 1.96 lux from a baseline mean of 2.29 lux. In addition, we are powered to detect an effect of 0.33 on the safety perception index from a baseline of 1.22, an effect of 0.48 on the night activity index from a baseline of 3.33, and an effect of 0.31 on the experience of crime index from a baseline of 0.51 (Table 3).[30]

Table 3. Power calculations

Outcome	Type	MDE P < 0.05	MDE in Std. Devs	MDE P < 0.01	Mean	Std. Dev.	Min/Max	ICC
1. Average Lux (path level)	continuous	1.96	0.44	2.40	2.29	4.43	0/25	N/A
Indices/*Individual Outcomes*								
2. Perceived Safety Index	ordinal	0.33	0.36	0.41	1.22	0.92	0/3	0.048
Ex. Feel Safe in PJS at Night	binary	0.33	0.80	0.36	0.22	0.41	0/1	0.042
3. Night Activity Index	ordinal	0.48	0.34	0.59	3.33	1.42	0/8	0.000
Ex. Use Shared Toilet at Night	binary	0.62	1.24	0.65	0.47	0.50	0/1	0.114
4. Experience of Crime Index	ordinal	0.31	0.39	0.38	0.51	0.80	0/3	0.112
Ex. Experience Vandalism in Previous Yea	binary	0.27	0.75	0.31	0.15	0.36	0/1	0.079

All calculations assume a desired power of 80%, a two-tailed test, an average of 3.75 houses per path segment/compound, and 73 clusters (path segments and compounds) in the treatment group. For each index, we also report a power calculation for one example input variable. Note that since the study was pre-registered, we made the following changes. The perceived safety index no longer contains two input variables it previously included. In addition, the experience of crime index and the input crime variables were reverse coded, such that no experience of crime was equal to 1 and an experience of crime was equal to zero. Since this caused confusion, we now code the variables as equal to one if a crime was experienced and zero if not.

4.3 ATTRITION

At endline, we experienced some attrition. Given the amount of resident turnover that is common in informal settlements this was expected. If the same family lived in the same house as at baseline, we interviewed the same person. In the event of death or if the previous respondent moved away, we spoke to the new household head. If a new family moved into the structure, we interviewed the new household head. A household-level observation dropped out of the sample if the house was demolished, is empty, or the household head declined to be surveyed.

Of the initial 599 structures in our baseline sample, one was demolished at endline, for 73 structures (12%) a new family moved in, for 64 structures (10.6%) we only could interview another member of the same family as the baseline respondent, and for 435 structures (72.6%) we interviewed the same person as at baseline. In addition, we interviewed 13 respondents at

[30] The study pre-registration can be found here: Borofsky, Yael and Isabel Günther. 2020. "New Public Lighting in Informal Settlements: A Field Experiment in Cape Town, South Africa." AEA RCT Registry. December 15. https://doi.org/10.1257/rct.3777-1.0

endline whose houses were empty at baseline. For the final analysis, we did not exclude structures where a new family moved in, so in total the attrition from baseline to endline is only 5% and we re-interviewed 95% of houses. Since we randomized at the path segment or compound level, this attrition affects our household sample and thus cluster size, but it also affected path-level sample size on two path segments, leaving us with a final sample of 112 path segments and 50 compounds.[31] To be sure that moving house was not correlated with treatment status, we test for differences between treatment groups for those who moved. Between the end of baseline and start of endline, 10% of the treatment group and 11% of the control group moved out of their home — this difference is not significant.

In April 2021, the field team collected a final round of lux measurements. For these measurements, attrition only occurs if a house no longer exists.

5. EMPIRICAL FRAMEWORK

5.1 HYPOTHESES

Based on the discussion in the existing literature about how light can affect life at night, we focus on measuring the impact of randomly assigned solar public lights on five broad outcomes of interest: light levels (avg. lux/path or compound), perception of safety, perceived risk of crime, nighttime activity, and experiences of crime.

Linked to these outcomes are the following five research questions and null hypotheses, H_0, that we expect to reject with our data.

1) The first-order question is whether wall-mounted, outdoor solar public lights provide effective public lighting. ***A1.H_0:*** *Path segments/compounds that receive the lighting intervention demonstrate no difference in measured brightness (lux) from areas that do not receive the lighting intervention.* We measure efficacy as average lux per path segment/compound. Additionally, we compare lux measurements to three variables indicating respondent perception of brightness at their front door, in their path, and in the informal settlement, overall.

2) The literature on public lighting for high-income countries indicates that people perceive an area to be safer if it is better lit. Therefore, we test whether respondents living in lit areas report feeling safer in the informal settlement, both during the night and the day. ***B1.H_0:*** *Residents living on path segments/compounds that receive the lighting intervention do not report any difference in feelings of safety as compared to residents living in areas that do not receive the lighting intervention.* We measure perceptions of safety using self-report survey questions focused on safety during the day and night in the informal settlement overall,

[31] This situation is possible since some paths have very few households on them, so attrition can mean that we lose household representation for a given path at endline.

in the path where they live, and inside their house. In addition, we include questions asking about perceptions of safety walking to do different activities and whether they carry a private source of light (e.g., cell phone light) when going out at night. Using these responses, we create a count index where the higher the value, the safer the respondent reports feeling. We also analyze perception of safety in the informal settlement, in the path, and inside the house during the day and night individually. By comparing the difference between reported daytime and nighttime safety survey responses, we also test the theory (see Section 2) that the infrastructure itself, rather than just the light, influences feelings of safety.

The literature is inconclusive about whether light affects perceived risk of crime (Atkins et al., 1991), therefore we test whether respondents living in lit areas report a lower perceived risk of certain crimes. ***B2.H$_0$:*** *Residents living on path segments/compounds that receive the lighting intervention do not report any difference in perception of risk of crime as compared to residents living in areas that do not receive the lighting intervention.* We ask respondents about their perceived risk of certain crimes happening to them or someone in their family in the next 12 months. We focus on burglary and vandalism since these are crimes that directly occur in the path segments/compounds we study.

3) We expect individuals living on lit path segments/compounds to report engaging in more activities outside at night. ***C1.H$_0$:*** *Residents living on path segments/compounds that receive the lighting intervention do not report a higher engagement in nighttime outdoor activities compared to residents living in areas that do not receive the lighting intervention. Moreover, residents in treatment areas do not go inside for the night or to bed later than residents in control areas.* We measure reported nighttime activities using self-reported survey responses to the following questions: time wake up, time go to sleep, use of shared sanitation facilities, go to Spaza shop at night,[32] go to church at night, do laundry outside at night, spend time with friends/family outside, spend time with friends/family in front the house, whether respondents report leaving the house at night, time men, women, and children come in for the night, and activity diary questions between 6:00 – 9:00 pm and between 5:00 – 8:00 am. We use these variables to create a count index to measure willingness to engage in activities in public space at night, where higher values indicate more activities or time in public space at night. We also separately analyze use of shared sanitation facilities, spending time with friends/family outside, spending time with friends/family in front of the house, and whether the respondent reports leaving the house at night at all.

4) Due to the relatively small sample size and the limitations of police-reported crime incidence (e.g., underreporting), we do not analyze the effect of public light on crime incidence, but rather on self-reported experiences of specific outdoor crimes in the

[32] A Spaza shop is a convenience store.

preceding six months. ***D1.H$_0$:*** *Residents living in areas that receive the lighting intervention do not report any difference in experience of crime in the previous six months as compared to residents living in areas that do not receive the lighting intervention.* We ask about robbery, physical attack (outside), vandalism, and burglary. For robbery and physical attacks that happened within the informal settlement, we asked whether they occurred during the day or night and asked respondents to point on the map where the crime occurred. This information allows us to create a measure of day crimes and night crimes at the path level, which we can also compare to try to understand whether the community investment mechanism dominates. We also create a count index to develop an overall measure of the burden of experienced crime for residents, where higher values indicate more experienced crimes. Finally, we analyze burglaries and vandalism individually since these crimes occur directly on the path segments/compounds we study.

Appendix D Table 1 reports the variables that make up each count index and shows the differences in the indices between baseline and endline.

5.2 TREATMENT EFFECTS

We will estimate the intention to treat (ITT) effect of the public lighting intervention, as well as the effect of lighting by applying two approaches. First, to test the impact of the light intervention (ITT) on the various outcomes, we will estimate equation (1):

$$OUTCOME_{ip} = \beta_0 + \beta_1 TREAT_p + \Theta X'_{ip} + \epsilon_{ip} \quad (1)$$

where $OUTCOME_{ip}$ is the endline outcome value measured for household i living on the path segment or compound p; $TREAT_p$ is an indicator for a path segment or compound assigned to the public lighting intervention (and zero otherwise); X'_{ip} is a vector of baseline covariates; and ϵ_{ip} is the standard error clustered at the level of randomization (path segment/compound).

For outcome variables for which we have baseline data (see Section 4.1 for a discussion of changes in questionnaire between baseline and endline), we will also estimate a difference-in-difference model (2):

$$OUTCOME_{ip} = \beta_0 + \beta_1 TREAT_p + \beta_2 ENDLINE_{ip} + \beta_3 (TREAT * ENDLINE)_{ip} + \Theta X'_{ip} + \epsilon_{ip} \quad (2)$$

Where $ENDLINE_{ip}$ is a dummy equal to 1 for the endline survey and 0 for the baseline survey; and β_3 is the difference-in-difference estimator.

Actual light intensity by the solar lights can vary due to the number of front doors in a particular path segment/compound, the variance of light created by the combination of the solar lights and the pre-existing high-mast lights, and, in rare incidences, non-compliance and light malfunctioning. To check for robustness to treatment non-compliance, we apply an instrumental variables (IV) approach, where our treatment dummy is the exogenous instrument that alters brightness levels (measured in lux):

$$D_p = \alpha_0 + \alpha_1 TREAT_p + \Theta X'_{ip} + \epsilon_{1ip} \qquad \text{first stage} \qquad (3)$$

$$OUTCOME_{ip} = \beta_0 + \beta_1 \widehat{D_p} + \Theta X'_{ip} + \epsilon_{2ip} \qquad \text{LATE} \qquad (4)$$

In equation (3), $TREAT_p$ is the instrument that equals 1 for path segments and compounds p assigned to the treatment group and 0 otherwise. D_{ip} is the light treatment intensity, which is the average lux on each path segment or compound p. In equation (4), $OUTCOME_{ip}$ is any of the mentioned outcomes of interest in Section 5.1 (except average lux). β_1 captures the Local Average Treatment Effect (LATE), which is the effect of having more light (measured as average lux) on the outcomes of interest. $\Theta X'_{ip}$ are additional control variables as measured at baseline. Finally, we also check for spillovers by estimating the treatment intensity for households living on the border of a path segment or compound of the opposite treatment status (see Section 7.2).

We recode all individual outcomes (non-index outcomes) as binary variables to make interpretation easier, since the results are very similar when individual outcomes that were originally ordinal are not recoded.

5.3 HETEROGENEOUS EFFECTS

We will analyze the effect of the new lights by proximity to the nearest high-mast light, for two reasons. First, the high-mast lights are likely to have an influence on brightness, however, the literature suggests that beyond a certain threshold there are diminishing returns to additional brightness (Boyce et al., 2000; Fotios & Castleton, 2016; Svechkina et al., 2020). Second, many households are rather far from both high-mast lights, and as a result, also far from what could be considered the center of gravity of the settlement, where the main Spaza shop is, the largest collection of toilets, etc. Therefore, we test to see how the dynamics captured by distance to the nearest high-mast light influences the impact of the treatment. In addition, we will analyze effects separately by gender, since gender is discussed in the literature as a key predictor of reassurance or confidence in public space at night and fear of crime (e.g., Blöbaum and Hunecke, 2005; Boomsma and Steg, 2014; Roman and Chalfin, 2008). Due to the discussion of gender effects in the literature, we will study it even though our survey targets household heads and we do not representatively sample for gender.

5.4 MULTIPLE HYPOTHESIS TESTING

We test the impact of the treatment on a total of 34 outcomes. Of these, six are indices (see Appendix D Table 1 for the variables constituting the indices). Aggregation using count indices mitigates some of the risks associated with multiple outcome and hypothesis testing, but not all of them, since we also look at several variables individually. Therefore, we use a Bonferroni correction to account for multiple hypothesis testing. We report all the main results with the adjusted p-values in Appendix D Table 2.

6. RESULTS

6.1 SOLAR PUBLIC LIGHTING INCREASES LIGHT LEVELS AT NIGHT

The first objective is to determine the extent to which the intervention improved lighting levels in the informal settlement. We estimate equation (1) and (2) in Table 4 on measured average lux and equation (1) on self-reported measures of brightness in front of the respondent's house, in the path where the respondent lives, and in the informal settlement, in general.[33]

The results in Table 4 show that the lights increase average lux by about 12.5 lux in paths and 16 lux in compounds or a six-fold increase in brightness on paths and an eight-fold increase in brightness in compounds. Since the front doors typically all face each other in compounds, the lights all shine into the center, making compounds likely to be brighter than paths. For comparison, the minimum average lux requirement for wholly pedestrian streets in the city center is 10 lux. The solar public lighting exceeds this requirement (Sustainable Energy Africa, 2012). It is important to note that we find these large effects despite the fact that lights which were stolen (N = 6) or vandalized (N = 7) during the intervention were not replaced. Columns 3-5 (paths) and 8-10 (compounds) report the effect of treatment assignment on self-reported perceptions of brightness. We find that among respondents in paths, 69% more report that the front door is well lit, 68% more report that where they live is well lit, and 15% more report the informal settlement is well lit. The size of the effect decreases as the location of interest broadens, which is expected since roughly two-thirds of the informal settlement did not receive solar public lighting. In compounds, there is no effect of treatment on the perception that the informal settlement, overall, is well lit — a minority, roughly 35% of each group, agrees it is. Meanwhile, 75% more report the area in front of their house is well lit and 57% more report the path where they live is well lit. Since we asked about the path, even to residents who live in compounds, it is likely they considered the path they use to access the compound where they live, which may or may not be treated. We re-estimate the models with binary outcomes using binary logistic regression and find very similar results. The average marginal effects are reported in Appendix D Table 3.

[33] We do not estimate a difference-in-difference model (equation 2) because we did not ask these questions at baseline.

Table 4. Effect of treatment on brightness

	Path					Compound				
	Endline Avg. Lux		Front of House	Path	Informal Settlement	Endline Avg. Lux		Front of House	Path	Informal Settlement
	OLS	DiD	OLS	OLS	OLS	OLS	DiD	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Treat (=1)	12.525***	0.499	0.694***	0.675***	0.145***	16.045***	-0.381	0.753***	0.572***	-0.013
	(1.828)	(1.111)	(0.039)	(0.042)	(0.048)	(1.672)	(0.813)	(0.061)	(0.072)	(0.081)
Endline (=1)		0.002					0.308			
		(0.950)					(0.817)			
Treat*Endline		11.874***					16.546***			
		(1.633)					(1.801)			
(Intercept)	2.354*	2.402***	0.217***	0.139***	0.242***	1.968**	1.675***	0.195***	0.222***	0.351***
	(1.347)	(0.677)	(0.033)	(0.027)	(0.032)	(0.781)	(0.589)	(0.054)	(0.063)	(0.053)
Adj. R^2	0.377	0.363	0.471	0.454	0.022	0.628	0.690	0.576	0.323	-0.006
Num. obs.	425	830	425	402	425	154	302	154	145	154
Clusters	112	112	112	112	112	50	50	50	49	50

Note: Standard errors clustered at the level of randomization. All three self-report variables are constructed as binary outcomes from variables in which respondents could answer, 'Totally dark' = 0, 'Somewhat dark' = 0, 'Not much light, but not dark' = 0, 'Somewhat lit' = 1, 'Very well lit' = 1. ***p < 0.01; **p < 0.05; *p < 0.1.

6.2 SOLAR PUBLIC LIGHTING INCREASES PERCEPTIONS OF SAFETY AT NIGHT

Table 5 (Panel A) reports the effect of treatment on perceived safety, both at night and during the day. Column 1 reports the effect of treatment on the extended perceived safety index for which we only have an endline measure (11 input variables). Treatment is associated with a significant 19% percentage point change ($p < 0.05$) in overall perception of safety (from an index of 3.45 out of 11 in the control to 4.11 in the treatment group). In column 2, when we use the shorter version of the perceived safety index as the outcome (3 input variables), we find a similar effect, however, the difference-in-difference estimator is not significant (column 3).

Columns 4-11 focus on perception of safety in three locations, all of which are inputs to the extended safety index. These measures allow us to compare daytime and nighttime perceptions of safety: in the informal settlement (columns 4-7), in the respondent's own path (columns 8-9), and inside the respondent's house (10-11). We find that the treatment is linked to a significant 10 percentage point increase (from 41% feeling safe during the day) in the share of respondents reporting they feel safe in the informal settlement during the day and a 6 percentage point increase (from 12.7% feeling safe during the night) at night: an almost 50% increase in perceived safety at night. Using the difference-in-difference model (columns 5 and 7), the coefficients are similar, but not statistically significant. We also see that overall perception of safety at night has decreased between baseline and endline. The reason is probably linked to an increase in gang-related crime in the neighborhood, particularly greater demands for protection money. In the path where the respondent lives, there is no effect of the treatment on daytime perception of safety, but there is a significant 10.7 percentage point increase (a doubling) in perception of safety in the path at night. We do not find that treatment has any effect on respondents' perception of safety inside their homes. In compounds, we find no effect of treatment status on any outcome (Table 5, Panel B).

In addition to perception of safety, we also test whether the treatment influences respondents' perceived risk of crime. In paths (Panel A), we find that the treatment is associated with a 4 percentage point decrease in perceived risk of burglary (column 12), however, when we control for differences at baseline, the difference-in-difference estimator is not significant (column 13). We do not find an effect of treatment on perceived risk of vandalism. In compounds (Panel B), we find no effect on either measure of perceived crime risk.

Finally, we also asked respondents who accepted a light some questions about their experience with the light. Almost every respondent agreed the light made the area in front of their house bright, it made them feel safer opening the front door at night, and safer in the area outside their house. These opinions are consistent with our findings that the treatment influences perception of safety, particularly at night.

We re-estimate all models with binary outcomes in Table 5 using binary logistic regression and find very similar results. We report the marginal effects in Appendix D Table 4.

Table 5. Impact of treatment on perceptions of safety

	Safety Index			Inf. Sett. Day		Inf. Sett. Night		Own Path Day	Own Path Night	In Home Day	In Home Night	Perceived Burglary Risk		Perceived Vandalism Risk
	OLS	OLS (Short)	DiD (Short)	OLS	DiD	OLS	DiD	OLS	OLS	OLS	OLS	OLS	DiD	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Panel A - Paths														
Treat (=1)	0.660**	0.210**	0.062	0.105**	0.037	0.061*	-0.012	0.085	0.107***	0.038	0.071	-0.044**	-0.007	0.003
	(0.286)	(0.086)	(0.104)	(0.047)	(0.050)	(0.034)	(0.048)	(0.054)	(0.034)	(0.042)	(0.054)	(0.020)	(0.023)	(0.035)
Endline (=1)			-0.140*		-0.047		-0.102***						0.043**	
			(0.081)		(0.040)		(0.037)						(0.020)	
Treat*Endline			0.157		0.075		0.068						-0.038	
			(0.127)		(0.064)		(0.056)						(0.030)	
(Intercept)	3.451***	1.111***	1.229***	0.414***	0.449***	0.127***	0.225***	0.467***	0.102***	0.730***	0.443***	0.984***	0.940***	0.918***
	(0.140)	(0.049)	(0.069)	(0.029)	(0.031)	(0.019)	(0.030)	(0.035)	(0.018)	(0.028)	(0.031)	(0.010)	(0.016)	(0.020)
Adj. R^2	0.014	0.011	0.006	0.009	0.003	0.005	0.008	0.005	0.020	0.000	0.003	0.012	0.006	-0.002
Num. obs.	425	425	830	425	830	425	830	425	425	425	425	425	826	422
Clusters	112	112	112	112	112	112	112	112	112	112	112	112	112	112
Panel B - Compounds														
Treat (=1)	-0.013	-0.182	-0.157	-0.104	-0.114	-0.091	-0.090	0.000	0.026	0.013	0.104	0.000	-0.042	0.024
	(0.497)	(0.145)	(0.156)	(0.087)	(0.078)	(0.060)	(0.061)	(0.097)	(0.073)	(0.085)	(0.088)	(0.045)	(0.027)	(0.044)
Endline (=1)			0.105		0.013		-0.026						-0.053	
			(0.174)		(0.093)		(0.065)						(0.035)	
Treat*Endline			-0.025		0.027		0.000						0.041	
			(0.242)		(0.134)		(0.079)						(0.055)	
(Intercept)	3.688***	1.312***	1.211***	0.506***	0.487***	0.208***	0.237***	0.506***	0.169***	0.727***	0.390***	0.935***	0.987***	0.896***
	(0.413)	(0.103)	(0.113)	(0.055)	(0.065)	(0.049)	(0.051)	(0.076)	(0.057)	(0.064)	(0.066)	(0.031)	(0.013)	(0.034)
Adj. R^2	-0.007	0.004	0.001	0.004	0.001	0.009	0.005	-0.007	-0.005	-0.006	0.004	-0.007	0.000	-0.005
Num. obs.	154	154	302	154	302	154	302	154	154	154	154	154	300	152
Clusters	50	50	50	50	50	50	50	50	50	50	50	50	50	50

Note: Standard errors clustered at the level of randomization. The extended version of the perceived safety index (only endline) contains 11 binary input variables, which include: perception of safety in the informal settlement during the day, perception of safety in the informal settlement at night, perception in the path where you live during the day, perception of safety in the path where you live at night, perception of safety inside your house during the day, perception of safety inside your house at night, feel safe walking to the spaza shop at night, feel safe walking to the toilet at night, feel safe walking to visit friend/family in the informal settlement at night, carries no private light when walking outside at night. The short version of the perceived safety index for which we also have a baseline measure contains 3 binary input variables, which include: perception of safety in the informal settlement during the day, perception of safety in the informal settlement at night, carries no private light when walking outside at night. The outcome variables for columns 4-11 are binary indicator of perception of safety in the informal settlement during the day/night, perception of safety in the path where you live during day/night, and perception of safety inside your house during day/night, where 'Never' and 'Rarely' are coded as 0 and 'Always', 'Most of the time' and 'About half the time' are coded as 1. The outcome variables for columns 12-14 are binary indicators of perceived risk of burglary and vandalism coded such that 'Not a risk' = 0, 'Small risk' = 0, 'Medium risk' = 1, 'Big risk' = 1, and 'Very big risk' = 1. There is no difference-in-difference estimation for perceived vandalism risk because we did not ask that question at baseline. ***p < 0.01; **p < 0.05; *p < 0.1.

6.3 SOLAR PUBLIC LIGHTING HAS NO EFFECT ON OVERALL NIGHTTIME ACTIVITY

Table 6 reports the impact of treatment assignment on both the extended nighttime activity index (18 variables), the short nighttime activity index (8 variables), and three input measures of nighttime activity for which we also have baseline data (whether respondents use shared sanitation at night, go out with family/friends at night, leave the house at night for any reason). In addition, we test the local effect of the light by estimating the effect on whether respondents report spending more time in front of their house at night with family and friends. As a comparative exercise, we also report effects on two outcomes in which respondents were asked to state how much they agree with two statements: 1) *A well-lit area in front of my home makes me more likely to leave my house at night*.; 2) *I am more likely to go somewhere in [the informal settlement] at night if I know the way to go there is well lit*. In other words, we also test how much people *think* they will go out at night if the area is well lit (expectation) in addition to how much they actually report going out at night.[34]

In general, we do not find that people spend more time outside when treated with lights – neither for lit paths nor for lit compounds (Columns 1-10), regardless of whether we use the extended or short nighttime activity index or any other nighttime activity variable. In treated compounds, households even seem to spend less time outside (when considering the nighttime activity index).

We do, however, find that over time (between baseline and endline) households are less likely to go outside, as indicated by the endline dummy in the difference-in-difference specification (Panel A, column 3). The lack of a treatment effect in paths is unlikely to be explained by spillover effects from treatment to control paths. If the treatment led to a substantial increase in households going out in both the treatment and control groups (i.e., with spillover effects), we would expect a positive time coefficient. Of course, without a counterfactual over time it might also be that without the intervention both control and treatment groups would go out even less, but at least the positive effect does not seem to be strong. Moreover, for feelings of safety we find a clear difference between the treatment and control groups – further indicating that spillovers cannot explain all of the missing effect on nighttime behavior.

We suspect that nighttime activity went down over time partly due to the COVID-19 pandemic and also partly due to the rise in gang activity, which is also reflected in the general decrease in perception of safety at night (see Table 5, column 7).

In both paths and compounds, however, we find that respondents are significantly more likely to report using shared sanitation at night at endline compared to baseline (column 5, both panels). This is the one outcome for which we find some evidence of spillover, as these effects indicate that respondents in both treatment groups are impacted. Given that access to sanitation is a basic need (different from social activities outside at night), it might be that more light

[34] We only asked these questions at endline.

availability, even if it is not directly where the respondent lives, prompts respondents from both the treatment and the control group to stop using a bucket at night, which people find highly shameful, and use shared sanitation facilities instead. Again, we cannot rule out that some other factor explains the behavior change. However, we do know that no additional toilets were installed between baseline and endline and that people, in general, did not go out more often. Use of shared sanitation at night is the only outcome for which the effect on the endline dummy is positive. In all other difference-in-difference estimations on nighttime activities, the time dummy is actually negative.

Columns 11 and 12 report the effect of treatment on respondents' agreement with the two prompts about how likely they are to leave their house at night if the area in front of the door is well lit and if the informal settlement is well lit. In both cases, we find a statistically significant effect of treatment assignment on agreement with these statements in paths ($p < 0.01$), but in compounds we only find a statistically significant effect on how likely respondents are to leave the house at night if the area in front of the door is well lit ($p < 0.05$). While about 17% of control group respondents in paths and about 21% in compounds agreed that they would be more likely to go out at night if the area in front of their house was more lit, 42% of path respondents and 36% of compound respondents assigned to the treatment group agreed. In paths only, the effect on agreement with the statement that one would leave the house if the informal settlement is well lit is also statistically significant, but slightly smaller with 22% of the control group reporting agreement, while 35% of the treatment group agreed. These findings suggest that, among respondents living on path segments, there are substantial discrepancies between their expectations about nighttime activities and the nighttime activities they actually report participating in outside at night, while there is a more modest discrepancy for compound respondents.

Similarly, when we asked only respondents who accepted a light, about 93% said the light made it nicer to spend time with friends or family in front of their house at night, despite the fact that we find no treatment effect on this activity when we asked about their actual behavior in the previous week.

When we re-estimate all models with binary outcomes in Table 6 using binary logistic regression, we again find very similar results. Average marginal effects are reported in Appendix D Table 5.

Table 6. Impact of treatment on nighttime activities

	Night Activity Index			Shared San. Night		Family/Friends Night		Leave House Night		Front House Night	Leave House if Lit in Front	Leave House if Inf. Set. Lit
	OLS	OLS (Short)	DiD (Short)	OLS	DiD	OLS	DiD	OLS	DiD	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A - Paths												
Treat (=1)	0.006	0.014	-0.069	-0.047	-0.080	0.001	-0.022	0.001	0.073	-0.015	0.252***	0.123***
	(0.212)	(0.119)	(0.141)	(0.049)	(0.060)	(0.035)	(0.061)	(0.044)	(0.054)	(0.044)	(0.043)	(0.046)
Endline (=1)			-0.470***		0.123***		-0.305***		-0.105**			
			(0.117)		(0.044)		(0.038)		(0.048)			
Treat*Endline			0.085		0.038		0.026		-0.074			
			(0.166)		(0.073)		(0.070)		(0.064)			
(Intercept)	4.668***	2.914***	3.381***	0.638***	0.511***	0.193***	0.492***	0.352***	0.453***	0.258***	0.168***	0.225***
	(0.132)	(0.079)	(0.094)	(0.030)	(0.035)	(0.023)	(0.037)	(0.033)	(0.037)	(0.027)	(0.025)	(0.026)
Adj. R^2	-0.002	-0.002	0.021	0.000	0.020	-0.002	0.094	-0.002	0.018	-0.002	0.076	0.016
Num. obs.	425	425	830	424	817	425	830	425	824	425	425	425
Clusters	112	112	112	112	112	112	112	112	112	112	112	112
Panel B - Compounds												
Treat (=1)	-0.779**	-0.377*	0.163	-0.169*	-0.011	-0.104	-0.034	0.065	0.017	-0.065	0.156**	0.091
	(0.342)	(0.213)	(0.245)	(0.086)	(0.084)	(0.064)	(0.092)	(0.078)	(0.076)	(0.064)	(0.077)	(0.073)
Endline (=1)			-0.132		0.303***		-0.224***		-0.146*			
			(0.170)		(0.064)		(0.071)		(0.079)			
Treat*Endline			-0.508*		-0.153		-0.070		0.040			
			(0.294)		(0.103)		(0.119)		(0.114)			
(Intercept)	5.156***	3.091***	3.211***	0.701***	0.394***	0.247***	0.474***	0.273***	0.423***	0.260***	0.208***	0.247***
	(0.229)	(0.153)	(0.195)	(0.052)	(0.051)	(0.044)	(0.068)	(0.051)	(0.053)	(0.050)	(0.048)	(0.050)
Adj. R^2	0.022	0.016	0.020	0.024	0.056	0.011	0.073	-0.002	0.009	-0.001	0.023	0.003
Num. obs.	154	154	302	154	295	154	302	154	297	154	154	154
Clusters	50	50	50	50	50	50	50	50	50	50	50	50

Note: Standard errors clustered at the level of randomization. The night activity index contains 18 binary input variables, which include: time wake up, time go to sleep, uses shared sanitation at night, visits spaza shop at night, visits church at night, does laundry outside at night, spends time with friends/family at night, spends time with friends/family in front of house at night, leaves house at night, latest time kids/women/men come inside for the night, outdoor activities between 6-7 pm, 7-8pm, 8-9pm, 5-6 am, 6-7 am, and 7-8 am. The short night activity index, for which we also have a baseline measure, contains 8 input variables, which include: time wake up, time go to sleep, uses shared sanitation at night, spends time with friends/family at night, leaves house at night, and latest time kids/women/men come inside for the night. All time variables are coded such that dark hours are coded as 1, and light hours are coded as 0. For columns 11 and 12, the outcome variables were recoded as binary variables such that 'Strongly agree' and 'Somewhat agree' were recoded as 1 and 'Neither agree nor disagree', 'Somewhat disagree', and 'Strongly disagree' were recoded as 0. ***p < 0.01; **p < 0.05; *p < 0.1.

6.4 SOLAR PUBLIC LIGHTING HAS NO EFFECT ON REPORTED EXPERIENCES OF CRIME

Table 7 shows the impact of treatment on experiences of crime. We analyze crime in three ways. First, at the household level, we create a binary indicator of whether the respondent or someone in the household experienced one of four crimes: robbery, vandalism, burglary, and physical attack (outside). We create an experience of crime count index from the sum of these binary variables that ranges from 0-4. In the regression analysis of individual outcomes, we focus on vandalism and burglary, rather than physical attacks and robberies, because they happen to the specific structure that did or did not receive a light depending on treatment group. In paths, we find no treatment effect on experiences of crime, both in the aggregate (index) or on vandalism and burglary, individually (columns 1-4 and 7, Panel A). In compounds, we find a significant decrease in crime using the short version of the experience of crime index (column 2, Panel B), however, since we find no effect on vandalism or burglary (columns 4 and 7), it is likely that these findings can be explained by the fact that there were significant differences between treatment groups at baseline.

For paths and compounds, we report the difference-in-difference using a shortened version of the experience of crime index (column 3) — which does not include burglary — because at baseline we asked about experiences of crime in the previous 12 months, while at endline we asked about the previous six months (i.e., the intervention period). The difference-in-difference estimator is not significant.[35]

Second, since we can assume we know where reported vandalisms and burglaries occurred, we also analyze both crimes at the path level.[36] In columns 5 and 8, the outcome is the number of vandalisms or burglaries per path segment. In columns 6 and 9, the outcome is a binary variable indicating whether any vandalism or burglary occurred on the path segment or not. These regressions allow us to check for displacement of burglaries or robberies to one particular experimental group or another. While intuition might suggest that lighting shifts crime from lit to unlit path segments (and hence an overestimation of the effect of lighting), a recent paper by Chalfin et al (2020) suggests that the opposite is also plausible if lit paths attract more pedestrians, i.e., potential victims. We find no effect of treatment on vandalism or burglary in paths or compounds.

Third, since we asked respondents who personally experienced a robbery or physical attack about the time of day and to point out on a map where it happened, we also analyze crime counts at

[35] At baseline, we planned the intervention to last for 12 months. Due to project delays, many of which were caused by the COVID-19 pandemic, we ultimately shortened the intervention timeline to 6 months, hence why we ask about different intervals at baseline and endline.

[36] If a person moved very shortly before the endline survey it is possible they experienced the vandalism or burglary at their previous house.

the path level and by time of day. We combine these into a night crimes and a day crimes outcome variable. As with vandalism and burglaries, this information allows us to check for displacement of robberies and physical attacks to one experimental group or another. For these variables, due to limited detail of the mapped crime points, we could only assign crimes to paths. For the same reasons that the analysis of the impact of the intervention on crime rates is limited (i.e., sample size, crime reporting, data availability, and study length, see Section 2.3), so is our test for crime displacement. We find no path-level treatment effect on day or night crimes (columns 10-13, Panel A).

Lastly, despite one or two households refusing a light for fear that it would attract crime, when we asked respondents about their perceptions of the solar public lights only about 10% across both treatment groups believe the solar lights attract criminals to paths with lights at night.

We re-estimate all models with binary outcomes in Table 7 using binary logistic regression and find very similar results. Average marginal effects are reported in Appendix D Table 6.

Table 7. Impact of treatment on experiences of crime

	Exp. of Crime Index			Vandalism			Burglary			Day Crimes		Night Crimes	
	OLS	OLS (short)	DiD	OLS	OLS (count)	OLS (bin)	OLS	OLS (count)	OLS (bin)	OLS (count)	OLS (bin)	OLS (count)	OLS (bin)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Panel A - Paths													
Treat (=1)	-0.032	-0.046	-0.055	-0.019	-0.036	-0.021	0.016	0.101	0.091	0.172	0.070	-0.037	-0.011
	(0.069)	(0.055)	(0.097)	(0.017)	(0.065)	(0.060)	(0.027)	(0.101)	(0.084)	(0.161)	(0.089)	(0.095)	(0.078)
Endline (=1)			-0.258***										
			(0.071)										
Treat*Endline			0.001										
			(0.106)										
(Intercept)	0.369***	0.295***	0.564***	0.041***	0.138***	0.123***	0.074***	0.246***	0.215***	0.338***	0.277***	0.262***	0.215***
	(0.047)	(0.035)	(0.067)	(0.013)	(0.048)	(0.041)	(0.017)	(0.062)	(0.051)	(0.074)	(0.056)	(0.067)	(0.051)
Adj. R^2	-0.002	-0.001	0.031	0.000	-0.006	-0.008	-0.002	0.000	0.002	0.003	-0.003	-0.008	-0.009
Num. obs.	425	425	830	425	114	114	423	114	114	114	114	114	114
Clusters	112	112	112	112			112						
Panel B - Compounds													
Treat (=1)	-0.195*	-0.169**	-0.259*	-0.026	-0.032	-0.032	-0.026	-0.054	-0.179				
	(0.104)	(0.068)	(0.137)	(0.031)	(0.086)	(0.086)	(0.061)	(0.199)	(0.123)				
Endline (=1)			-0.289**										
			(0.131)										
Treat*Endline			0.089										
			(0.150)										
(Intercept)	0.390***	0.273***	0.566***	0.052**	0.115*	0.115*	0.117***	0.346***	0.346***				
	(0.065)	(0.057)	(0.116)	(0.025)	(0.064)	(0.064)	(0.032)	(0.095)	(0.095)				
Adj. R^2	0.019	0.028	0.058	-0.002	-0.018	-0.018	-0.005	-0.019	0.022				
Num. obs.	154	154	302	153	50	50	154	50	50				
Clusters	50	50	50	50			50						

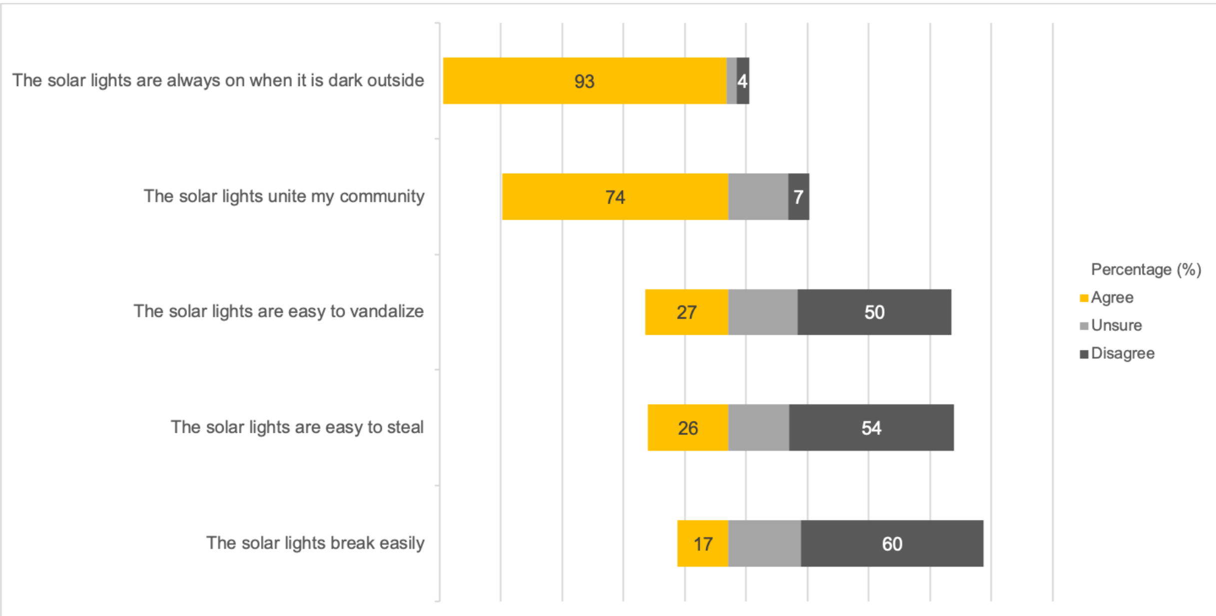
Note: Standard errors clustered at the level of randomization. Standard errors clustered at the level of randomization. The experience of crime index is made up of 4 input variables, which include experience of robbery in the previous 6 months, experience of physical attack (outside) in the previous 6 months, experience of vandalism in the previous 6 months, experience of burglary in the previous 6 months. The short version of the experience of crime index does not include burgarly and the questions ask about the previous 12 months. Column 3 reports the difference-in-difference between baseline and endline in order to show that there is no differential treatment effect despite the difference in the way we asked the question. Columns 5-6 and 8-13 are all aggregated at the cluster level, such that the count outcome is the number of occurrences per cluster and the binary outcome indicates whether any crime occurred on that cluster or not. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

6.5 EXPERIENCE AND SUSTAINABILITY OF THE SOLAR PUBLIC LIGHTS

Overall, we find high satisfaction with the solar public lighting intervention among households in both treatment groups. When asked to rate, on a scale from 0 – 10, whether households would recommend the lights to another informal settlement, treatment is associated with a statistically significantly higher score — 8.38 in the treatment group and 7.75 in the control — however both scores are reasonably high.

We also asked respondents in the treatment group who accepted a light various questions about their direct experience with the light. About 92% of respondents agreed that the light made it difficult to renovate their house, which often requires removing the entire system and reinstalling it after the renovation is complete (Appendix D Figure 4). Figure 3 shows that the majority of respondents in the treatment group agree that the lights are on at night, and that the lights unite the community. At the same, the majority disagrees that the lights are easy to steal and that they break easily. Still, about 50% either think the lights are easy to vandalize or are unsure. We also asked the questions in Figure 3 to the control group, and find results are similar (Appendix D Figure 5).

Figure 3. Opinions about the solar public light among the treatment group



The graph shows how much respondents assigned to the treatment group agree with each statement on the left. The results for the control group are similar, except the share of respondents saying they are unsure is larger (Appendix D Figure 5).

Respondents in both groups reported a high level of individual and community ownership of the lights, despite the fact that they are public lights. About 84% of the treatment group and 72% of the control group said individual households were among those responsible for taking care of the

lights and 41% of the treatment group and 46% of the control group also agreed the entire community was responsible for the lights. Despite the visible presence of a maintenance team, just 20% of the treatment group and 13% of the control group list the maintenance team as one of the responsible parties. Similarly, 16% of respondents in both groups believe the leaders of the informal settlement are responsible for the lights. Perhaps because of this high level of personal and community ownership of the lights, relatively few lights were stolen or vandalized, despite the fact that many stakeholders, including community members, were concerned about theft
and vandalism.

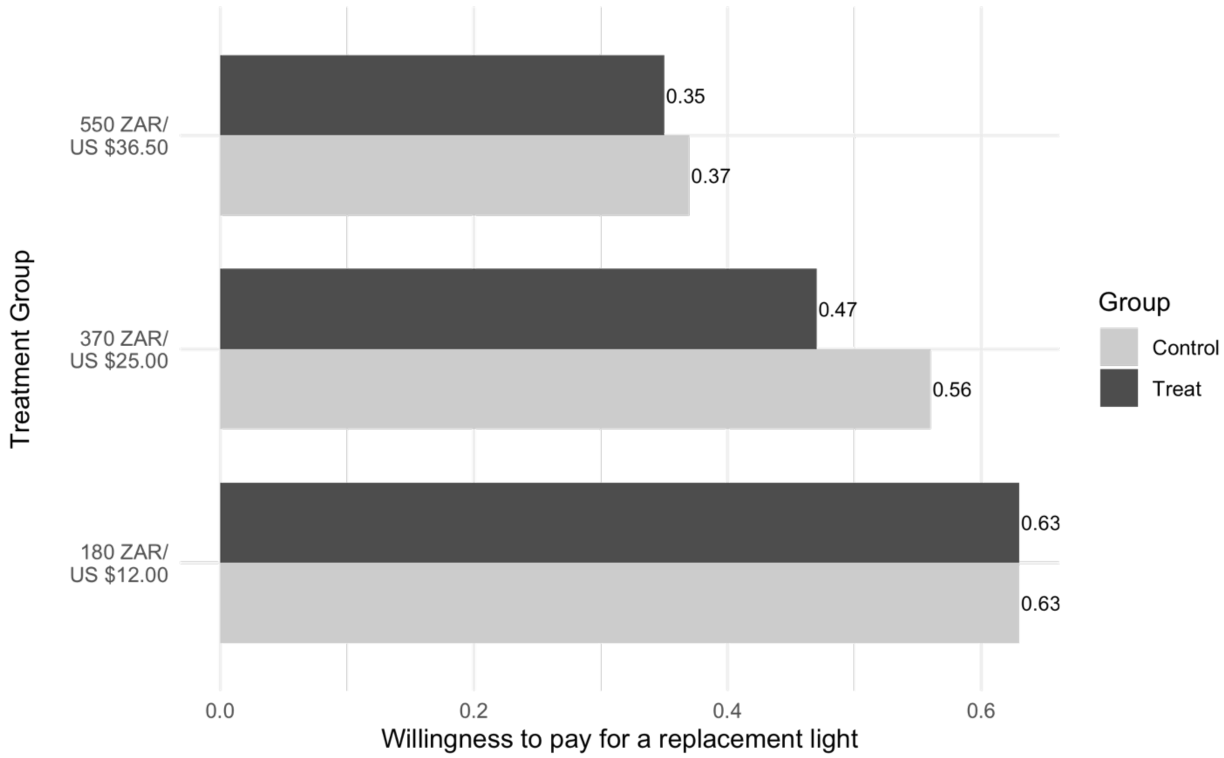
Even though ownership is high and theft and vandalism are low, the question is still whether providing public lighting on private houses would be financially sustainable. Public lighting is a public service that is generally provided by the government. We still asked respondents whether they personally would be willing to purchase a replacement light if their light were to be stolen or vandalized.[37] The reason we did not ask about willingness to fund lighting through an increase in taxes (as for example Willis et al. (2005) and Kaplan and Chalfin (2021) do) is that the population in informal settlements is generally extremely poor, often informally employed, and unlikely to pay any income tax at all (SARS, 2021).[38]

To determine willingness to pay (WTP), respondents were randomly assigned to one of three different replacement costs: 180 ZAR/US $12, 370 ZAR/US $25, 550 ZAR/US $36.50. The middle price level represents the approximate cost of the actual light used in the intervention, the low price is approximately half the cost of that light, and the high price is the approximate cost of a similar, but higher quality light. We find no difference across treatment groups in WTP, but as Figure 4 shows, we find about 63% of respondents are willing to pay US $12, about 52% are willing to pay US $25, but only 36% are willing to pay US $36.50 (Appendix D Table 7).

[37] At a community meeting announcing the solar public lighting installation process, we made clear that the solar public lights would be offered for free, but that if the light was stolen or vandalized it would not be replaced. Prior to installing the light, households that accepted a light were told that if the light broke the maintenance team would do its best to repair the light, but if the light was vandalized or stolen, it would not be replaced. During the intervention phase, this rule was enforced so most people in the community understood the consequences of theft or vandalism, hence why we structured the question this way.

[38] According to the South African Revenue Service, the threshold for paying personal income tax in 2021 was 83,100 ZAR for people under 65.

Figure 4. Willingness to pay for a replacement solar public light



The graph shows the share of each group that is willing to pay the randomly shown price for a replacement light.

As these numbers are only stated rather than revealed preferences, and hence actual WTP might be lower, they provide an indication that residents in this community do not view the solar public lights as a purely public service and residents in both the treatment and control groups value their presence in the community.

6.6 HETEROGENEITY

We analyze heterogeneous impacts of the solar public lighting treatment by gender (of the respondent) and by distance of the respondent's structure to the nearest high-mast light on a selection of the most important outcomes presented in the main analysis. If, as some literature suggests, women are particularly fearful at night, we would expect to see a stronger impact of solar public lighting on women's perception of safety, in particular. Appendix D Table 8 reports the heterogeneous effects for gender in both paths and compounds. In paths (Panel A), however, there is no evidence of differences between men and women. Although we do see that despite the increase in safety in the path where respondents live at night associated with the treatment, women in both experimental groups still feel significantly less safe than men.

Women in both groups also have a significantly lower score in the night activity index and are significantly less likely to report going outside to use shared sanitation at night. In compounds (Panel B), the situation is slightly different. We find that women overall perceive a 14% higher risk of burglary, but although women in the treatment group still perceive a higher risk of burglary, the effect is smaller (8%) than for women, overall. Outside of this, we do not find a stronger effect of treatment for women on any other outcome, though we do learn that women who live in compounds, in both groups, are significantly less likely to report feeling safe in the informal settlement during the day. It is possible that this is one reason why these women have chosen to live in a compound, rather than directly on a path, in the first place.

Distance from the nearest high-mast light is determined by calculating the Euclidean distance between each front door and each of the two high-mast lights. For each house, we keep the smaller of the two distances, measured in meters. Since much of the literature finds diminishing returns beyond a certain (as yet undetermined) level of brightness (Boyce, 2019; Fotios & Castleton, 2016; Svechkina et al., 2020), we do not expect to find stronger treatment effects for those living close to one of the high-mast lights. Rather, since those who live farthest from the high-mast lights tend to also live farthest from the central institutions within the neighborhood (the largest Spaza shop, the largest collection of toilets, etc.), we would expect the treatment to somewhat mitigate any negative effects of living far from a high-mast light and therefore, possibly, also far from the neighborhood's so-called center of gravity. Appendix D Table 9 reports the results of our test for heterogeneous effects on distance to the nearest high-mast light in both paths and compounds. In paths (Panel A), we find that while treatment is linked to a significant decrease in perceived risk of burglary, the decline gets smaller as distance from the nearest high-mast light increases, indicating that those who live further from high-mast lights experience a muted effect. We find no other heterogeneous effects in paths for the other outcomes we study and no heterogeneous effects of distance to the nearest high-mast light in compounds (Panel B).

7 ROBUSTNESS CHECKS

7.1 NON-COMPLIANCE

We have so far analyzed the intention-to-treat effect and the differential effect of treatment assignment on the five categories of outcomes we are interested in: effectiveness of the solar public light, perception of safety, perceived risk of crime, willingness to engage in public space through nighttime activities, and experience of crime. As noted in Section 5.2, however, we do not have perfect compliance with treatment assignment. First, the pre-existing high-mast lights generally provide light to those houses located closest to each light, and hence also control paths. Second, as in most experiments, eligible households had the option to refuse the light. In our case, we had a 94% take-up rate, so most accepted, still about 19 houses did not want the light. Even if someone did not want the light, they may have still lived in a lit path or compound if their neighbors were offered a light and accepted. Finally, the last source of non-compliance is theft and vandalism, since these lights were not replaced. Again, these houses may have no longer had a light on their house, but likely continued living in a lit path or compound.

These examples of treatment non-compliance are potential sources of bias in the estimations presented above. In order to determine the robustness of our main findings, we follow the example of many other researchers and use an instrumental variables approach (e.g., Devoto et al., 2012), where treatment assignment is the instrument, which satisfies the requirement that it is correlated with actually receiving the treatment by design and, we argue, satisfies the exclusion restriction because the randomization only effects our outcomes of interest via the treatment. In the first stage, our dependent variable is the endline average lux at the path or compound level, which captures variation in light intensity.

Appendix D Table 10 reports the first stage estimation (column 1) and the LATE on respondent perception of brightness (Appendix D Table 10, columns 1-3), on perception of safety (Appendix D Table 10, columns 4-11), perception of crime risk (Appendix Table 10, columns 12-13), nighttime activities (Appendix D Table 10, Cont'd, columns 1-8), and on experiences of crime (Appendix D Table 10, Cont'd, columns 10-12). Similar to the OLS regression, the LATE on perception of brightness in paths is positive and significant for all three outcomes in paths, but only the first two outcomes in compounds. An increase in lux of 1 (note that on average treatment paths are 12.5 lux brighter than control paths) leads to a 5.5 percentage point increase in perceived brightness in front of the house in paths and 4.7 percentage point increase in compound. In paths, an increase in lux of 1 leads to a 5.3 percentage point increase in perceived brightness in the path where the person lives, whereas in compounds the increase is 3.6 percentage points. In terms of the perception that the informal settlement is well lit, an increase of 1 lux leads to a 1.2 percentage point increase in paths and no effect in compounds. In paths, we also find an additional unit of lux leads to an increase in perceived safety in both the extended and short perceived safety indices and a .09 percentage point increase in perceived safety in the path where the respondent lives at night. In paths, we also find a significant decrease in perceived risk of burglary.

Again, we find no effect on perceived safety in compounds and no effects on nighttime activity or experience of crime in either paths or compounds. Hence, these results indicate that our main results do not suffer unduly from bias caused by treatment non-compliance.

7.2 SPILLOVER EFFECTS

Since we could only cover a single neighborhood in this field study due to the community engagement required to work in informal settlements (at night) in South Africa, spillovers are a major threat to identification. By design, spillovers were unavoidable in this experimental set-up given that it was not feasible to randomize at a higher neighborhood level (see Section 3.2) and we therefore had to randomize at the path segment and compound level. Spillovers could occur because all residents are free to use any path segment or visit (almost) any compound they wish, therefore all residents experience the treatment, but to different extents.

While we could not control experientially for spillover (e.g., Egger et al., 2019), we made sure that no light from a treated path segment or compound could directly spillover onto an untreated path segment or compound occurs. For example, households on a treatment path whose front door was close to an intersection with a control path did not receive a light to prevent light spillover onto a control path (they are still considered treatment households in the analysis because the front door faces a treatment path segment/compound). On the other hand, we expect that living near a lit path segment may affect the perception of safety and behavior of residents in nearby path segments or compounds[39] and living near an unlit path segment may also diminish the effect of the treatment. Hence, our estimated effects likely underestimate the real effect of the public light intervention.

To better understand the magnitude of these spillover effects, we define a third group called $BORDER_{ip}$, which equals 1 for any household that lives directly adjacent to a cluster of the opposite treatment status, and 0 otherwise. Therefore, we test for an effect of living *near* a treated/untreated path segment/compound to account for the fact that self-reported outcomes may be influenced by the immediately surrounding path network and not only the path segment or compound where a resident lives. To analyze spillovers, we estimate equation (6):

$$OUTCOME_{ip} = \beta_0 + \beta_1 TREAT_p + \beta_2 BORDER_{ip} + \Theta X'_{ip} + \epsilon_{ip} \quad (6)$$

where $OUTCOME_{ip}$ is the endline outcome measure for household i living on the path segment or compound p; $TREAT_p$ is an indicator for a path segment or compound assigned to the public lighting intervention (and zero otherwise); $BORDER_{ip}$, as explained above, is a dummy variable indicating the "spillover" treatment group, where 0 is the control group, 1 is the treatment group, and 2 is the border group; and ϵ_{ip} is the standard error clustered at the level of randomization (path segment/compound).

Appendix D Table 11 reports both the treatment effect and the effect of being in the *border* group on several endline outcomes of interest. Using this approach, we do not find widespread evidence for spillover on most outcomes.

7.3 MULTIPLE-HYPOTHESIS TESTING

Since we test several different outcomes, we account for multiple hypothesis testing using the Bonferroni adjustment. Assuming 34 outcomes in the analysis of paths and 30 outcomes in the analysis of compounds, we report the adjusted p values in Appendix D Table 2. After the adjustment, in paths, the effects documented on the perception that the informal settlement is well lit, the effect on both safety perception indices, and the effects on perception of safety in the informal settlement during the day and night are no longer significant even at the 10% level.

[39] Blattman et al. (2019) encounter a similar dynamic in which spillovers cannot be avoided in the study design.

The effects on endline average lux, perception that the front of the house is well lit, perception that the path is well lit, perception of safety in the path at night, and the perception that a respondent would be more willing to leave the house at night if the area in front of their home is well lit all remain significant. In compounds, endline average lux, the perception that the front of the house is well lit, and the perception that the path is well lit all remain significant, while the effects on the night activity index, the perception that a respondent would be more willing to leave the house at night if the area in front of their home is well lit, and the effect on the experience of crime index are no longer significant.

8. DISCUSSION

8.1 CONTEXTUALIZING THE RESULTS

The results of this field experiment present evidence that solar public lighting can provide effective light at night in informal settlements. While it may seem obvious that installing more lights would result in higher light levels, it is not as trivial a finding as it seems. Many stakeholders, including residents of the informal settlement, were worried about vandalism and theft of the lights as well as general maintenance, yet there were relatively few instances of either. In addition, in the absence of an objective lighting standard for informal settlements, the fact that respondents' subjective perceptions of brightness levels corroborate the objective average lux measure indicates that the increase in light levels is practically as well as statistically significant. This result is important given that the settlement already has high-mast lighting, which our lux measurements show is unevenly distributed throughout the neighborhood (see Article 3).

We also find suggestive evidence that higher levels of lighting lead to a 19% percentage point increase in perceptions of safety overall for residents living in paths, but we find no effect in compounds. The absence of an effect in compounds may be due to the fact that a) those living in compounds may already have been more concerned about safety, hence the formation of the compound, and b) the compound connects to a path that may or may not have been treated, meaning compound respondents may still have felt quite insecure leaving their lit compound. The finding that residents in paths feel safer at night lends support to what has been found by previous observational studies (Atkins et al., 1991; Blöbaum and Hunecke, 2005; Boyce et al., 2000; Kaplan, 2019; Kaplan and Chalfin, 2020; Nair et al., 1997; Nasar and Jones, 1997; Peña-García et al., 2015; Roman and Chalfin, 2008; Svechkina et al., 2020; Vrij and Winkel, 1991; Wu and Kim, 2018). Furthermore, we find that the treatment has a positive and significant impact on path respondents' perception of safety in the informal settlement, broadly, both during the day (10.5 percentage points) and at night (6 percentage points). In actuality, though, perceptions of safety are still relatively low, with only 52% of the treatment group reporting feeling safe during the day and 19% feeling safe at night. When we ask about perception of safety in the path where the respondent lives, we find no effect of treatment on perception of safety during the day, but a statistically significantly 10.7 percentage point increase in the number of residents who report feeling safe in their path at night — double the control group. We find no difference between treatment groups in perceptions of safety inside the home at night, however, it is worth noting that just 44% of the control group and 51% of the treatment group report feeling safe in their own homes at night. These results underscore the level of insecurity felt by residents living in this informal settlement, indicating that lighting leads to a significant, but likely not sufficient improvement in feelings of safety for residents of informal settlement, given the large number of other factors that can influence these perceptions.

Perhaps not surprisingly then, greater perceptions of safety do not necessarily translate to widespread changes in behavior or experiences of crime. In paths, we find no effect of the treatment on the index of reported nighttime activity (extended or short), however, we do find an effect on respondents' expectations about their willingness to leave the house at night. In compounds, we actually find a negative effect of treatment on the two nighttime activity indices, as well as on the use of shared sanitation at night, yet positive effects on respondents' expectation that they will go out more if the front of the house is well lit. This discrepancy between reported nighttime activities and residents' expectations about the influence of light on their lives is consistent with our findings on perception of safety. Kaplan and Chalfin (2021) conduct a Mechanical Turk survey experiment to test the effect of hypothetical brighter street lighting in Chicago, Illinois and conclude that people do not change nighttime behavior in response to brighter light, however, these findings are primarily based on vignettes and a question about how many nights respondents expect to go out per week. These questions are similarly hypothetical to the two outcomes for which we do find significant treatment effects. Though we arrive at similar conclusions, the difference in approach also highlights how responses to a physical intervention may differ from a hypothetical one.

In our setting, residents may not participate in significantly more nighttime activities either because they do not feel safe enough to do many more things at night, because the intervention was not long enough to realize substantial behavioral changes, or because people simply do not want to be outside more at night. When we look at the three individual nighttime activities — use of shared sanitation at night, going out with friends or family at night, and whether or not respondents leave the house at all at night — and use a difference-in-difference estimation, we find no treatment effects, but find that the time dummy on going out with friends/family and on leaving the house at night is negative, whereas it is positive and significant with respect to the use of shared sanitation at night (both paths and compounds). This finding indicates that over time (between baseline in March 2019 and endline in May/June 2021) residents are less likely to go out at night for social activities, but more likely to go out at night to use the toilet. We cannot say whether this increased use of sanitation is due to the impact of the intervention spilling over onto the control group or some other time trend. However, spillover is likely. When we discussed the results for shared sanitation with local field staff they were not surprised because there is a lot of shame associated with using a bucket or other in-home toilet alternative. Therefore, any improvement in lighting in the settlement could lead to an increased use of sanitation. For policymakers, the takeaway is that better public lighting likely enables access to shared sanitation infrastructure, which is a basic need. But more research is needed: particularly a larger-scale study that randomizes across informal settlements to eliminate spillover effects.

In contrast, even though we cannot completely rule out spillover effects for other nighttime activities, the fact that they generally decrease over time indicates that the null effect between the treatment and the control group for nighttime activities is not likely to be driven by spillover effects. Moreover, when we looked at the border group — those living adjacent to a cluster of the opposite treatment status — we find no systematic evidence of spillover to this group.

We also find no consistent evidence that lighting affects reported experiences of crime, however, this was expected given the relative rarity of crime (even in a high-crime area), the study sample size, and possible reporting bias (if respondents were afraid to be honest about crime experiences). Thus, our findings should not be interpreted to mean that lighting does not affect experiences of crime, but rather that a larger sample size is essential to conclude either way. Furthermore, any effect of light on crime would likely only be a small part of the story, as many other factors influence crime. For context, leading up to the intervention, Khayelitsha has seen a rise in gang activity, with gang members frequently demanding "protection money" and threatening physical harm if the money is not paid. This situation creates an enormous amount of fear about going out at night that is not related to the lighting. Although it would have been useful to ask about this at endline, the issue is sensitive as some respondents may actually be gang members (or relatives), thus we could not account for this in our estimates.

8.2 CONTRIBUTION TO THEORY

As discussed in Section 2, there are two main mechanisms through which light is theorized to affect nighttime life:[40] 1) either via the direct effect of brighter, more uniform lighting which provides visibility and opportunities for surveillance (Cozens et al., 2005; Farrington and Welsh, 2002); and/or 2) via the investment and care in the community that improvements in environmental design (i.e., lighting infrastructure) may signal. The first channel should only lead to effects at night, while the community investment channel should lead to effects during the day and at night (Chalfin et al., 2021; Cozens et al., 2005; Farrington and Welsh, 2002). In their RCT, Chalfin et al. (2021) find evidence in support of the community investment channel, documenting a reduction in both daytime and nighttime crimes in response to the introduction of flood light towers. While we also leverage variation in lighting intensity to estimate effects, we cannot study the impact of light on crime in a comparable way, therefore we focus primarily on effects on perception of safety, which Chalfin et al. (2021) do not study.

[40] As mentioned in Section 2 there are other theories specifically related to crime, but these theorized channels most pertain to non-crime outcomes.

We find that in paths treatment is associated with an increase in perceived safety in the informal settlement, broadly, during both the day and night, which would support the community investment channel. Chalfin et al. (2021) speculate that the visibility of the lights they study as well as the presence of maintenance personnel may have contributed a crime deterrent effect. Similarly, our results may be attributable, not only to the visibility of the lights, but to the presence of the maintenance team, who responded to service requests and periodically checked that all lights were working. On the other hand, we find that the treatment is only associated with a significant increase in perception of safety in paths at night. These findings complicate the community investment interpretation. It is possible that the dominant mechanism is dependent on the scale at which the outcome variable is measured and we cannot rule out either mechanism based on this study.

8.3 LIMITATIONS

Since blinding is not possible in a study where people receive a light installed on their front door, social desirability bias in survey responses is (always) a concern. To manage expectancy or social desirability bias, all household survey data (collected March 2019) were gathered before the lighting intervention was announced. While it was unavoidable that the topic of light came up in the survey, we did not link our data collection to any future intervention.

When we announced the lighting intervention in February 2020, we explained to the entire community, regardless of treatment status, that the project would run in two phases and that houses who did not receive a light in the first phase would receive one in the second. In this way, households should not have been incentivized to adjust their responses at endline, since the control group knew it would receive a light and the treatment group knew they could keep their lights. We also made clear that no stolen or vandalized lights would be replaced.

Since we worked within a single neighborhood and community support for the field study was essential, the respondents were aware that the endline survey is linked to the intervention, in that we wanted to know their opinion of the lights. However, residents did not know the specific hypotheses being tested. To further minimize priming, we asked all questions related to satisfaction with the lights at the end of the survey. Furthermore, since the community cannot influence the lux measurements, we have a measure that is not vulnerable to experimenter demand or social desirability bias. The last reason we are less concerned about social desirability bias is the nature of the treatment itself. Although the lights are installed on individual houses, the use of the light is available to the public. Thus, we are not concerned that people will link their answers about safety perception to whether they directly received a light or not.

Finally, it is impossible to ignore the impact that the COVID-19 pandemic has had on the residents of the informal settlement we study. Since we conducted the baseline survey one year prior to the onset of COVID-19 pandemic and the endline one year after, we cannot rule out that self-reported responses about nighttime activity, perception of safety and crime risk, and experiences of crime are in some way directly or indirectly affected by the pandemic. That said, since the pandemic impacts all residents of the informal settlement, the significant effects we did find may be underestimations.

9. CONCLUSION

Public lighting is ubiquitous in the vast majority of formal cities; indeed, it is easy to take for granted. Yet, only one other RCT studies the impact of public lighting infrastructure, while only a small number of studies rigorously study the impact of ambient lighting, exploiting variation caused by public light outages or DST. None of these studies take place in informal settlements, where public lighting is usually an afterthought. Our study provides the first experimental evidence of the impact of public lighting in the context of an informal settlement, a form of urban neighborhood that is only becoming more numerous alongside rapid urbanization.

The results of our study demonstrate two types of findings. First, we show that even in the presence of high-mast lights, a common form of public lighting in South African informal settlements, solar public lights positively and significantly improve the availability of light on paths and compounds that received lighting. Importantly, especially to residents and policymakers, theft and vandalism were relatively minor. Second, the provision of this additional lighting results in respondents feeling safer overall, particularly at night, where baseline levels of perception of safety were very low. While we do not demonstrate a treatment effect of additional lighting on residents' willingness to spend time in public space at night, we find that residents in both groups appear to be more likely to report using shared sanitation at night over time. These findings are important for the academic literature, as they support previous findings. They are also important for policymakers, who now have evidence of an alternative to high-mast lighting and standard streetlighting in informal settlements that can improve perceptions of safety and likely enhances access to shared sanitation.

Importantly, although we do not find any effect on crime, we cannot be sure if that is due to an actual absence of an effect, our limited sample size, or measurement error. There is no way to know if a respondent held back such information out of fear or embarrassment. Police crime statistics may not have drastically improved our estimations as field staff said that many crimes, especially robberies, are never reported to the police because residents feel it is a waste of time.

Similar to the vast majority of field experiments, external validity of the results is not clear. In sub-Saharan Africa, South Africa is often considered an outlier because it is a middle-income country, while many other countries with large numbers of informal settlements are much lower income overall. Yet, we argue that our experiment, if anything, underestimates effects as the study site already had some form of public lighting. In informal settlements that are either not surrounded by formal areas with standard streetlighting or do not have any residential public lighting, it is plausible to expect the impact would have been larger.

Finally, the results of this study provide useful additional evidence that informs both the theoretical and empirical research on the impact of light at night. Although we cannot conclusively determine the channel through which light affects life at night, we provide evidence from a new context that can form the foundation for future work, particularly a larger study across several informal settlements. Furthermore, our study underscores the importance of designing infrastructure solutions that fit the particular characteristics of informal settlements. Importantly, we also show that experimental research on public lighting and the lived experience of people in informal settlements is possible and necessary.

10. APPENDIX D

Figure 1. A high-mast light in the informal settlement

Figure 2. Randomization approach

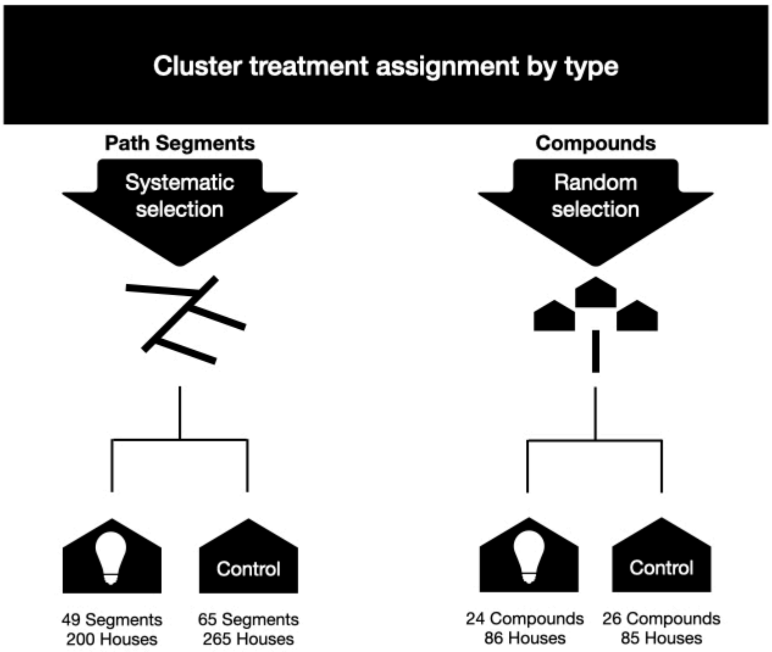


Figure 3. The solar public light installed on a household living on a treatment path

Table 1. Construction of indices at baseline and endline

Index	Baseline Inputs	Endline Inputs	Coding
Perception of Safety Index	Do you feel safe when you are outside in your neighborhood during the daytime?	Do you feel safe when you are outside anywhere in your neighbourhood during the daytime?	Always, Most of the time, About half the time = 1; Never, Rarely = 0
	Do you feel safe when you are outside in your neighborhood at night?	Do you feel safe when you are outside anywhere in your neighbourhood at night?	Always, Most of the time, About half the time = 1; Never, Rarely = 0
		Do you feel safe when you are outside in the path in front of your house during the daytime?	Always, Most of the time, About half the time = 1; Never, Rarely = 0
		Do you feel safe when you are outside in the path in front of your house at night?	Always, Most of the time, About half the time = 1; Never, Rarely = 0
		Do you feel safe when you are inside your house during the daytime?	Always, Most of the time, About half the time = 1; Never, Rarely = 0
		Do you feel safe when you are inside your house at night?	Always, Most of the time, About half the time = 1; Never, Rarely = 0
		I feel safe walking to the toilet alone at night.	Strongly Agree, Somewhat Agree, Neither Agree nor Disagree = 1; Somewhat Disagree, Strongly Disagree = 0
		I feel safe walking to the nearest spaza shop alone at night.	Strongly Agree, Somewhat Agree, Neither Agree nor Disagree = 1; Somewhat Disagree, Strongly Disagree = 0
		I feel safe walking to visit a friend of family member somewhere else in the informal settlement alone at night.	Strongly Agree, Somewhat Agree, Neither Agree nor Disagree = 1; Somewhat Disagree, Strongly Disagree = 0
		I feel safe walking home from church alone at night.	Strongly Agree, Somewhat Agree, Neither Agree nor Disagree = 1; Somewhat Disagree, Strongly Disagree = 0
	What private source(s) of light do you use when you go outside of your house after sunset?	What private source(s) of light have you used during the last week when you were walking outside at night.	Any light selected = 0; Never went outside = 0; None = 1
Nighttime Activity Index	Today, what time did you wake up?	Today, what time did you wake up?	Dark times = 1; Daylight times = 0
	Yesterday, what time did you go to sleep?	Yesterday, what time did you go to sleep?	Dark times = 1; Daylight times = 0
	How do you use the toilet after sunset?	How do you use the toilet at night?	Walk alone, Somebody walks with me = 1; Do not need toilet, Flush toilet, Portable toilet, Bucket in house = 0
		Do you ever go to the Spaza shop for any reason at night	Yes = 1, No = 0
		Do you ever go to church for any reason at night	Yes = 1, No = 0
		In the last week, on how many days did you go outside at nighttime to do washing?	Response > 0 = 1; 0 = 0
	In the last 7 days, did you go outside at nighttime to spend time with friends or family members?	In the last week, did you go outside anywhere at nighttime to spend time with friends or family members?	Yes = 1; No = 0; I do not have friends/family = 0
		In the last week, on how many days did you spend time in front of your house at nighttime?	Response > 0 = 1; 0 = 0
	Last night, how many times did you leave the house at nighttime?	Last night, how much time did you spend outside your house at nighttime?	Response > 0 = 1; I never went outside at night = 0
	When is the latest time that children in this household are allowed to be outside in the evening?	When is the latest time that children in this household are allowed to be outside in the evening?	Times after 8 pm/No specific time = 1; Times before 8 pm = 0
	When is the latest time that women in this household are allowed to be outside in the evening?	When is the latest time that women in this household are allowed to be outside in the evening?	Times after 8 pm/No specific time = 1; Times before 8 pm = 0
	When is the latest time that men in this household are allowed to be outside in the evening?	When is the latest time that men in this household are allowed to be outside in the evening?	Times after 8 pm/No specific time = 1; Times before 8 pm = 0
		Activities between 6 - 7 pm	Outdoors activities = 1; Indoor activities = 0
		Activities between 7 - 8 pm	Outdoors activities = 1; Indoor activities = 0
		Activities between 8 - 9 pm	Outdoors activities = 1; Indoor activities = 0
		Activities between 5 - 6 am	Outdoors activities = 1; Indoor activities = 0
		Activities between 6 - 7 am	Outdoors activities = 1; Indoor activities = 0
		Activities between 7 - 8 am	Outdoors activities = 1; Indoor activities = 0
Experience of Crime Index	Have you or anyone in your household been robbed in the last 12 months?	Have you or anyone in your household been robbed in the last 6 months?	Yes = 1, No = 0
	Has your house ever been vandalized in the last 12 months?	Has your house ever been vandalized in the last 6 months?	Yes = 1, No = 0
	Have you or anyone in your household been physically attacked in the last 12 months?	Have you or anyone in your household been physically attacked in the last 6 months?	Yes = 1, No = 0
		Has your house ever been burglarized in the last 6 months?	Yes = 1, No = 0

Notes: If respondents answered "I don't know" or "Not applicable" the response was re-coded as NA, however, when compiling the indices NA responses were ignored (as it is a sum), therefore these observations do not drop out. For the crime experience input variables, we asked about different time intervals at baseline and endline because we originally planned for a 12-month intervention, however, due to the COVID-19 pandemic we ultimately had to adjust to a six-month intervention.

Table 2. Bonferroni adjusted p-values to account for multiple hypothesis testing

	Path				Compound			
Outcome	Treat (=1)	p.value	Bonferroni adjustment	Remains Sig. at 10%	Treat (=1)	p.value	Bonferroni adjustment	Remains Sig. at 10%
Endline Avg. Lux	12.525	0.000	0.000	**Yes**	16.045	0.000	0.000	**Yes**
Lit Front of House	0.694	0.000	0.000	**Yes**	0.753	0.000	0.000	**Yes**
Lit Path	0.675	0.000	0.000	**Yes**	0.572	0.000	0.000	**Yes**
Lit Informal Settlement	0.145	0.003	0.107	No	-0.013	0.874	1.000	
Safety Perception Index	0.660	0.023	0.782	No	-0.013	0.979	1.000	
Safety Perception Index (Short)	0.210	0.016	0.557	No	-0.182	0.217	1.000	
Safe in Inf. Sett. in Day	0.105	0.026	0.885	No	-0.104	0.236	1.000	
Safe in Inf. Sett. at Night	0.061	0.076	1.000	No	-0.091	0.139	1.000	
Safe in Path in Day	0.085	0.116	1.000		0.000	1.000	1.000	
Safe in Path at Night	0.107	0.002	0.069	**Yes**	0.026	0.724	1.000	
Safe Inside in Day	0.038	0.367	1.000		0.013	0.879	1.000	
Safe Inside at Night	0.071	0.188	1.000		0.104	0.241	1.000	
Perceived Burglary Risk	-0.044	0.029	0.977	No	0.000	1.000	1.000	
Perceived Vandalism Risk	0.003	0.926	1.000		0.024	0.587	1.000	
Night Activity Index	0.006	0.977	1.000		-0.779	0.027	0.809	No
Night Activity Index (Short)	0.014	0.905	1.000		-0.377	0.083	1.000	
Shared Sanitation at Night	-0.047	0.346	1.000		-0.169	0.056	1.000	
Out Family/Friends at Night	0.001	0.983	1.000		-0.104	0.113	1.000	
Leave House at Night	0.001	0.979	1.000		0.065	0.412	1.000	
Front House w/ Family/Friends at Night	-0.015	0.729	1.000		-0.065	0.315	1.000	
Leave House if Lit in Front	0.252	0.000	0.000	**Yes**	0.156	0.048	1.000	No
Leave House if Inf. Sett. Lit	0.123	0.008	0.287	No	0.091	0.218	1.000	
Experience of Crime Index	-0.032	0.646	1.000		-0.195	0.068	1.000	
Experience of Crime Index (Short)	-0.046	0.401	1.000		-0.169	0.017	0.512	No
Vandalism (binary, HH-Level)	-0.019	0.259	1.000		-0.026	0.406	1.000	
Vandalism (# per path)	-0.036	0.578	1.000		-0.032	0.711	1.000	
Vandalism (binary, path-level)	-0.021	0.726	1.000		-0.032	0.711	1.000	
Burglary (binary, HH-level)	0.016	0.562	1.000		-0.026	0.673	1.000	
Burglary (# per path)	0.101	0.322	1.000		-0.054	0.786	1.000	
Burglary (binary, path-level)	0.091	0.282	1.000		-0.179	0.151	1.000	
Day Crimes (# per path)	0.172	0.288	1.000					
Day Crimes (binary, path-level)	0.070	0.431	1.000					
Night Crimes (# per path)	-0.037	0.696	1.000					
Night Crimes (binary, path-level)	-0.011	0.884	1.000					

Notes: Effects that remain significant are marked with a bold "Yes." Effects that are significant in the main results, but are no longer significant are marked with a "No."

Table 3. Marginal effects of treatment on self-reported brightness variables

	Paths			Compounds		
	Front of House	Path	Inf. Sett.	Front of House	Path	Inf. Sett.
	(1)	(2)	(3)	(4)	(5)	(6)
Treat (=1)	0.477***	0.440***	0.141***	0.446***	0.438***	-0.013
	(0.013)	(0.006)	(0.042)	(0.030)	(0.017)	(0.077)
Log Likelihood	-181.785	-175.413	-255.744	-53.694	-75.216	-99.124
AIC	367.570	354.827	515.488	111.388	154.432	202.247
BIC	375.674	362.820	523.592	117.462	160.385	208.321
N	425	402	425	154	145	154

Note: All three self-report variables are constructed as binary outcomes from variables in which respondents could answer, 'Totally dark' = 0, 'Somewhat dark' = 0, 'Not much light, but not dark' = 0, 'Somewhat lit' = 1, 'Very well lit' = 1. The table reports average marginal effects with standard errors in parentheses. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 4. Marginal effects of treatment on perceived safety variables

	Inf. Sett. Day	Inf. Sett. Night	Path Day	Path Night	Inside House Day	Inside House Night	Burglary Risk	Vandalism Risk
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A - Paths								
Treat (=1)	0.104**	0.060*	0.085*	0.104***	0.039	0.071	-0.046**	0.003
	(0.047)	(0.035)	(0.048)	(0.034)	(0.043)	(0.048)	(0.022)	(0.027)
Log Likelihood	-290.819	-180.338	-293.064	-173.643	-240.488	-292.908	-61.876	-118.218
AIC	585.639	364.677	590.127	351.287	484.977	589.817	127.752	240.437
BIC	593.743	372.781	598.231	359.391	493.081	597.921	135.856	248.527
N	425	425	425	425	425	425	425	422
Panel B - Compounds								
Treat (=1)	-0.103	-0.092	0.000	0.026	0.013	0.103	0.000	0.024
	(0.078)	(0.060)	(0.081)	(0.062)	(0.071)	(0.078)	(0.040)	(0.047)
Log Likelihood	-105.268	-67.120	-106.732	-72.930	-89.223	-104.846	-37.012	-46.592
AIC	214.535	138.240	217.463	149.860	182.446	213.692	78.023	97.184
BIC	220.609	144.313	223.537	155.934	188.520	219.766	84.097	103.231
N	154	154	154	154	154	154	154	152

Note: The table reports average marginal effects with standard errors in parentheses. The first six variables are constructed as binary outcomes from variables in which respondents could answer, 'Never' = 0, 'Rarely' = 0, 'About half the time' = 1, 'Most of the time' = 1, 'Always' = 1. The last two variables are constructed as binary outocmes from variables in which the respondent could answer, 'Not a risk' = 0, 'Small risk' = 0, 'Medium risk' = 1, 'Big risk' = 1, and 'Very big risk' = 1. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 5. Marginal effects of treatment on nighttime activity variables

	Paths						Compounds					
	Shared Sanitation Night	Friends/ Family Night	Leave House Night	Front House Night	Leave House if Lit in Front	Leave House if Inf. Set. Lit	Shared Sanitation Night	Friends/ Family Night	Leave House Night	Front House Night	Leave House if Lit in Front	Leave House if Inf. Set. Lit
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Treat (=1)	-0.046	0.001	0.001	-0.015	0.235***	0.119***	-0.166**	-0.104	0.065	-0.065	0.154**	0.091
	(0.047)	(0.039)	(0.047)	(0.043)	(0.037)	(0.042)	(0.073)	(0.064)	(0.074)	(0.067)	(0.069)	(0.072)
Log Likelihood	-281.512	-208.445	-275.930	-239.750	-233.598	-247.185	-100.161	-74.602	-94.358	-82.074	-89.820	-92.262
AIC	567.024	420.890	555.861	483.500	471.196	498.370	204.323	153.204	192.716	168.149	183.641	188.525
BIC	575.123	428.995	563.965	491.604	479.301	506.475	210.397	159.278	198.789	174.223	189.715	194.599
N	424	425	425	425	425	425	154	154	154	154	154	154

Note: The table reports average marginal effects with standard errors in parentheses. Use of shared sanitation is coded as 1 if the respondent reports walking to use shared sanitation alone or with someone at night and 0 otherwise, spending time with friends/family outside at night is 1 if the person engaged in this activity in the previous week and 0 otherwise, leave house at night is coded as 1 if the person reports going outside 1 or more times per night and 0 otherwise, spending time with friends/family in front of the house at night is coded as 1 if the respondent reports engaging in the activity and 0 otherwise. Columns 5-6 and 11-12 are recoded as binary variables such that 'Strongly agree' and 'Somewhat agree' were recoded as 1 and 'Neither agree nor disagree', 'Somewhat disagree', and 'Strongly disagree' were recoded as 0. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 6. Marginal effects of treatment on experience of crime variables

	Paths						Compounds			
	Vandalism	Vandalism (Path)	Burglary	Burglary (Path)	Day Crimes (Path)	Night Crimes (Path)	Vandalism	Vandalism (Comp)	Burglary	Burglary (Comp)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Treat (=1)	-0.020	-0.021	0.015	0.089	0.069	-0.011	-0.027	-0.032	-0.026	-0.179
	(0.020)	(0.061)	(0.027)	(0.080)	(0.086)	(0.077)	(0.034)	(0.087)	(0.050)	(0.119)
Log Likelihood	-60.942	-40.393	-118.141	-64.047	-69.983	-58.660	-24.973	-16.182	-51.228	-27.584
AIC	125.885	84.787	240.282	132.095	143.965	121.319	53.946	36.365	106.457	59.169
BIC	133.989	90.259	248.376	137.567	149.438	126.792	60.007	40.189	112.531	62.993
N	425	114	423	114	114	114	153	50	154	50

Note: The table reports average marginal effects with standard errors in parentheses. The outcome variables in columns 1, 3, 7, and 9 are reported experiences of vandalism and burglary at the household level, coded such that if a respondent reported they experienced the crime in the previous 6 months the variable is 1 and 0 if not. The remaining outcome variables represent the occurance of the specified crime at the path level, coded such that if the crime occurred on the path at all the value is 1 and 0 otherwise. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Figure 4. Perceived impacts of the solar public lights amongst those who accepted a light

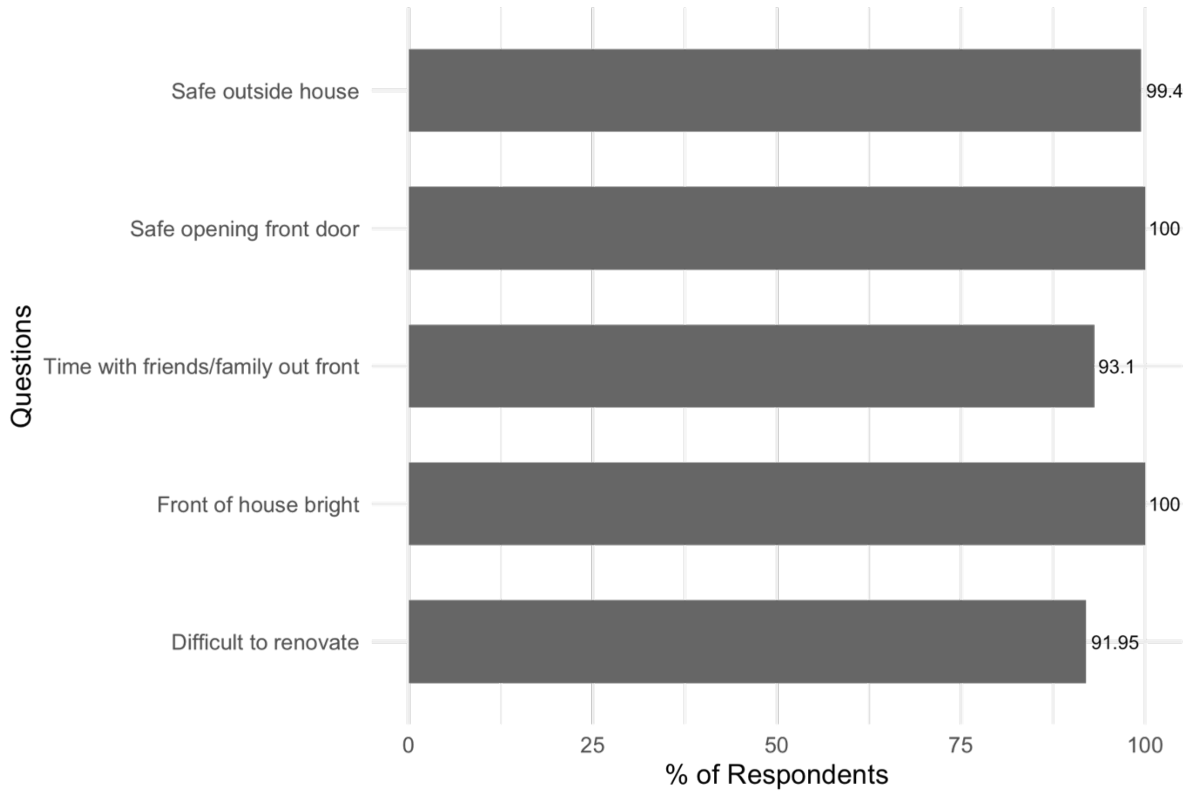


Figure 5. Opinions about the solar public light among the control group

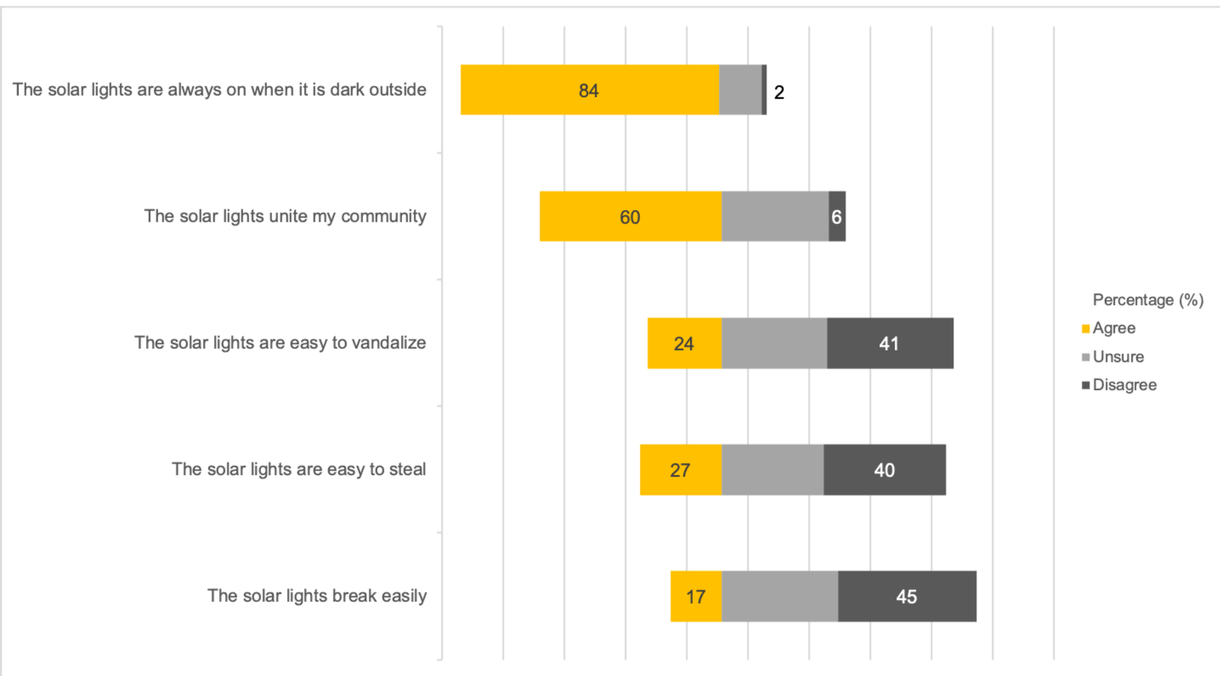


Table 7. Willingness to pay for a replacement solar public light

	Pay 180 ZAR	Pay 370 ZAR	Pay 550 ZAR
	(1)	(2)	(3)
Treat (=1)	-0.006	-0.091	-0.016
	(0.068)	(0.089)	(0.070)
(Intercept)	0.631***	0.564***	0.366***
	(0.042)	(0.059)	(0.047)
Adj. R^2	-0.005	0.002	-0.004
Num. obs.	191	152	212
Clusters	113	96	106

Note: Standard errors clustered at the level of randomization. Each respondent was asked to consider whether they would be willing to pay for a replacement light if their light was stolen or vandalized, at one of three randomly shown price points: 180 ZAR, 370 ZAR, 550 ZAR. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 8. Heterogeneous effects: Gender

	Path Lit	Inf. Sett Lit	Safe Inf. Sett. Day	Safe Inf. Sett. Night	Safe Path Day	Safe Path Night	Risk of Burglary	Night Activity Index	Toilet at Night	Front House Night	Exp. of Crime Index	Burglary
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A - Paths												
Treat (=1)	0.695***	0.061	0.092	0.091	0.114	0.101*	-0.065*	-0.258	-0.066	-0.016	0.083	0.035
	(0.065)	(0.070)	(0.077)	(0.055)	(0.071)	(0.054)	(0.034)	(0.345)	(0.073)	(0.068)	(0.115)	(0.050)
Female (=1)	0.069	-0.060	-0.042	-0.061	-0.016	-0.088**	0.005	-0.867***	-0.202***	-0.082	0.096	-0.004
	(0.042)	(0.059)	(0.063)	(0.039)	(0.064)	(0.036)	(0.020)	(0.303)	(0.061)	(0.052)	(0.093)	(0.036)
Treat*Female	-0.034	0.152*	0.022	-0.059	-0.054	0.008	0.039	0.443	0.025	-0.003	-0.208	-0.035
	(0.080)	(0.090)	(0.099)	(0.068)	(0.095)	(0.067)	(0.040)	(0.495)	(0.096)	(0.077)	(0.146)	(0.063)
(Intercept)	0.100***	0.276***	0.438***	0.162***	0.476***	0.152***	0.981***	5.162***	0.752***	0.305***	0.314***	0.076***
	(0.033)	(0.050)	(0.052)	(0.032)	(0.042)	(0.028)	(0.014)	(0.239)	(0.045)	(0.042)	(0.068)	(0.028)
Adj. R^2	0.455	0.024	0.005	0.016	0.002	0.029	0.013	0.019	0.034	0.002	-0.001	-0.004
Num. obs.	402	425	425	425	425	425	425	425	424	425	425	423
Clusters	112	112	112	112	112	112	112	112	112	112	112	112
Panel B - Compounds												
Treat (=1)	0.683***	-0.112	-0.206	-0.148	0.005	0.063	0.107	-0.771	-0.155	-0.189	-0.375**	-0.001
	(0.092)	(0.124)	(0.132)	(0.093)	(0.131)	(0.115)	(0.075)	(0.615)	(0.119)	(0.115)	(0.155)	(0.069)
Female (=1)	0.071	-0.192*	-0.257**	-0.107	-0.138	-0.046	0.141**	-0.598	-0.087	-0.208*	-0.134	0.055
	(0.095)	(0.113)	(0.123)	(0.079)	(0.114)	(0.097)	(0.062)	(0.487)	(0.117)	(0.112)	(0.173)	(0.075)
Treat*Female	-0.191	0.131	0.117	0.078	-0.057	-0.089	-0.165**	-0.217	-0.057	0.177	0.311	-0.031
	(0.119)	(0.151)	(0.155)	(0.097)	(0.141)	(0.122)	(0.076)	(0.759)	(0.151)	(0.139)	(0.222)	(0.100)
(Intercept)	0.174**	0.480***	0.680***	0.280***	0.600***	0.200**	0.840***	5.560***	0.760***	0.400***	0.480***	0.080
	(0.076)	(0.093)	(0.101)	(0.079)	(0.115)	(0.094)	(0.067)	(0.428)	(0.085)	(0.099)	(0.143)	(0.054)
Adj. R^2	0.323	0.000	0.031	0.006	0.008	-0.002	0.018	0.032	0.025	0.014	0.022	-0.014
Num. obs.	145	154	154	154	154	154	154	154	154	154	154	154
Clusters	49	50	50	50	50	50	50	50	50	50	50	50

Note: Standard errors clustered at the level of randomization. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 9. Heterogeneous effects: Distance from the nearest high-mast light

	Path Lit	Inf. Sett Lit	Safe Inf. Sett. Day	Safe Inf. Sett. Night	Safe Path Day	Safe Path Night	Risk of Burglary	Night Activity Index	Toilet at Night	Front House Night	Exp. of Crime Index	Burglary
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A - Paths												
Treat (=1)	0.549***	0.291**	-0.056	0.066	0.006	0.202**	-0.156***	1.026	0.086	0.196	-0.011	0.029
	(0.107)	(0.135)	(0.150)	(0.091)	(0.135)	(0.095)	(0.042)	(0.662)	(0.130)	(0.135)	(0.209)	(0.092)
Dist. to Nearest HML (m)	-0.000	0.003**	-0.002	-0.000	-0.002	0.001	-0.000	0.004	0.000	0.001	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.005)	(0.001)	(0.001)	(0.002)	(0.001)
Treat*Nearest HML	0.001	-0.002	0.002	-0.000	0.001	-0.001	0.001***	-0.011*	-0.001	-0.002*	-0.000	-0.000
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.000)	(0.007)	(0.001)	(0.001)	(0.002)	(0.001)
(Intercept)	0.149**	0.030	0.542***	0.130**	0.600***	0.058	1.008***	4.335***	0.617***	0.163	0.253	0.062
	(0.075)	(0.080)	(0.114)	(0.060)	(0.109)	(0.049)	(0.010)	(0.417)	(0.089)	(0.099)	(0.178)	(0.067)
Adj. R^2	0.454	0.032	0.009	0.000	0.005	0.018	0.024	0.001	-0.001	0.001	-0.004	-0.006
Num. obs.	401	424	424	424	424	424	424	424	423	424	424	422
Clusters	112	112	112	112	112	112	112	112	112	112	112	112
Panel B - Compounds												
Treat (=1)	0.744***	0.450*	-0.139	0.101	0.105	0.237	-0.021	-0.438	-0.164	-0.268	-0.646**	-0.348**
	(0.171)	(0.257)	(0.263)	(0.181)	(0.290)	(0.201)	(0.104)	(0.965)	(0.230)	(0.162)	(0.251)	(0.141)
Dist. to Nearest HML (m)	0.003**	0.003	-0.001	0.001	-0.001	0.001	-0.000	-0.004	-0.001	-0.003***	-0.002	-0.002**
	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.006)	(0.002)	(0.001)	(0.002)	(0.001)
Treat*Nearest HML	-0.002	-0.005*	0.000	-0.002	-0.001	-0.002	0.000	-0.004	-0.000	0.002	0.005*	0.003*
	(0.001)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)	(0.001)	(0.010)	(0.002)	(0.002)	(0.003)	(0.002)
(Intercept)	-0.052	0.022	0.589***	0.159	0.558**	0.034	0.956***	5.503***	0.835***	0.542***	0.620***	0.277***
	(0.140)	(0.180)	(0.148)	(0.151)	(0.209)	(0.137)	(0.086)	(0.576)	(0.137)	(0.113)	(0.182)	(0.081)
Adj. R^2	0.336	0.020	-0.006	0.007	-0.013	-0.007	-0.019	0.016	0.022	0.022	0.025	0.020
Num. obs.	145	154	154	154	154	154	154	154	154	154	154	154
Clusters	49	50	50	50	50	50	50	50	50	50	50	50

Note: Standard errors clustered at the level of randomization. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 10. Local Average Treatment Effects

	Front House Lit	Path Lit	Inf. Sett Lit	Safety Index	Safety Index (Short)	Safe Inf. Sett. Day	Safe Inf. Sett. Night	Safe Path Day	Safe Path Night	Safe Inside Day	Safe Inside Night	Risk of Burglary	Risk of Vandalism
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Panel A - Paths													
Endline Avg. Lux	0.055***	0.053***	0.012***	0.053**	0.017**	0.008**	0.005*	0.007	0.009***	0.003	0.006	-0.004**	0.000
	(0.007)	(0.007)	(0.004)	(0.025)	(0.008)	(0.004)	(0.003)	(0.004)	(0.003)	(0.003)	(0.004)	(0.002)	(0.003)
(Intercept)	0.087	0.021	0.215***	3.327***	1.071***	0.394***	0.116***	0.451***	0.082***	0.722***	0.429***	0.992***	0.917***
	(0.075)	(0.074)	(0.043)	(0.187)	(0.070)	(0.042)	(0.024)	(0.042)	(0.023)	(0.033)	(0.037)	(0.013)	(0.025)
First Stage Instrument													
Treatment	12.525***												
Robust St. Error	1.828												
F stat. for IV in First Stage	46.93***												
Adj. R^2	-0.081	-0.083	-0.034	-0.023	-0.027	-0.024	-0.005	-0.003	-0.009	-0.006	-0.003	-0.011	-0.003
Num. obs.	425	402	425	425	425	425	425	425	425	425	425	425	422
Clusters	112	112	112	112	112	112	112	112	112	112	112	112	112
Panel B - Compounds													
Endline Avg. Lux	0.047***	0.036***	-0.001	-0.001	-0.011	-0.006	-0.006	-0.000	0.002	0.001	0.006	-0.000	0.001
	(0.006)	(0.006)	(0.005)	(0.031)	(0.009)	(0.005)	(0.004)	(0.006)	(0.005)	(0.005)	(0.006)	(0.003)	(0.003)
(Intercept)	0.102	0.148*	0.352***	3.690***	1.334***	0.519***	0.219***	0.506***	0.166**	0.726***	0.377***	0.935***	0.893***
	(0.071)	(0.078)	(0.060)	(0.465)	(0.117)	(0.062)	(0.055)	(0.085)	(0.065)	(0.072)	(0.076)	(0.035)	(0.039)
First Stage Instrument													
Treatment	16.045***												
Robust St. Error	1.672												
F stat. for IV in First Stage	92.14***												
Adj. R^2	0.337	0.219	-0.009	-0.006	0.001	0.009	0.003	-0.007	-0.008	-0.008	-0.021	-0.007	-0.010
Num. obs.	154	145	154	154	154	154	154	154	154	154	154	154	152
Clusters	50	49	50	50	50	50	50	50	50	50	50	50	50

Note: Standard errors clustered at the level of randomization. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Table 10, Cont'd

	Night Activity Index	Night Act. Index (Short)	Toilet at Night	Friends/Family Night	Leave House Night	Front House Night	Leave House if Front Lit	Leave House if Inf. Sett. Lit	Exp. of Crime Index	Exp. Crime Index (Short)	Vandalism	Burglary
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A - Paths												
Endline Avg. Lux	0.000	0.001	-0.004	0.000	0.000	-0.001	0.020***	0.010**	-0.003	-0.004	-0.002	0.001
	(0.017)	(0.010)	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.006)	(0.004)	(0.001)	(0.002)
(Intercept)	4.667***	2.911***	0.647***	0.192***	0.352***	0.261***	0.121***	0.202***	0.375***	0.304***	0.045***	0.071***
	(0.160)	(0.095)	(0.036)	(0.027)	(0.039)	(0.032)	(0.042)	(0.036)	(0.058)	(0.044)	(0.017)	(0.020)
First Stage Instrument												
Treatment	12.525***											
Robust St. Error	1.828											
F stat. for IV in First Stage	46.93***											
Adj. R^2	-0.002	-0.002	0.002	-0.002	-0.002	-0.001	-0.013	-0.027	-0.005	-0.005	-0.016	0.001
Num. obs.	425	425	424	425	425	425	425	425	425	425	425	423
Clusters	112	112	112	112	112	112	112	112	112	112	112	112
Panel B - Compounds												
Endline Avg. Lux	-0.049**	-0.023*	-0.011*	-0.006	0.004	-0.004	0.010*	0.006	-0.012*	-0.011**	-0.002	-0.002
	(0.021)	(0.013)	(0.006)	(0.004)	(0.005)	(0.004)	(0.005)	(0.005)	(0.007)	(0.005)	(0.002)	(0.004)
(Intercept)	5.251***	3.137***	0.722***	0.259***	0.265***	0.268***	0.189***	0.236***	0.414***	0.293***	0.055*	0.120***
	(0.256)	(0.168)	(0.062)	(0.049)	(0.059)	(0.056)	(0.054)	(0.057)	(0.074)	(0.064)	(0.029)	(0.036)
First Stage Instrument												
Treatment	16.045***											
Robust St. Error	1.672											
F stat. for IV in First Stage	92.14***											
Adj. R^2	0.019	0.016	-0.046	0.024	-0.017	-0.022	0.019	-0.006	-0.034	-0.008	-0.014	-0.020
Num. obs.	154	154	154	154	154	154	154	154	154	154	153	154
Clusters	50	50	50	50	50	50	50	50	50	50	50	50

Note: Standard errors clustered at the level of randomization. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 11. "Border" group effects on endline outcomes of interest

	Average Lux	Front House Lit	Path Lit	Inf. Sett Lit	Safety Index	Safe Inf. Sett. Day	Safe Inf. Sett. Night	Safe Path Day	Safe Path Night	Risk of Burglary	Risk of Vandalism
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
					Panel A - Paths						
Treat (=1)	13.321***	0.707***	0.702***	0.163***	0.699**	0.067	0.046	0.081	0.103**	-0.024	-0.013
	(1.715)	(0.042)	(0.043)	(0.057)	(0.326)	(0.054)	(0.040)	(0.060)	(0.041)	(0.022)	(0.044)
Border (=1)	5.870***	0.366***	0.333***	0.060	0.575	0.087	0.070	0.142**	0.128***	-0.041	0.034
	(1.166)	(0.072)	(0.068)	(0.051)	(0.379)	(0.068)	(0.050)	(0.067)	(0.043)	(0.027)	(0.035)
(Intercept)	2.132*	0.212***	0.135***	0.241***	3.389***	0.419***	0.123***	0.448***	0.089***	0.980***	0.916***
	(1.224)	(0.034)	(0.030)	(0.033)	(0.145)	(0.030)	(0.021)	(0.036)	(0.017)	(0.011)	(0.024)
Adj. R^2	0.347	0.388	0.390	0.020	0.011	0.001	0.002	0.008	0.021	0.003	-0.001
Num. obs.	422	422	399	422	422	422	422	422	422	422	419
Clusters	112	112	112	112	112	112	112	112	112	112	112
					Panel B - Compounds						
Treat (=1)	15.459***	0.716***	0.610***	-0.045	-0.391	-0.160	-0.098	-0.059	0.003	0.032	-0.022
	(1.666)	(0.076)	(0.081)	(0.093)	(0.581)	(0.100)	(0.068)	(0.113)	(0.089)	(0.047)	(0.046)
Border (=1)	10.093***	0.372**	0.270**	-0.043	-0.479	-0.063	-0.070	-0.004	-0.082	0.025	0.025
	(3.671)	(0.151)	(0.134)	(0.085)	(0.644)	(0.105)	(0.075)	(0.108)	(0.087)	(0.070)	(0.041)
(Intercept)	1.852*	0.217***	0.214***	0.367***	3.950***	0.533***	0.217***	0.533***	0.200***	0.917***	0.917***
	(0.927)	(0.064)	(0.071)	(0.052)	(0.491)	(0.066)	(0.055)	(0.091)	(0.071)	(0.039)	(0.031)
Adj. R^2	0.458	0.400	0.283	-0.011	-0.007	0.007	0.001	-0.010	-0.005	-0.010	-0.010
Num. obs.	153	153	144	153	153	153	153	153	153	153	151
Clusters	50	50	49	50	50	50	50	50	50	50	50

Note: Standard errors clustered at the level of randomization. The reference category is the control group. ***p < 0.01; **p < 0.05; *p < 0.1.

Table 11, Cont'd.

	Night Activity Index	Toilet at Night	Friends/Family Night	Leave House Night	Front House Night	Leave House if Front Lit	Leave House if Inf. Sett. Lit	Exp. of Crime Index	Vandalism	Burglary
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A - Paths										
Treat (=1)	0.164	-0.080	0.014	0.001	-0.006	0.237***	0.134**	-0.034	-0.027*	0.026
	(0.242)	(0.057)	(0.040)	(0.048)	(0.048)	(0.047)	(0.055)	(0.079)	(0.016)	(0.030)
Border (=1)	0.013	0.012	-0.035	0.041	-0.027	0.158**	0.113*	-0.003	0.038	0.032
	(0.276)	(0.050)	(0.045)	(0.060)	(0.053)	(0.061)	(0.060)	(0.103)	(0.033)	(0.039)
(Intercept)	4.601***	0.639***	0.192***	0.345***	0.256***	0.167***	0.212***	0.365***	0.034**	0.064***
	(0.146)	(0.032)	(0.023)	(0.035)	(0.028)	(0.025)	(0.028)	(0.054)	(0.014)	(0.019)
Adj. R^2	-0.004	0.002	-0.003	-0.004	-0.004	0.053	0.015	-0.004	0.011	-0.002
Num. obs.	422	421	422	422	422	422	422	422	422	420
Clusters	112	112	112	112	112	112	112	112	112	112
Panel B - Compounds										
Treat (=1)	-0.807**	-0.157	-0.131*	0.072	-0.006	0.206**	0.106	-0.247*	-0.049	-0.032
	(0.399)	(0.101)	(0.076)	(0.088)	(0.048)	(0.086)	(0.083)	(0.125)	(0.036)	(0.076)
Border (=1)	-1.220***	-0.187*	-0.166**	0.057	-0.027	0.081	0.090	-0.198	-0.037	-0.075
	(0.331)	(0.094)	(0.074)	(0.096)	(0.053)	(0.085)	(0.085)	(0.127)	(0.042)	(0.051)
(Intercept)	5.367***	0.717***	0.283***	0.267***	0.256***	0.183***	0.233***	0.433***	0.067**	0.133***
	(0.256)	(0.056)	(0.049)	(0.061)	(0.028)	(0.050)	(0.058)	(0.079)	(0.032)	(0.037)
Adj. R^2	0.032	0.016	0.019	-0.008	-0.004	0.029	-0.002	0.021	0.000	-0.005
Num. obs.	153	153	153	153	422	153	153	153	152	153
Clusters	50	50	50	50	112	50	50	50	50	50

Note: Standard errors clustered at the level of randomization. The reference category is the control group. ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

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