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Eclipse: How Darkness Shapes Violence in Africa

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Abstract

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Keywords: Eclipse, Darkness, Violence, Conflict, Africa, Natural experiment

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On 9 January 2001, when the Earth cast a shadow on the surface of the Moon, darkness covered Nigeria, including the city of Maiduguri in the north. While many people enjoyed watching the celestial event, the eclipse precipitated an unexpected outcome—violence. Hundreds of Muslim youth poured into Maiduguri, blaming the eclipse for "what they call the preponderance of sinful activities in the city" and burning down over 40 buildings (Phillips 2001). Shocked by the event, the Nigerian government issued official warnings (Palmer 2001). Prior to the next solar eclipse in 2006, a deputy police commissioner of the Gombe State "enjoined people not to panic or resort to violence, stressing that the solar eclipse was a natural phenomenon and had nothing to do with moral decadence in society" (News 24 2006).

What are the effects of eclipses on political violence? Do eclipses really drive people to violence? If so, why? Although the claim that eclipses cause violence may appear extraordinary, eclipses have been historically linked to violence, such as "the Battle of the Eclipse" between Lydians and Medes in Herodotus's *Histories,* Athen's expedition of Syracuse recorded by Thucydides, the Battle of Gaugamela by Alexander the Great, Pannonian Mutiny under the Roman Empire, the succession wars after the fall of Charlemagne, Ottoman's Conquest of Constantinople, the Battle of Tippecanoe during the American Indian Wars, and the Zulu War against the British Empire (Micah 2016; Steel 2001). Despite these examples, theories and evidence on how eclipses cause violence remain speculative. It is unclear how the standard frameworks—such as grievance theses (Gurr 1970), collective action theories (Tullock 1971), contentious politics approach (McAdam, Tarrow, and Tilly 2001), bargaining models (Fearon 2004), and territorial control (Kalyvas 2006)—explain the eclipse-led violence.

In this paper, I theorize potential pathways through which eclipse-induced darkness affects violence, and provide the first causal evidence regarding the "eclipse effect" on violence.

Expanding on anecdotal stories and psychological theories,[1] I hypothesize that the darkness causes violence by triggering a feeling of fear, which in turn incites violence against outgroups. Indeed, eclipses are interpreted as a sign of misfortune by many societies, reinforcing the psychological effects (Berezkin 2015).

However, eclipses can also spur violence by changing the tactical environments of insurgent groups. Eclipses induce darkness and limit visibility. As suggested in criminology and other studies,[2] limited visibility allows insurgent groups to hide their identities and covertly attack people. More importantly, unlike other dark environments (e.g., night and light outages), eclipses gather people, creating an easy target for violence. Despite the short duration, therefore, solar eclipses create a window of opportunity for insurgents to attack civilians.

I test those hypotheses through a series of natural experiments. I first establish the "eclipse effect" by exploiting the exogenous variations in the dates and locations of 26 solar eclipses across 49 African countries for the period 1997–2022. This study focuses on Africa as there exists substantial variation in the cultural interpretations of eclipses, which allows me to examine the roles of cultural and psychological factors (Berezkin 2015; Litina and Roca Fernández 2024; Michalopoulos and Xue 2021). The prevalence of insurgent violence also enables me to examine

[1] Li et al. (2015), Page and Moss (1976), Schaller, Park, and Mueller (2003), Steidle, Hanke, and Werth (2013), Steidle and Werth (2013, 2014), Steidle, Werth, and Hanke (2011), Wennekers et al. (2012), Zhong, Bohns, and Gino (2010).

[2] Chalfin et al. (2022), Chalfin, Kaplan, and LaForest (2022), Condra et al. (2018), Coupe and Blake (2006), Doleac and Sanders (2015), Domínguez and Asahi (2023), Tealde (2022), Toro, Tigre, and Sampaio (2019), Welsh and Farrington (2008).

the tactical dynamics (Raleigh, Linke, and Dowd 2014).[3] The analysis indicates a spike in the number of violence against civilians on the days of solar eclipses. Moreover, the effect size is not negligible; for average observations, eclipses increased the likelihood of violence by over 36%. Extensive analyses of robustness suggest that the finding is unlikely to be a false positive.

What then makes eclipses deadly? To answer the question, I disaggregate the violent events to their initiators and even to the *original texts* describing the events, finding that the main results are primarily driven by organized but covert armed groups such as "unidentified militias," instead of communal, religious, ethnic, tribal, and governmental groups. Moreover, the analysis of weather conditions during eclipses indicates that the effect is particularly large on *cloudy* days. Although clouds make eclipses less visible, they block out the remaining sunlight, and thus, further limits visibility. In other words, while clouds prevent superstitious people from observing eclipses, they provide even better tactical environments for insurgent groups. Overall, these findings are consistent with the tactical rather than psychological explanation.

However, it is still possible that psychological and cultural mechanisms play a role in a subset of the sample. To account for this possibility, I examine whether the effect depends on the prevailing ethnic folklore regarding eclipses (Berezkin 2015; Michalopoulos and Xue 2021). To establish causality, I exploit the fact that ethnic groups that were historically exposed to a larger number of eclipses tend to have more folklore about eclipses. However, the analysis provides no

[3] Another interesting case is the Middle East, where insurgent violence is prevalent while Islamic religion is predominant and thus the variation is limited in terms of cultural interpretation. India and South East Asia are also insightful given the religious and cultural diversity, while insurgent violence is not as prevalent as in Africa or the Middle East.

evidence that the effect depends on the existence of eclipse folklore. Furthermore, the analysis of individual-level surveys provides no definite evidence that eclipses directly affected people's feelings of insecurity, hostility toward outgroups, or trust in ingroup leaders. Thus, despite the extensive analyses, I find almost no evidence for the psychological or cultural explanation, and the results remain consistent with the tactical explanation.

These findings highlight the crucial role of darkness in political violence. Although darkness has long been associated with insecurity in human history (Edwards 2019), and scholars in other fields have extensively analyzed how darkness affects crimes and aggressive behavior,[4] conflict scholars have mostly ignored it.[5] Given the renewed attention on other tactical features (T. A. Carter and Veale 2013), such as rugged terrain (D. B. Carter, Shaver, and Wright 2019), rainfall (Kikuta 2023a, 2023b), temperature (van Weezel 2020), and natural resources (Aronson et al. 2024; Denly et al. 2022), this void of knowledge must be filled. To this end, eclipses provide a unique opportunity. In many conflict countries, street lights are limited to urban areas, and daylight-saving time has not been implemented in Africa except for Egypt. These features would otherwise make it difficult to identify the causal effects of darkness.[6] By examining eclipse-

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[4] See footnote 2 for references.

[5] An exception is Condra et al. (2018), who use the nighttime cloud cover as an instrumental variable for electoral violence in Afghanistan. However, they use the darkness only as an instrumental variable, providing no dedicated theories or detailed analyses. Carter and Veale (2013) analyze the effects of visibility but examine fogs and dusts.

[6] A simple comparison of violence during daytime and nighttime does not allow us to identify the causal effect of darkness, as they are confounded by time (Schafer and Holbein 2020). Similarly,

induced darkness, this study shows how a seemingly innocuous event—an eclipse—affects political violence by altering tactical conditions.

Moreover, among other darkness-inducing events (e.g., night and light outages), eclipses are arguably the least politically relevant, allowing me to examine the roles of (ir)rationality in political violence. In an attempt to understand the limitations of people's rationality, scholars have analyzed how politically irrelevant events,[7] such as shark attacks (Achen and Bartels 2017), college football (Healy, Malhotra, and Mo 2010), and U.F.O. sightings (Kitamura 2022), affected public opinions in the U.S.,[8] and the framework has recently been extended to soccer and conflict in Africa (Kikuta and Uesugi 2023). Nevertheless, conflict studies remain dismissive of irrationality.[9] Scholars continue to believe that political violence is not "irrational, random, or the

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I cannot compare locations with and without street lights, as they are confounded by urbanization and other features. Criminological studies address these problems by using daylight saving time and light outages (see footnote 2 for references).

[7] A politically irrelevant event is one that does not provide any objective information about politics.

[8] The validity of the results is still debated (Achen and Bartels 2018; Ashworth, Bueno de Mesquita, and Friedenberg 2018; Busby and Druckman 2018; Busby, Druckman, and Fredendall 2016; Fowler and Hall 2016; Fowler and Montagnes 2015, 2023; Graham et al. 2023b, 2023a; Healy and Malhotra 2013; Healy, Malhotra, and Mo 2015).

[9] Irrationality refers to a belief that does not follow the Bayesian update (Ashworth, Bueno de Mesquita, and Friedenberg 2018), including misperception, psychological biases, and cultural interpretation. Politically irrelevant events, for instance, should not affect rational people's evaluation of politicians, as those events provide no objective information. Even though Ashworth

result of ancient hatreds between ethnic groups" (Valentino 2014, 91; Balcells and Stanton 2021), although this assertion is yet to be subjected to rigorous analysis.[10] This runs counter to the continued attention being paid to the behavioral aspects of economics (Kamenica 2012), politics (Wilson 2011), and international relations (Hafner-Burton et al. 2017; Kertzer and Tingley 2018). By examining eclipses, this study shows how seemingly subtle changes in the amount of light can shape psychological and tactical conditions for political violence.

Indeed, previous studies have shown that eclipses have influenced human history. These studies have examined how eclipses sparked curiosity, complex thinking, and social complexities in Africa (Litina and Roca Fernández 2024); eclipses prompted the invention of the mechanical clock and printing press, thus facilitating the spread of Protestantism in Europe (Boerner, Rubin, and Severgnini 2021); and eclipses diminished the legitimacy of Chinese dynasties, triggering peasant uprisings (Miao, Ponticelli, and Shao 2021; Sun and Li 2023). Additionally, a few studies have shown that moderate earthquakes, which were perceptible but resulted in no real damage, deteriorated the governments' legitimacy in Imperial China and Italian city-states (Bai 2023;

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et al. (2018) claim that events such as natural disasters are politically relevant, they admit that others such as football games are genuinely irrelevant.

[10] The assertion is based on correlational and anecdotal evidence (see studies cited by Valentino 2014). By contrast, several studies have used more rigorous approaches and found that irrationality, culture, and ancient hatred are important, if not sufficient, drivers of violence (see Depetris-Chauvin, Durante, and Campante 2020; Lowes and Montero 2021; Michalopoulos and Papaioannou 2016; Moscona, Nunn, and Robinson 2020; Nunn 2007; Zhang, Xu, and Kibriya 2021 among many others).

Belloc, Drago, and Galbiati 2016). Although these studies indicate the critical roles of eclipses and other politically irrelevant events in human history, it is uncertain whether those findings can be extended to the contemporary era.[11] Moreover, previous studies tend to assume, rather than analyze, the causal mechanisms, partly due to the lack of fine-grained historical data. This study addresses those limitations by extensively analyzing the causal mechanisms. My findings indicate that although eclipses continue to bring sizable changes, the mechanism differs; superstition plays only a marginal role, at least in violence, and eclipses cause violence by altering the tactical environments of insurgent groups.

Theory: Psychological and Tactical Explanations

Peter J. Huber—a statistician known for his contribution to the heteroskedasticity-robust standard errors (i.e., Huber-White standard errors)—discovered that major historical events coincided with eclipses. By back-calculating the dates of eclipses, Huber (1987) demonstrated that they correlated with major historical events such as the fall of the Akkad dynasty. Although his calculation was imprecise, Micah (2016) reviewed the history of eclipses and proposed a weaker corollary: "an eclipse may precipitate conflict" (100). Steel (2001) suggested that the hypothesis could be extended to the present world, referring to the case of Maiduguri in Nigeria. Although these studies rely on correlational and anecdotal evidence, we cannot reject their propositions without empirical evidence. But why would we think that eclipses cause violence?

[11] A few studies have analyzed how eclipses affect the moods and other psychological conditions in contemporary China and U.S. (Chen 2021; Goldy, Jones, and Piff 2022).

Psychological Explanation

From a psychological standpoint, eclipses cause violence by stirring a feeling of fear. In fact, it is frequently mentioned that "many people associate misfortunes or calamities in their lives with occurrence of eclipses" (Wuam and Shehu 2022, 356; see also; Oruru et al. 2020, 2021; Steel 2001; Tennakone 2018). Eclipses block sunlight and moonlight, suddenly darkening the scenery. As psychological studies report, darkness gives rise to feelings of isolation and anonymity, which in turn induce fear (Li et al. 2015), hostility toward outgroups (Schaller, Park, and Mueller 2003; Wennekers et al. 2012), trust in ingroups (Steidle, Hanke, and Werth 2013), and even aggressive behavior (Page and Moss 1976), while making people more risk-taking, disinhibited, and selfish (Steidle and Werth 2013, 2014; Zhong, Bohns, and Gino 2010). Thus, it is not surprising that eclipses and the resultant darkness panic people and drive them to attack outgroups.

Furthermore, eclipses can result in negative contact between diverse social groups (i.e., negative contact hypothesis in social psychology; Barlow et al. 2012; Chung and Rhee 2022; Paolini, Harwood, and Rubin 2010). Muslims, for instance, consider eclipses as divine moments and quietly pray (Musharraf and Dars 2021). Hausa and other ethnic groups make loud noises (e.g., beat drums) to drive away evil from the Sun and Moon (Oruru et al. 2020, 2021; Urama 2008; Wuam and Shehu 2022). Secular people and foreign tourists enjoy the celestial events often with snacks, music, and alcohol (Tennakone 2018). These different reactions indicate a potential for negative contact; the loud noises and alcohol consumption, for instance, may irritate Muslims. The negative contact strengthens hostility toward outgroups and incites aggression.

These psychological effects are reinforced by the cultural interpretations of eclipses. In fact, eclipses are almost exclusively interpreted as a negative event across the world (Musharraf and Dars 2021; Steel 2001; Tennakone 2018). Eclipses are interpreted either as (i) creatures, monsters, demons, or heinous animals (e.g., crows and bats) eating, attacking, or hiding the Sun and Moon, (ii) the Sun and Moon fighting with each other, or (iii) God's punishment or the apocalypse (Berezkin 2015; Michalopoulos and Xue 2021).[12] These negative images reinforce the psychological impacts of eclipses, heightening the feeling of fear.

The fear, in turn, motivates people to take hostile attitudes toward outgroups. Tajfel (1982; 2010) shows that fear increases hostility toward outgroups while bolstering the unity of ingroups. The outgroup hostility and ingroup favoritism lower the subjective costs for violence and make it easier for ingroup leaders to mobilize people. This ingroup-outgroup dynamics is illustrated by the violence at Maiduguri, where Muslims misattributed the eclipse to the "sinful activities" of Christians (Phillips 2001). Thus, psychological and cultural theories predict that eclipses increase violence, especially against outgroups, including communal, ethnic, and religious violence.

Tactical Explanation

A different strand of literature—criminology—provides an alternative explanation; eclipses cause violence by changing the tactical environment of perpetrators. The eclipse-induced darkness allows perpetrators to hide their identities and covertly attack targets. In fact, darkness—measured by street lights and daylight-saving time—is shown to increase crimes in general (Chalfin et al. 2022; Welsh and Farrington 2008), and homicides (Arvate et al. 2018; Toro, Tigre, and Sampaio 2019), robberies (Chalfin, Kaplan, and LaForest 2022; Doleac and Sanders 2015; Domínguez and

[12] An exception is folklore that depicts eclipses as romantic trysts of the Sun and Moon. This type of folklore is very rare and has not been reported in Africa. Although Abrahamic religions, such as Christianity and Islam, deny these superstitions (Wuam and Shehu 2022), they are adapted to the local cultures in Africa (Oruru et al. 2020, 2021; Urama 2008; Wuam and Shehu 2022).

Asahi 2023; Tealde 2022), and burglaries (Coupe and Blake 2006), specifically. Thus, in contrast to the psychological explanation, which focuses on the *motivation* for violence, the tactical explanation emphasizes *opportunities* for violence.

A similar argument can be made for insurgent groups in Africa, who tend to rely on unconventional tactics (e.g., guerilla warfare; Kalyvas and Balcells 2010). Indeed, as suggested by previous studies (Collier and Hoeffler 2004; Gleditsch and Ruggeri 2010; McAdam, Tarrow, and Tilly 2001 among many others), while insurgents have various motivations (e.g., looting, extortion, and punishing enemy supporters), they use violence only under feasible tactical environments. By hiding their identities, insurgents can mitigate the risks of retaliation and counterinsurgency (D. B. Carter, Shaver, and Wright 2019; T. A. Carter and Veale 2013; Condra et al. 2018; Kalyvas 2006). Secrecy also minimizes the damage to their popularity among local citizens (i.e., people cannot blame the groups for violence), which is particularly important when insurgents rely on local support (Krcmaric 2019; see also Balcells and Stanton 2021 for review). Furthermore, insurgents can use eclipses as focal points to coordinate their actions (Ketchley and Barrie 2020).

However, given the short duration of eclipses,[13] more important is the fact that people come together and collectively experience the celestial events. People travel to observe eclipses. Muslims also attend communal prayer (i.e., Eclipse Prayer). Although people take precautionary measures against nighttime crimes (Coupe and Blake 2006),[14] people's responses to eclipses can

[13] See footnote 15 for the distribution of eclipse durations in the sample.

[14] See footnote 2 for references. Another possibility is the deployment of police or military forces. In Africa, where the state capacity is often limited, police or military forces are rarely deployed during eclipses. As I later explain, the case of Maiduguri in Nigeria is a rather exceptional case.

be less cautious. Because eclipses are rare, people are not accustomed to anticipating violence. The rarity of solar eclipse observations—often considered "once in a lifetime"—also makes people discount security risks. The presence of unguarded crowds, therefore, constitutes another, and perhaps more important, tactical opportunity: abundant targets for violence.

These tactical opportunities—concealment and targets—incentivize insurgents to use violence. Although their motivation may substantially differ, the tactical opportunities are likely to lead to a short-term increase in violence. Because only insurgent groups can enjoy these tactical advantages, eclipses are likely to increase those groups' violence. Moreover, civilians are particularly susceptible to violence, as they may go outside without much caution. In contrast, governments and other armed groups rarely put aside their weapons to observe eclipses. They may even anticipate insurgents' attacks and take preventive measures, canceling out the insurgents' tactical advantages. Thus, from the tactical perspective, eclipses increase violence against civilians by insurgent groups.

Null Expectations

Notwithstanding these predictions, the conventional belief is that "eclipses of the sun and moon are … irrelevant to other affairs of the society" (Tennakone 2018, 25). Although eclipses may evoke fear, they may not cause hostility or aggression against outgroups. Similarly, citizens may anticipate eclipse-induced violence and take precautionary measures. A government may issue warnings and deploy police and military forces. These measures can diminish the tactical opportunities for violence. Finally, psychological and criminological studies predominantly focus on the U.S., raising concerns about generalizability. Therefore, the theoretical relationship between eclipses and violence is indeterminate, and thus, I subject it to empirical analysis. Table 1 summarizes the hypotheses. To be clear, the psychological and tactical explanations are not mutually exclusive.

Table 1. Predicted Effects of Eclipses on Violence

	The effect of eclipses on violence	Relevant types of violence
Null expectations	0	
Psychological explanation	↑	Communal, religious, ethnic violence
Tactical explanation	↑	Violence against civilians by insurgents

The table summarizes the predicted effects of eclipses on violence. ↑ refers to an increase in violence, and 0 refers to no effect.

Design: Natural Experiments with Solar Eclipses

I evaluate the null expectation against the alternative hypotheses by estimating the "eclipse effect." To this end, I leverage exogenous variation in the dates and locations of solar eclipse observations. A solar eclipse occurs when the Moon passes between the Earth and the Sun, and thus, blocks the sunlight. Although total solar eclipses can be observed only for a few minutes, the entire duration can be several hours (Steel 2001).[15] Solar eclipses are subject to multiple cycles of the same intervals (6,585 days) but with different starting dates.[16] Combining all of those cycles, solar eclipses occur between two to five times per year across different locations on the Earth. Although solar eclipses are not infrequent, they are observable only from specific locations. The paths of totality usually span 100–150 km, whereas partial eclipses are observed across broader areas

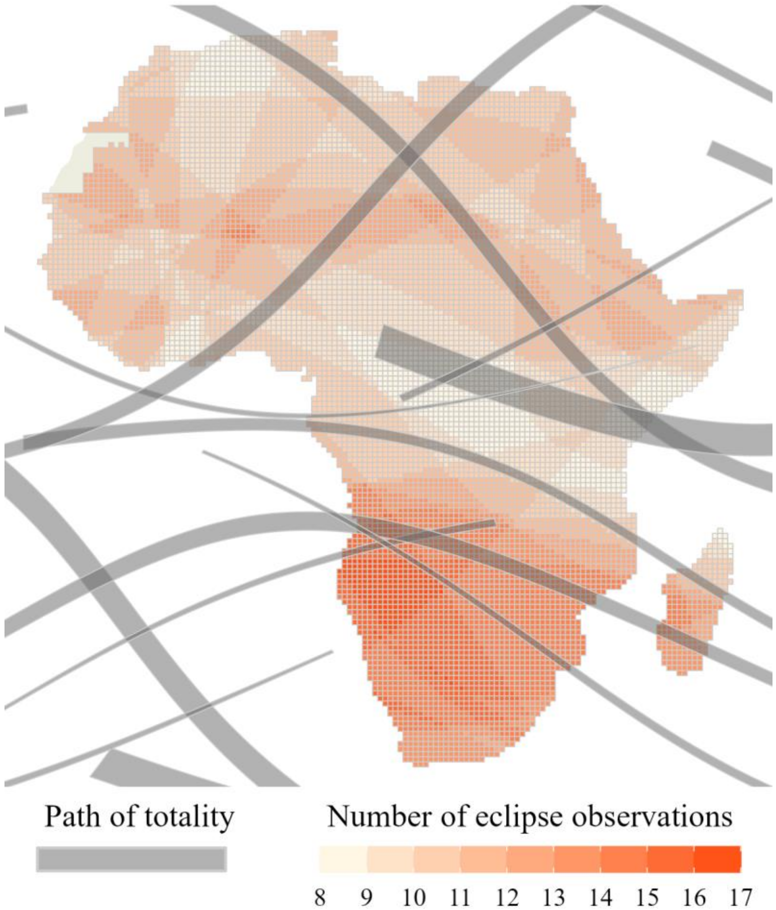
[15] In my sample, the average duration of solar eclipses is 2.03 hours with the 95% percentile range of 0.56 to 3.38 hours. The duration of total solar eclipses is only a few minutes.

[16] Currently (2023-12-14), about 40 cycles are active.

(radius of 3,000–3,500 km). Within each cycle, the path of totality shifts from the prior event's path to one about 115 degrees to the west and four degrees to the south or north. Thus, even though the dates and locations of eclipse observations are not random and indeed circular, they are "as-if" random due to the multiplicity of the cycles and exogenous to human behavior.[17] Figure 1 shows the paths of totality and the number of eclipse observations (both total and partial) in Africa for 1997–2022.

[17] Although the dates of solar eclipses are orthogonal to the Gregorian calendar, they perfectly correlate with the dates of the Islamic calendar; solar eclipses occur only at the end of a month. I later check the robustness by extending the pre-treatment period to 30 days before eclipses and adding fixed effects for Islamic calendar days.

Figure 1. Solar Eclipses in Africa, 1997–2022



The figure shows the paths of totality (yellow areas) and the number of eclipse observations (including both total and partial eclipses) in Africa, 1997–2022.

I focus on solar eclipses in the main paper and present the analyses on lunar eclipses in the appendix. A lunar eclipse occurs when the Earth passes between the Sun and the Moon and blocks the sunlight cast on the Moon. Lunar eclipses occur approximately twice a year, and can be observed *anywhere in the night hemisphere*. This means that lunar eclipses perfectly correlate with time differences and have much smaller cross-sectional variation. In my study period, 43 out of 67 lunar eclipses were observed in more than 96% of Africa. Moreover, as Litina and Fernandez (2024) argued, lunar eclipses are less salient; they are more frequently observed and thus, less impressive, they occur at night and can go unnoticed by people, and moonlight is over 400,000 times weaker than sunlight. Thus, despite the anecdotal evidence, it would not be surprising if lunar eclipses have no tangible effect (I will re-examine the anecdote in the conclusion).

One challenge for causal identification is anticipatory behavior. Because eclipses are predictable, people and armed groups may exhibit anticipatory behavior. Insurgent groups, for instance, may prepare and thus, become less active before an eclipse. Eclipse observers also move and lodge in advance and thus can be exposed to violence even before an eclipse. To account for this problem, I use difference-in-differences (DiD) and, more importantly, event study. That is, in addition to cross-sectional variation, I also compare the changes in violence before and after eclipses. This allows me to account for any static confounders (e.g., latitude and geography). As DiD cannot account for anticipatory behavior, I also graphically show the effect of eclipses for each day before and after, and thus, empirically assess whether there are anticipatory changes.

Sample

The unit of analysis is grid-cell i on t days before or after solar eclipse j. Following the convention, I use the PRIO-GRID cells (Tollefsen, Strand, and Buhaug 2012), which span 0.5 decimal degrees (about 55 km). The sample includes 10,549 cells across Africa. I remove West Sahara, where the outcome variable is unavailable. Because the violence data are available only at daily or higher levels, I use the day as a temporal unit. Since eclipses should only have immediate effects, I include one week before and after eclipses (i.e., $t \in [-7, 7]$), though the results are nearly identical for longer time periods.[18] Finally, because the outcome variable is available only after 1997, I analyze 26 solar eclipses that were observed anywhere in Africa between 1997 and 2022.

[18] I later check the robustness with different time windows of the pretreatment period.

Outcome Variable

The outcome variable y_{ijt} comprise the incidence of violence ($violence_{ijt}$; main), battles among governments and rebels ($battle_{ijt}$), and peaceful protests ($protest_{ijt}$). I analyze the effects on $battle_{ijt}$ and $protest_{ijt}$ as references. The data are derived from the ACLED (Raleigh, Linke, and Dowd 2014). The main outcome variable, $violence_{ijt}$, includes any violence other than battles (e.g., violence against civilians by governments and armed groups, communal violence, and riots; I later disaggregate the event types). The outcome variables take 1 if there is any violence, battle, or protest in cell i t days after eclipse j.[19] The sample contains 4,098, 12,036, and 13,331 incidences of violence, battles, and protests, respectively.

Compared to the UCDP GED (Croicu and Sundberg 2012) and SCAD (Hendrix and Salehyan 2013), the ACLED contains a larger number of events and, more importantly, provides the *original texts* describing the events.[20] This allows me to disaggregate the events to the original texts, and thus, explore the mechanisms. Although these datasets are based on media reports, and thus, subject to reporting biases (Parkinson 2023), "as long as the measurement error is uncorrelated with the independent variables, measurement error in the dependent variable is not particularly problematic in a standard regression framework other than increasing the uncertainty around the estimates we obtain" (Weidmann 2016, 208). To be sure, I also examine the effects on $battle_{ijt}$ and $protest_{ijt}$, which are not directly relevant to my theory but can similarly be influenced by reporting biases.

[19] I later check the robustness with different measurements of the outcome variables (e.g., count).

[20] The SCAD has not been updated since 2018, and the UCDP GED mostly focuses on countries in armed conflict. I later conduct robustness checks with these datasets.

Ideally, I would like to use *hourly* data to analyze violence during solar eclipses. However, to the best of my knowledge, there is no such data in Africa. Exceptions exist only outside Africa, such as in Afghanistan and Iraq, where the U.S. collected fine-grained data (Condra et al. 2018). However, the data are still classified and inaccessible outside the U.S. The replication data of Condra et al. (2018) contain only times around the elections at a subnational level. Wikileaks data are currently inaccessible (as of 2024-01-05) and have ethical issues. Data on the Vietnam War do not contain hourly information (Kalyvas and Kocher 2009). Most of the original event stories in ACLED contain only daily information (see Table A15-1 for example). Thus, while admitting the limitation, this study focuses on daily changes. This allows me to analyze the entire African continent, fortifying the external validity of this study.

Treatment Variables

The treatment variable $eclipse_{ij}$ takes 1 if eclipse j is observable in cell i (including total and partial eclipses). For simplicity, I ignore eclipse magnitudes and weather conditions in the main analysis, leaving them to a later mechanism check.[21] The data are computed from Astronomy Engine in Python (Cross 2023). Although previous studies have used the datasets pre-compiled by Jubier (2023) and others, these datasets contain only paths of totality and their dates, making it difficult to account for partial eclipses, eclipse magnitudes, hourly changes in weather, and other characteristics of eclipses (Boerner, Rubin, and Severgnini 2021; Litina and Roca Fernández 2024; Miao, Ponticelli, and Shao 2021; Sun and Li 2023). This study addresses these limitations by

[21] As I later explain, the psychological and tactical explanations make different predictions about weather during eclipses. Similarly, as I later explain, measuring eclipse magnitude is not trivial and requires additional functional-form assumptions.

compiling an original dataset, which contains all relevant information on eclipses, such as obscuration rates (i.e., the fraction of the Sun's surface shaded by the Moon), the Sun's altitudes, and start, peak, and end times of eclipse observations. I compute the maximum obscuration of an eclipse observed in each location and dichotomize it, $eclipse_{ij} = I(obscuration_{ij} > 0)$, where I is an indicator function.[22] About 37% of the cells are treated.[23] Another treatment variable $after_t$ takes 1 for $t \geq 0$ (a day of an eclipse or later), otherwise 0.

Specification

With these variables,[24] I use double differences to estimate the average treatment effects on the treated (ATT):

$$100\, y_{ijt} = \alpha + \beta_1\, eclipse_{ij} + \beta_2\, after_t + \delta\, eclipse_{ij} \times after_t + \varepsilon_{ijt} \quad \text{for } t \in [-7, 0] \tag{1}$$

DiD only considers the immediate effects at $t = 0$, leaving the analysis of later periods $t \in [1, 7]$ to the event study.[25] The outcome variable is the incidence of events $y_{ijt} \in \{violence_{ijt}, battle_{ijt}, protest_{ijt}\}$.[26] Since the righthand side of (1) contains only dichotomous treatment variables and their interaction, the model is saturated and literally "difference-in-differences" with no functional-form assumptions. Equation (1) is identical to the following model aggregated at a cell-eclipse level:

[22] $obscuration_{ij}$ takes 0 if an eclipse is not observable (i.e., control cells) and 1 for a total eclipse.

[23] The fraction of the treated observations is relatively high as the treatment includes partial eclipses. I later analyze effect heterogeneity due to the obscurations rates of the eclipses.

[24] See Table A1-1 of Appendix A1 for the summary statistics.

[25] I later check the robustness with different time windows of the pretreatment period (1~30 days).

[26] For interpretability, I scale y_{ijt} in percentage points by multiplying them by 100.

$$\Delta y_{ij} = 100\left(y_{ijt=0} - \frac{\sum_{t=-7}^{-1} y_{ijt}}{7}\right) = a + \delta\ eclipse_{ij} + \epsilon_{ij} \tag{2}$$

Equations (1) and (2), and thus, the coefficients δ are identical.[27] I use equation (2) in the main analysis to reduce computational time. Since the treatment is assigned for each eclipse, I cluster the standard errors by eclipse to account for any spatial or temporal correlation within an eclipse event (Abadie et al. 2023).[28]

I do not include any covariates or fixed effects in the main specification, and consider them in the later robustness checks.[29] Additionally, most of the new DiD approaches are not directly relevant to this study (see Xu 2023 for review). My design is a simple 2-by-2 DiD without staggered adoption and persistent effects,[30] two-way fixed effects, or a clear violation of the common trend assumption. The main design of this study is the natural experiment, and DiD is rather supplementary.

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[27] If any doubt, compare Table 2 and Model 1 of Table A14-1.

[28] This ensures that the standard errors in equations (1) and (2) are numerically identical. Other standard errors, such as spatial HAC errors, do not ensure the equality. In Appendix A3, I find that the standard error does not over-reject placebo effects. I later check the robustness with different standard errors. The analysis is implemented with fixest in R (Berge et al. 2020).

[29] Without strong evidence to the contrary, I prefer the parsimonious specification as it does not rely on functional forms, arbitrary selection of covariates, or fixed effects. I later extensively check robustness. Note that DiD accounts for any static confounders.

[30] Although eclipses are repeatedly observed at different times, the effect is instantaneous, and an eclipse occurs at least a half year, and usually, several years after the last eclipse. Thus, it is empirically and substantively plausible to consider each eclipse as an independent treatment.

Results: The Eclipse Effects

Table 2 shows the main estimates of the eclipse effect. Although the effects on battles and protests are indistinguishable from zero, solar eclipses increased violence against civilians ($p = 0.016$). Solar eclipses increased the likelihood of violence by 0.034 percentage points. The estimate takes a small value as it is the daily probability of violence in a cell. If the estimate is compared to the average probability of violence, it is equivalent to a 36% increase from the sample average. Note that these numbers include only events reported in ACLED, and thus, are likely to understate the effect sizes (Weidmann 2016).

Table 2. The Effects of Solar Eclipses on Violence, Battle, and Protests

	ΔViolence	ΔBattle	ΔProtest
Eclipse	0.034*	-0.003	-0.003
	(0.013)	(0.011)	(0.015)
(Intercept)	-0.018	-0.002	-0.001
	(0.012)	(0.009)	(0.015)
N	274,274	274,274	274,274

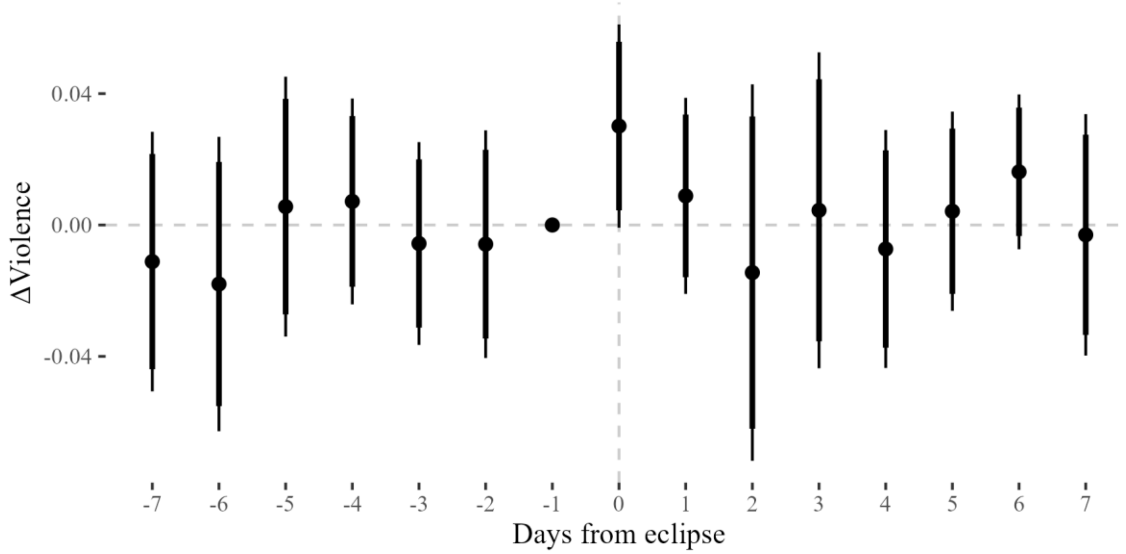
The figure shows the estimated effects of solar eclipses on the incidences of violence, battles, and protests in Africa. The sample contains 10,549 PRIO-GRID cells and 26 solar eclipses for the period 1997–2022. The standard errors are clustered by eclipse. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$.

Conversely, I do not find the effects on battles or protests; the point estimates are about one-tenth of violence. From the tactical perspective, armed groups and government forces are not easy targets even during eclipses. It is unlikely that they would put aside their weapons to watch an eclipse. Notably, they can anticipate and prepare for the insurgents' attacks. Similarly, while eclipse-induced darkness provides tactical opportunities to insurgents, it is orthogonal (or even negative) to tactical opportunities for peaceful protests.[31] From the psychological perspective, organized groups are less influenced by biased decisions and superstitions (Varshney 2003), which may explain the null effect on battles, although the null effect on protests is less clear. The null results also suggest that reporting biases are unlikely to explain the effect on violence.

Figure 2 shows the event study of violence, wherein the difference in the probabilities of violence on each day preceding and following eclipses is compared to the baseline difference at $t = -1$. Although the estimates are centered around zero before and after the solar eclipses, there is a spike in violence on the days of the eclipses ($t = 0$). That is, solar eclipses instantly increased violence. The absence of a pretreatment trend implies that there was no anticipatory behavior or concern about the common trend assumption.

[31] Eclipses lure people outside, which may provide opportunities for mass mobilization and collective action. However, eclipses also increase the opportunity costs for joining protests; people would like to observe an eclipse or pray instead of joining a protest. These countervailing effects may explain the null result as well.

Figure 2. Event Study of Violence against Civilians



The figure shows the results of the event study for violence. The baseline category is a day before the eclipses. The sample contains 10,549 PRIO-GRID cells and 26 solar eclipses for the period 1997–2022. The standard errors are clustered by eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

Because the possibility that the estimate is a false positive must be considered, I conduct extensive robustness and other checks, which are summarized in Table 3. The covariates are balanced, and the treatment effect is significantly larger than the placebo effects generated from the simulation, in which I randomly reshuffle the eclipses. I also do not find evidence for the spatial displacement of violence. The results are robust for different configurations of the sample (i.e., temporal spans, subsample to inhabited cells, and omission of countries), measurements of the outcome variable, spatial regression (SEM, SAR, and ESF), parametric models (logit, Poisson, and negative binomial regressions), inclusion of control variables and fixed effects, and standard errors. Only when I use the SCAD does the estimate become imprecise. This is not surprising as the SCAD contains less than 16% of violent events relative to the ACLED.[32] This results in smaller variance of the outcome variable, and thus, larger standard errors. Nevertheless, the point estimate

[32] The UCDP GED also contains less than 18% of violence events compared to the ACLED.

is positive and sizable. The estimate is also significant at a 10% level for violence unrelated to religious or ethnic issues (Table A12-2), which is consistent with the findings in the next subsection.

Table 3. Validity and Robustness Checks

	Violence	Battle	Protest	Appx.
Validity checks				
1. Balance checks		✓		A2
2. Randomization test		✓		A3
3. Spatial displacement		✓		A4
Sample				
4. Inclusion of $t = 1$ in the posttreatment period	$+^{*}$	Null	Null	A14
5. Subsample to the cells of over 1,000 population	$+^{*}$	Null	Null	A14
6. Time windows of the pretreatment period (1 ~ 30 days)	$+^{*2}$	Null	Null	A10
7. Leave-one-country-out tests	$+^{*3}$	Null	Null	A11
Measurement				
8. Count outcome	$+^{*}$	Null	Null	A14
9. Logged count outcome	$+^{*}$	Null	Null	A14
10. UCDP GED	$+^{\dagger}$			A12
11. SCAD	Null[4]			A12
Regression Models				
12. Spatial error model (SEM)	$+^{*}$			A13
13. Spatial autoregressive model (SAR)	$+^{*}$			A13
14. Eigenvector spatial filtering (ESF)	$+^{*}$			A13
15. Logit model	$+^{*}$	Null	Null	A14
16. Poisson model with the count outcome	$+^{*}$	Null	Null	A14
17. Negative binomial model with the count outcome	$+^{*}$	Null	Null	A14
Control Variables and FEs				
18. Control variables[1]	$+^{*}$	Null	Null	A14
19. Country-eclipse FEs	$+^{*}$	Null	Null	A14
20. Province-eclipse FEs	$+^{*}$	Null	Null	A14
21. Time FEs	$+^{*}$	Null	Null	A14
22. Year, month, day of the week, and day FEs	$+^{\dagger}$	Null	Null	A14
23. Islamic calendar day FEs	$+^{**}$	Null	Null	A14
24. Adjustment for pretreatment time trends	$+^{*}$	Null	Null	A14
25. Spatial controls	$+^{*}$	Null	Null	A14
Standard errors				
26. Two-way clustering by eclipse and cell	$+^{*}$	Null	Null	A14
27. Conley standard errors with a 500km window	$+^{*}$	Null	Null	A14

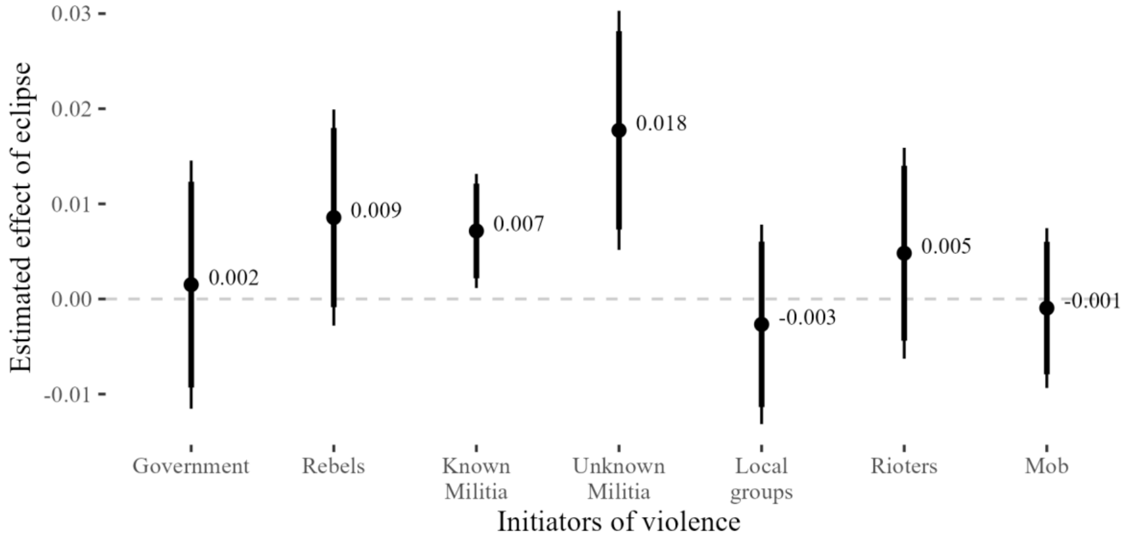
The table summarizes the results of the validity and robustness checks. $+$, $-$, and Null refer to increase, decrease, and no change in the incidences of corresponding events, respectively. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$. Note 1: The control variables include the proportions of Christians and excluded ethnic groups, indicator of conflict zones, logarithms of night light density, GCP, population and annual precipitation, temperature, elevation, latitude, and longitude. Note 2: Significant at a 10% level when the pre-treatment time period is limited to $t = -1$. Note 3: Significant at a 10% level when Nigeria is dropped. Note 4: Positive and significant at a 10% level for violence unrelated to religious or ethnic issues.

Mechanism Check I: Disaggregation by Event Types

Given the results of the main analysis, the null expectation is rejected. However, a crucial question lies in the mechanism: the psychological and tactical explanations. To this end, I disaggregate violent events by the initiators. Based on the actor classification in the ACLED (Raleigh, Linke, and Dowd 2014), I disaggregate violence to that initiated by governments (army and police), rebels, known and unknown militias, local groups (communal, ethnic, religious, tribal, and cult groups),[33] rioters (i.e., violent demonstrators), and mobs (e.g., "crowds of people"). Figure 3 presents the results of the analysis. Although the effects on violence by governments, local groups, rioters, and mobs are indistinguishable from zero, the effects are positive and precise for violence initiated by known and unknown militias. The point estimates are also large for violence by rebels and militias, especially *unknown* militias such as "unidentified armed groups" and "unknown groups with heavy arms." The large effect on unknown militias is not surprising as the eclipse-induced darkness makes it difficult even for the media to identify the perpetrators.

[33] I also further disaggregate the events to those initiated by communal, ethnic, religious, tribal, and cult groups, and find nearly zero point estimates with very large confidence intervals.

Figure 3. The Effects of Solar Eclipses by the Initiators of Violence



The figure shows the estimated effects of solar eclipses on the incidences of violence against civilians initiated by the actors in the horizontal axis. The sample contains 10,549 PRIO-GRID cells and 26 solar eclipses for 1997–2022. The standard errors are clustered by eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

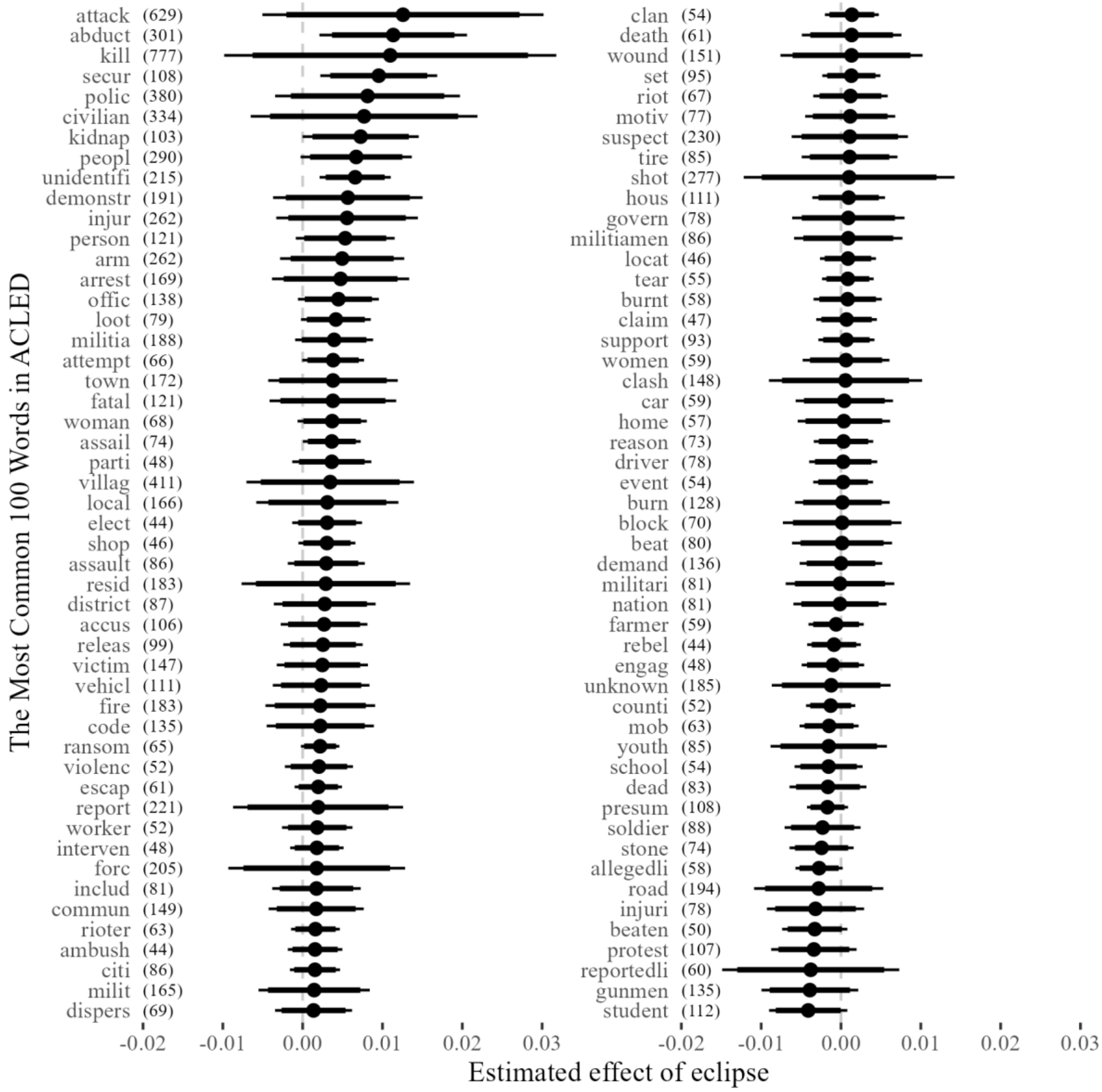
To further understand the characteristics of violent events, I disaggregate the events to the *original texts*. After the initial cleaning of the text data,[34] I pick up the most common 100 words across the descriptions and create a dichotomous variable $violence(w)_{ijt}$ that takes 1 if there is any description of violence that contains word w.[35] Figure 4 shows the results when the outcome variable is replaced with $\Delta violence(w)_{ij}$. Note that the words displayed on the vertical axis are stemmed (e.g., "police" is stemmed to "polic"). As seen in Figure 4, although the point estimates are large for events with words that commonly appear, such as "attack," "kill," "polic(e)," and "civilian," the estimates are imprecise. By contrast, the estimates are positive and precise for events

[34] The texts are tokenized and stemmed, and the stop words and other irrelevant words (non-English words, numbers, months, weeks, country names, directions) are dropped.

[35] I do not use topic or other methods as I am interested in disaggregating, rather than aggregating, the event categories.

with more context-specific words, such as “abduct,” “secur(ity),” “kidnap,” and “unidentifi(ed).” These words imply that eclipses increased abductions and kidnappings by unidentified armed groups. Moreover, the effects are small and imprecise for events with words related to intergroup violence, such as “commun(ity),” “rioter,” “clan,” “riot,” and “mob” with the exception being “demonstr(ation).” Similarly, the words associated with ethnicity and religion, such as “Muslim,” “Christian,” “religi(on)”, and “ethnic(ity),” are less common (not in the most common 100 words), and thus, those events are unlikely to explain the main estimates. Overall, the analysis of the original texts confirms that the main results are mostly driven by unidentified armed groups who attacked, abducted, and kidnapped people under the cover of darkness—a finding consistent with the tactical explanation.

Figure 4. The Effects of Solar Eclipses by Keywords in the Original Event Descriptions



The figure shows the estimated effects of solar eclipses on the incidences of violence against civilians whose descriptions contains the words displayed in the vertical axis. The number of events whose descriptions contained a given word is in the parenthesis. The words displayed on the vertical axis are stemmed words (e.g., "police" is stemmed to "polic"). The sample contains 10,549 PRIO-GRID cells and 26 solar eclipses for the period 1997–2022. The standard errors are clustered by eclipse. The thick and thin horizontal intervals are the 90% and 95% confidence intervals, respectively.

Mechanism Check II: Eclipse or Sight Visibility?

Another way to weigh the psychological and tactical explanations is to analyze the effects of eclipse and sight visibility. The psychological explanation predicts that solar eclipses have a particularly large effect when people can observe them (*eclipse visibility*). This requires sunny weather. By contrast, the tactical explanation indicates that the effect is pronounced when it is especially dark, and thus, *sight visibility* is limited. Because clouds can block the remaining sunlight, the effect should be larger on cloudy days.[36] Thus, even though I cannot deny the possibility that limited sight visibility also evokes fear, the analysis of weather conditions allows me to isolate the effects of eclipse observation and darkness.

To measure the eclipse and sight visibility, I first use eclipse obscuration. However, the visual magnitude of solar eclipses is not a linear function of obscuration; because the Sun is so bright, small obscurations are hardly noticeable. Thus, I use Hughes' (2000) transformation and calculate the visual magnitude of solar eclipses (standardized to 0-1).[37] Finally, the visual magnitude is interacted with the cloud cover during solar eclipses to quantify real visibility. The data of hourly cloud cover are derived from the European Center for Medium-Range Weather

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[36] Fewer people might go outside and watch eclipses on cloudy days, resulting in a smaller number of targets. Although this may diminish the tactical opportunities, it is counteracted by the limited visibility induced by the cloudy weather. As criminological studies suggest (see footnote 2 for references), I conjecture that the latter effect is larger than the former. Additionally, people may still go outside in the hope of catching glimpses of an eclipse. Muslims attend prayer regardless of weather, and ethnic rituals can potentially be conducted even on cloudy days.

[37] $magnitude = -26.75 - 2.5\log_{10}(1 - obscuration + v)$, where v is an infinitesimal value (approximated by the smallest non-zero value of obscuration in the sample).

Forecasts Reanalysis version 5 (ERA5; 2023), and averaged over the hours of an eclipse observation in cell i.[38]

Table 4 shows the effects of eclipse obscuration, visual magnitude, and cloud cover. As seen in Columns 1 and 2, the main results hold even with the continuous predictors. Moreover, the results of Column 3 indicate a positive interactive effect; that is, solar eclipses increased violence on *cloudy* days. In Column 4, I include the cloud cover during the same hours but in the year prior to an eclipse to control for any geographic, climatic, seasonal, daily, and hourly confounders. The estimate becomes slightly smaller due to a high correlation but remains similar. These results are consistent with the tactical rather than psychological explanation.

[38] The ERA5 is available at the resolution of 0.25 decimal degrees. Because the weather during the peak of an eclipse (i.e., totality in case of a total eclipse) is more important, I use triangular weights when I average over hours. The results are nearly identical even without the triangular weights. For the control cells, I use the average starting and ending hours of solar eclipse observations.

Table 4. The Effects of Eclipse Obscuration, Visual Magnitude, and Cloud Cover

	1	2	3	4
Obscuration (0-1)	0.066^{**} (0.022)			
Visual magnitude (0-1)		$0.163^{\dagger}$ (0.085)	0.052 (0.085)	-0.047 (0.088)
Cloud cover during eclipse (0-1)			-0.026 (0.015)	$-0.026^{\dagger}$ (0.015)
Visual magnitude × Cloud cover during eclipse			0.331^{*} (0.127)	$0.221^{\dagger}$ (0.118)
Cloud cover a year before eclipse (0-1)				0.000 (0.015)
Visual magnitude × Cloud cover a year before eclipse				0.338 (0.201)
(Intercept)	-0.015 (0.010)	-0.007 (0.009)	0.003 (0.011)	0.003 (0.012)
N	274,274	274,274	274,274	274,274

The figure shows the estimated effects of eclipse obscuration, visual magnitude, and cloud cover on the incidences of violence in Africa. The sample contains 10,549 PRIO-GRID cells and 26 solar eclipses for the period 1997–2022. The standard errors are clustered by eclipse. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$.

Mechanism Check III: Eclipse Folklore as a Moderator?

Thus far, the results are consistent with the tactical explanation. However, it is still possible that the psychological mechanism applies to a subset of the sample. Solar eclipses, for instance, may incite violence only when people hold negative images of eclipses. To explore this possibility, I use Berezkin's catalog of folklore. Based on 6,239 books and journal articles between 1800 and 2000, Berezkin (2015) collected and classified ethnic folklore across the world. Michalopoulos and Xue (2021) cleaned Berezkin's catalog and demonstrated that ethnic folklore continues to shape people's beliefs and values in the present day. I use Berezkin's catalog and extract folklore about solar eclipses for each ethnic group. Using information regarding the geographic distribution of ethnic groups (Michalopoulos and Xue 2021), I create a dichotomous variable $folklore_i$ that takes 1 if cell i has an ethnic group who has negative folklore about solar eclipses, otherwise 0.

However, Berezkin's catalog is far from complete. Because his database is based on the academic literature, $folklore_i$ not only measures the presence of eclipse folklore but is also influenced by scholarly attention. This is concerning as the outcome variable $violence_{ijk}$ is also based on media reports and subject to reporting biases. Furthermore, I cannot compare the areas with positive and negative folklore; as I mentioned earlier, eclipse folklore is almost exclusively negative in Berezkin's catalog.[39] This forces me to compare the areas with and without folklore.

I address this problem by using historical exposures to solar eclipses as an instrumental variable (IV) for $folklore_i$. Figure 5 is a graphical representation of the design. The exposure to solar eclipses should motivate people to generate folklore about eclipses, which is then inherited across generations. Moreover, historical eclipses are exogenous and unaffected by reporting biases. Because Berezkin's data were recorded between 1800 and 2000, I calculate the number of total solar eclipses observed in cell i for 1700–1800.[40] The variable $eclipses_{hist,i}$ is then used to predict $folklore_i$. Because I am interested in the effect moderation, instead of the direct effect of folklore, I use the following specification;

$$\Delta y_{ij} = u + \gamma_1 eclipse_{ij} + \gamma_2 folklore_i + \vartheta\, eclipse_{ij} \times folklore_i + e_{ij}; \quad (3)$$

$$folklore_i = a_1 + b_{11} eclipse_{ij} + b_{12} eclipse_{hist,i} + b_{13} eclipse_{ij} \times eclipse_{hist,i} + e_{1ij}; \quad (4)$$

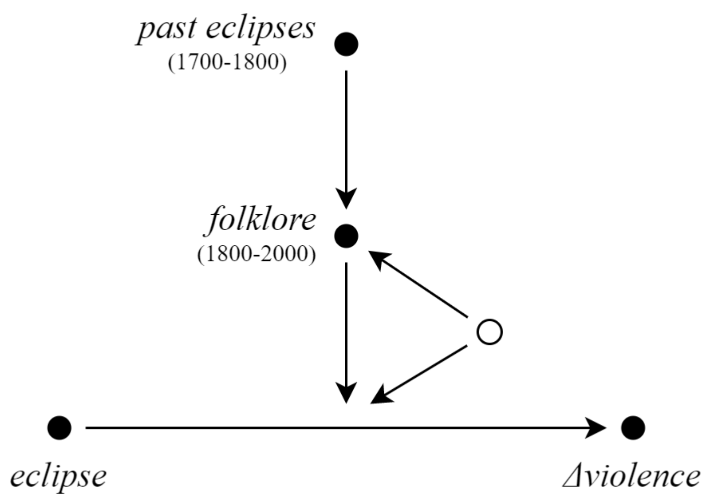
$$eclipse_{ij} \times folklore_i = a_2 + b_{21} eclipse_{ij} + b_{22} eclipse_{hist,i} + b_{23} eclipse_{ij} \times eclipse_{hist,i} + e_{2ij}. \quad (5)$$

[39] See footnote 12 for exceptions.

[40] Over such a long time period, the number of partial and total eclipse observations converges to an average value with a small variance due to the as-if randomness and the law of large numbers. For this reason, I focus on *total* solar eclipses (see also Litina and Roca Fernández 2024).

Following Wooldridge (2009), I include the same predictors for the two first-stage regressions (4) and (5). The quantity of interest is ϑ, which represents the difference in the eclipse effects with and without eclipse folklore.[41] The coefficients are estimated with two-stage least squares (TSLS). Since $folklore_i$ and $eclipse_{hist,i}$ are constant for cell i, the standard errors are two-way clustered by eclipse and cell.[42]

Figure 5. Graphical Representation of the Instrumental Variable Design



The figure is the directed acyclic graph of the instrumental variable design. The effect of solar eclipses on violence is moderated by ethnic folklore about solar eclipses (1800–2000), which, in turn, is instrumented by the number of total solar eclipses for 1700–1800.

Although $eclipse_{hist,i}$ is exogenous, the IV analysis requires the exclusion restriction; historical exposure to eclipses should modify the effect of eclipses on violence only through their effects on ethnic folklore. Because this assumption may or may not be plausible given the broad impacts of eclipses (Litina and Roca Fernández 2024), I informally check the validity by using a

[41] γ_1 and γ_2 are not "direct" effects of eclipse and folklore. γ_1 is the effect of eclipses without folklore, and γ_2 is the descriptive difference with and without folklore when $eclipse_{ij} = 0$.

[42] I also two-way cluster the standard errors by eclipse and ethnic group and find null results.

placebo instrumental variable: the number of total eclipses between 2100 and 2200, $eclipse_{future,i}$. Because future eclipses should not affect folklore or contemporary violence, this constitutes a placebo test.

Table 5 summarizes the results of the IV analysis. As seen in the first two columns, I find no evidence that ethnic folklore about eclipses moderates the effects of eclipses on violence. The estimates are null in the naïve OLS (first column) and the TSLS (second column). Although the coefficient of the interaction term is positive and large in TSLS, the estimate is imprecise, and the OLS estimate is even smaller. These null results are unlikely to be explained by the weak power of the instrumental variable. As seen in the third and fourth columns, historical exposure to eclipses increased the likelihood of having folklore about solar eclipses. As seen at the bottom of Table 5, the first-stage F statistics (Kleibergen-Paap) are 32.8 and 11.3, which are above the conventional criterion of 10 or 12 (Stock, Wright, and Yogo 2002). By contrast, the placebo IV has no tangible effects, and the F statistics are nearly zero (fifth and sixth columns). Thus, without denying the potential roles of eclipse folklore, the analysis provides no evidence that the effect depends on folklore. The cultural explanation is unlikely to explain the main results in Table 2.

Table 5. The Effects of Solar Eclipses Conditional on the Presence of Eclipse Folklore

	Naive OLS	TSLS (2nd stage)	TSLS (1st stage)		Placebo (1st stage)	
	ΔViolence	ΔViolence	Folklore	Eclipse × Folklore	Folklore	Eclipse × Folklore
Folklore	-0.016 (0.018)	-0.116 (0.154)				
Eclipse × Folklore	0.008 (0.020)	0.128 (0.202)				
Historical eclipses			0.042** (0.007)	0.000 (0.000)		
Eclipse × Historical eclipses			-0.001 (0.012)	0.041** (0.009)		
Future eclipses					0.005 (0.006)	0.000** (0.000)
Eclipse × Future eclipses					-0.006 (0.010)	-0.001 (0.008)
Eclipse	0.032* (0.015)	0.000 (0.054)	0.011 (0.012)	0.241** (0.009)	0.017 (0.013)	0.279** (0.010)
(Intercept)	-0.014 (0.013)	0.013 (0.045)	0.229** (0.007)	0.000** (0.000)	0.262** (0.008)	0.000 (0.000)
F			32.816	11.282	0.297	0.010
N	274,274	274,274	274,274	274,274	274,274	274,274

The figure shows the estimated effects of solar eclipses on violence, conditional on the presence of folklore about solar eclipses. The endogenous moderator, folklore, takes 1 if there is folklore about solar eclipse. The instrumental variable, historical eclipses, is the number of total solar eclipses observed in cell i for the period 1800–1900. The placebo variable, future eclipses, is the number of total solar eclipses observed in cell i for the period 2100–2200. Following Wooldridge (2009), I use the same predictors in the first-stage regressions. The sample contains 10,549 PRIO-GRID cells and 26 solar eclipses for the period 1997–2022. The standard errors are two-way clustered by eclipse and cell. The Kleibergen-Paap F statistics are also included for the first-stage regressions. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$.

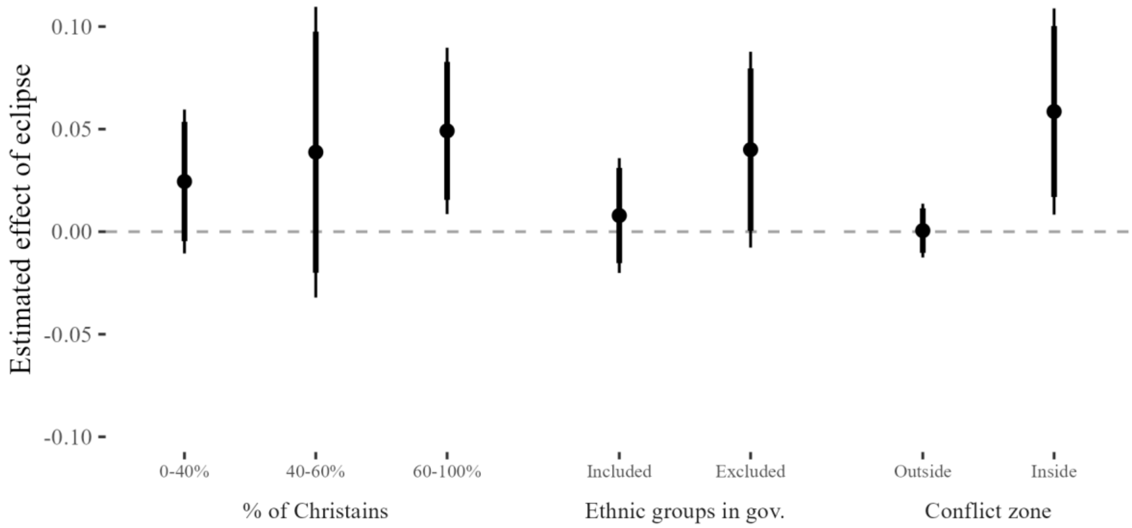
Mechanism Check IV: Heterogenous Effects by Covariates

I also check for heterogeneity by relevant covariates. Although I do not present these findings as strong evidence (the covariates are endogenous, and thus, the results are open to a myriad of interpretations), it is still a useful check. To gauge the heterogeneity by intergroup dynamics, I use two indicators: percentages of the Christian population (Johnson and Grim 2023) and the presence of politically included and excluded ethnic groups (Vogt et al. 2015).[43] The psychological explanation assumes the presence of ingroups and outgroups, and the religious and ethnic divisions are the primary drivers of intergroup dynamics in Africa. For the tactical explanation, I examine whether cell i belongs to a conflict zone on the day of solar eclipse j (Kikuta 2022). Although the tactical explanation assumes the presence of insurgent groups, they are not everywhere and are generally concentrated in conflict zones. I interact each of these covariates with $eclipse_{ij}$ in equation (2) and separately estimate the conditional effects.

As seen in Figure 6, there is a weak tendency for the effect to be larger in locations with a larger number of Christians. In addition, the effect tends to be large with politically excluded ethnic groups. These findings may provide support for the psychological explanation. Nonetheless, the estimates are imprecise. By contrast, the effects are significantly large in conflict zones, with the point estimate over 50 times larger. Nevertheless, these results should not be over-interpreted as the covariates are endogenous, and hence, open to various interpretations. For instance, religious and ethnic differences may lead to armed conflict, which in turn strengthens the effects of solar eclipses.

[43] An overwhelming majority of people Africa (at least officially) belong to Christian or Islamic denominations. Excluded ethnic groups are “powerless” and “discriminated” groups in the EPR dataset (Vogt et al. 2015).

Figure 6. The Effects of Solar Eclipses on Violence by Endogenous Covariates



The figure shows the estimated effects of solar eclipses by endogenous covariates displayed in the horizontal axis. Each of the covariates are interacted with the treatment variable in equation (1). The sample contains 10,549 PRIO-GRID cells and 26 solar eclipses for the period 1997–2022. The standard errors are clustered by eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

Other Mechanism Checks

To further examine the mechanisms, I consider whether the effect depends on the time from the last observation of a solar eclipse (Appendix A5). With multiple observations within a short time, eclipses may become less impressive. Similarly, people can learn that eclipses cause insurgents' violence, take precautionary measures, and thus, deter violence. Consistent with those expectations, I find that the effect is closer to zero when a solar eclipse is observed within a year after the last event. Similarly, I find that the effect is larger when a larger fraction of the Sun's surface is shaded (i.e., darker environments; Appendix A6) and the Sun's altitude during an eclipse is not too low (i.e., eclipses had no effect without substantially darkening the environments; Appendix A7).

Additionally, in Table A8-1 of Appendix A8, I present the results of lunar eclipses, wherein I find only weaker effects. This is not surprising as lunar eclipses have much smaller cross-sectional variation; they are more frequently observed, and thus, less impressive; and they occur at night, and thus, may go unnoticed (see p.15 of this manuscript). These results corroborate the null results in Litina and Fernandez (2024). The results are also consistent with the tactical explanation; nighttime is dark enough to hide insurgents, regardless of lunar eclipses.

Finally, I use Afrobarometer surveys to test whether eclipses influenced people's psychological conditions, including the sense of insecurity, hostility toward outgroups, and trust in ingroup leaders at an individual level (Appendix A9). The analysis provides no definite evidence. Although the analysis suggests that solar eclipses increased hostility toward outgroups, the results are better interpreted as the effect of eclipse-induced violence, rather than the direct effect of solar eclipses. Indeed, consistent with Table 4, the effect is stronger with eclipses on *cloudy* days.

Overall, despite the extensive analyses, I do not find definite evidence for the psychological or cultural mechanisms. The findings are more consistent with the tactical explanation. Certainly, I cannot fully reject the psychological mechanism given the limitations of this study, indirectness of the evidence, potential for other effect heterogeneity, and difference between "null" and "no" effects (Rainey 2014). However, it seems too simplistic to consider that the "irrational" and "superstitious" African people overreacted to eclipses and used violence; rather, insurgent groups in Africa may have rationally used eclipses for their tactical advantages.

Conclusion: Beyond Anecdotes

In this study, I showed that eclipses—which are seemingly irrelevant to any aspect of politics or violence—affected violence in Africa. To explain the "eclipse effect," I hypothesized two mechanisms; eclipses affect violence by psychologically motivating people to attack outgroups, or by creating tactical opportunities for insurgent groups. The statistical analysis indicated a spike in violence on the days of solar eclipses. The analyses provided support for the tactical explanation, instead of the psychological.

These findings challenge conventional knowledge. Although social scientists tend to believe that seemingly irrelevant events such as eclipses and football games are indeed irrelevant to violence or other political outcomes, this belief belies historical and contemporary records (Kikuta and Uesugi 2023).[44] However, this does not mean that we can simply accept anecdotal records or assume that eclipses would drive "irrational" and "superstitious" African people to violence. We are tempted to accept clear-cut stories that confirm stereotypes while disregarding more nuanced stories that contradict our prior beliefs. Statistical analysis provides a useful way to evaluate these beliefs and theories. Indeed, my findings rather unexpectedly supported Valentino's claim that political violence is not "irrational, random, or the result of ancient hatreds between ethnic groups" (2014, 91).

To observe these points, it is suggestive to return to the 2001 and 2006 eclipses. The anecdote about Maiduguri in Nigeria, which was the initial motivation for this study, contradicts the statistical findings; I did not find strong effects of lunar eclipses (Appendix A8), effects on religious violence or riots, or evidence for the psychological or cultural explanation. However, the violence at Maiduguri can be safely considered an outlier. During the 2001 lunar eclipse, violence occurred in three locations of eclipse observations; however, the violence at Maiduguri was the *only* case that was evidently consistent with the psychological and cultural explanation. The other events were an attack by "unidentified armed men" in Malawi, and a students' riot in Ivory Coast. The pattern is even more stark in the 2006 solar eclipse. *All* the events that occurred in locations of eclipse observations were violence by insurgent groups: the Lord's Resistance Army's and Karamojoing militia's violence against civilians in Uganda. Despite (or because of) the fear of

[44] See footnote 8 for reference.

violence, no violence was reported in Nigeria. These broader patterns are consistent with the tactical explanation and statistical findings; the effects of lunar eclipses were ambiguous, and solar eclipses caused insurgents' violence against civilians. Even though we are tempted to generalize the intriguing story of Maiduguri, theories and statistical evidence warn against such overgeneralization.

This certainly does not mean that irrationality plays no role. Although the tactical explanation emphasizes insurgents' rational choices, it also rests on the careless reactions of victims. Indeed, if people were fully rational, they should anticipate violence, take precautionary measures, and avoid violence. Moreover, the tactical and psychological explanations are not mutually exclusive; to explain people's reactions to eclipses, we need to understand the psychological effects of eclipses. Additionally, the psychological explanation also does not deny insurgents' rational choices. The tactical and psychological explanations are therefore not neatly mapped onto the dichotomy of rational (i.e., Bayesian) and irrational (i.e., non-Bayesian) theories; both explanations lie somewhere between the extremes. Thus, the critical question is not *whether* people are rational but *to what extent* and *under what conditions* people are rational, and *how* rationality and irrationality interact.

A crucial task for future studies is, therefore, to delimit and expand the scope of psychological, tactical, and other explanations. The scope of this study is limited to eclipses in contemporary Africa. From a theoretical perspective, it appears that the presence of armed groups fighting unconventional warfare is a necessary, if not sufficient, scope condition; other groups, such as governments, are unlikely to use eclipses for their tactical advantages. Finally, and most critically, it is essential to examine whether my findings can be extended to other darkness-inducing events, such as nighttime and light outages.[45] Although it is prudent to consider that the effects substantially differ across those events, the fact that the tactical mechanism remains effective even in the case of solar eclipses—an event of high psychological and cultural salience—suggests that darkness leads to violence primarily through tactical channels in contemporary cases. This is contrastive to previous findings about historical cases, which emphasize psychological and cultural mechanisms (Litina and Roca Fernández 2024; Miao, Ponticelli, and Shao 2021; Sun and Li 2023). Future studies should expand theoretical and methodological approaches to further elucidate how darkness shapes political violence.

Reference List

Abadie, Alberto, Susan Athey, Guido W Imbens, and Jeffrey M Wooldridge. 2023. "When Should You Adjust Standard Errors for Clustering?" *The Quarterly Journal of Economics* 138(1): 1–35.

Achen, Christopher H., and Larry M. Bartels. 2017. Democracy for Realists *Democracy for Realists: Why Elections Do Not Produce Responsive Government*. Princeton, NJ: Princeton University Press.

Achen, Christopher H., and Larry M. Bartels. 2018. "Statistics as If Politics Mattered: A Reply to Fowler and Hall." *The Journal of Politics* 80(4): 1438–53.

Afrobarometer. 2019. "Afrobarometer Data. Rounds 2-7." https://www.afrobarometer.org/data/merged-data/ (July 30, 2020).

[45] See footnote 6 and corresponding sentences for identification challenges.

Aronson, Jacob, Kyosuke Kikuta, Michael Findley, and James Igoe Walsh. 2024. “The Tyranny of Supply: Natural Resources and Rebel Territorial Control in Civil Conflicts.” *International Studies Quarterly* 68(3): sqae093.

Arvate, Paulo, Filipe Ortiz Falsete, Felipe Garcia Ribeiro, and André Portela Souza. 2018. “Lighting and Homicides: Evaluating the Effect of an Electrification Policy in Rural Brazil on Violent Crime Reduction.” *Journal of Quantitative Criminology* 34(4): 1047–78.

Ashworth, Scott, Ethan Bueno de Mesquita, and Amanda Friedenberg. 2018. “Learning about Voter Rationality.” *American Journal of Political Science* 62(1): 37–54.

Bai, Ying. 2023. “Shaking Legitimacy: The Impact of Earthquakes on Conflict in Historical China.” *The Economic Journal* 133(652): 1286–1317.

Balcells, Laia, and Jessica A. Stanton. 2021. “Violence Against Civilians During Armed Conflict: Moving Beyond the Macro- and Micro-Level Divide.” *Annual Review of Political Science* 24(1): 45–69.

Bansak, Kirk. 2020. “Comparative Causal Mediation and Relaxing the Assumption of No Mediator–Outcome Confounding: An Application to International Law and Audience Costs.” *Political Analysis* 28(2): 222–43.

Barlow, Fiona Kate, Stefania Paolini, Anne Pedersen, Matthew J. Hornsey, Helena R. M. Radke, Jake Harwood, Mark Rubin, and Chris G. Sibley. 2012. “The Contact Caveat: Negative Contact Predicts Increased Prejudice More than Positive Contact Predicts Reduced Prejudice.” *Personality & Social Psychology Bulletin* 38(12): 1629–43.

Belloc, Marianna, Francesco Drago, and Roberto Galbiati. 2016. “Earthquakes, Religion, and Transition to Self-Government in Italian Cities*.” *The Quarterly Journal of Economics* 131(4): 1875–1926.

Berezkin, Yu E. 2015. "Folklore and Mythology Catalogue: Its Lay-out and Potential for Research." *The Retrospective Methods Network*: 58–70.

Berge, Laurent, Sebastian Krantz, Grant McDermott, and Maintainer Laurent Berge. 2020. "R Package Fixest." http://cran.salud.gob.sv/web/packages/fixest/fixest.pdf (July 22, 2022).

Berrebi, Claude, and Esteban F. Klor. 2008. "Are Voters Sensitive to Terrorism? Direct Evidence from the Israeli Electorate." *American Political Science Review* 102(03): 279–301.

Boerner, Lars, Jared Rubin, and Battista Severgnini. 2021. "A Time to Print, a Time to Reform." *European Economic Review* 138: 103826.

Busby, Ethan C., and James N. Druckman. 2018. "Football and Public Opinion: A Partial Replication and Extension." *Journal of Experimental Political Science* 5(1): 4–10.

Busby, Ethan C., James N. Druckman, and Alexandria Fredendall. 2016. "The Political Relevance of Irrelevant Events." *The Journal of Politics* 79(1): 346–50.

Carter, David B., Andrew C. Shaver, and Austin L. Wright. 2019. "Places to Hide: Terrain, Ethnicity, and Civil Conflict." *The Journal of Politics* 81(4): 1446–65. doi:10.1086/704597.

Carter, Timothy Allen, and Daniel Jay Veale. 2013. "Weather, Terrain and Warfare: Coalition Fatalities in Afghanistan." *Conflict Management and Peace Science* 30(3): 220–39.

Chalfin, Aaron, Benjamin Hansen, Jason Lerner, and Lucie Parker. 2022. "Reducing Crime Through Environmental Design: Evidence from a Randomized Experiment of Street Lighting in New York City." *Journal of Quantitative Criminology* 38(1): 127–57.

Chalfin, Aaron, Jacob Kaplan, and Michael LaForest. 2022. "Street Light Outages, Public Safety and Crime Attraction." *Journal of Quantitative Criminology* 38(4): 891–919.

Chen, Xin. 2021. "Lunar Eclipses, Analyst Sentiment, and Earnings Forecasts: Evidence from China." *International Review of Economics & Finance* 76: 1007–24.

Chung, Eunbin, and Inbok Rhee. 2022. “Disasters and Intergroup Peace in Sub-Saharan Africa.” *Journal of Peace Research* 59(1): 58–72.

Collier, Paul, and Anke Hoeffler. 2004. “Greed and Grievance in Civil War.” *Oxford Economic Papers* 56(4): 563–95.

Condra, Luke N., James D. Long, Andrew C. Shaver, and Austin L. Wright. 2018. “The Logic of Insurgent Electoral Violence.” *American Economic Review* 108(11): 3199–3231.

Coupe, Timothy, and Laurence Blake. 2006. “Daylight and Darkness Targeting Strategies and the Risks of Being Seen at Residential Burglaries.” *Criminology* 44(2): 431–64.

Croicu, Mihai Catalin, and Ralph Sundberg. 2012. “UCDP GED Conflict Polygons Dataset Codebook Version 1.1-2011.” https://ucdp.uu.se/downloads/old/polygon/ucdp-ged-polygons-v-1-1-codebook.pdf (July 10, 2024).

Cross, Don. 2023. “Astronomy Engine.” https://github.com/cosinekitty/astronomy (November 6, 2023).

Denly, Michael, Michael G. Findley, Joelean Hall, Andrew Stravers, and James Igoe Walsh. 2022. “Do Natural Resources Really Cause Civil Conflict? Evidence from the New Global Resources Dataset.” *Journal of Conflict Resolution* 66(3): 387–412.

Depetris-Chauvin, Emilio, Ruben Durante, and Filipe Campante. 2020. “Building Nations through Shared Experiences: Evidence from African Football.” *American Economic Review* 110(5): 1572–1602.

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

Domínguez, Patricio, and Kenzo Asahi. 2023. “Crime-Time: How Ambient Light Affects Crime.” *Journal of Economic Geography* 23(2): 299–317.

Edwards, Nina. 2019. *Darkness: A Cultural History*. London, UK: Reaktion Books.

European Center for Medium-Range Weather Forecasts. 2023. "ECMWF Reanalysis V5." https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5 (November 9, 2023).

Fearon, James D. 2004. "Why Do Some Civil Wars Last So Much Longer than Others?" *Journal of Peace Research* 41(3): 275–301.

Fowler, Anthony, and Andrew B. Hall. 2016. "Do Shark Attacks Influence Presidential Elections? Reassessing a Prominent Finding on Voter Competence." *The Journal of Politics* 80(4): 1423–37.

Fowler, Anthony, and B. Pablo Montagnes. 2015. "College Football, Elections, and False-Positive Results in Observational Research." *Proceedings of the National Academy of Sciences* 112(45): 13800–804.

Fowler, Anthony, and B. Pablo Montagnes. 2023. "Distinguishing between False Positives and Genuine Results: The Case of Irrelevant Events and Elections." *The Journal of Politics* 85(1): 304–9.

Gleditsch, Kristian Skrede, and Andrea Ruggeri. 2010. "Political Opportunity Structures, Democracy, and Civil War." *Journal of Peace Research* 47(3): 299–310.

Goldsmith, Benjamin E., Yusaku Horiuchi, and Kelly Matush. 2021. "Does Public Diplomacy Sway Foreign Public Opinion? Identifying the Effect of High-Level Visits." *American Political Science Review* 115(4): 1342–57.

Goldy, Sean P., Nickolas M. Jones, and Paul K. Piff. 2022. "The Social Effects of an Awesome Solar Eclipse." *Psychological Science* 33(9): 1452–62.

Graham, Matthew H., Gregory A. Huber, Neil Malhotra, and Cecilia Hyunjung Mo. 2023a. "How Should We Think about Replicating Observational Studies? A Reply to Fowler and Montagnes." *The Journal of Politics* 85(1): 310–13.

Graham, Matthew H., Gregory A. Huber, Neil Malhotra, and Cecilia Hyunjung Mo. 2023b. "Irrelevant Events and Voting Behavior: Replications Using Principles from Open Science." *The Journal of Politics* 85(1): 296–303.

Griffith, Daniel, Yongwan Chun, and Bin Li. 2019. *Spatial Regression Analysis Using Eigenvector Spatial Filtering*. London, United Kingdom: Academic Press.

Gurr, Ted Robert. 1970. *Why Men Rebel*. Boulder, Colorado: Paradigm Publishers.

Hafner-Burton, Emilie M., Stephan Haggard, David A. Lake, and David G. Victor. 2017. "The Behavioral Revolution and International Relations." *International Organization* 71(S1): S1–31.

Healy, Andrew, and Neil Malhotra. 2013. "Retrospective Voting Reconsidered." *Annual Review of Political Science* 16(1): 285–306.

Healy, Andrew, Neil Malhotra, and Cecilia Hyunjung Mo. 2010. "Irrelevant Events Affect Voters' Evaluations of Government Performance." *Proceedings of the National Academy of Sciences* 107(29): 12804–9.

Healy, Andrew, Neil Malhotra, and Cecilia Hyunjung Mo. 2015. "Determining False-Positives Requires Considering the Totality of Evidence." *Proceedings of the National Academy of Sciences* 112(48): E6591–E6591.

Hendrix, Cullen S., and Idean Salehyan. 2013. "Social Conflict in Africa Database (SCAD)." https://www.strausscenter.org/ccaps-research-areas/social-conflict/database/ (May 1, 2022).

Huber, Peter J. 1987. "Dating by Lunar Eclipse Omina with Speculations on the Birth of Omen Astrology." In *From Ancient Omens to Statistical Mechanics*, eds. Bernard R. Goldstein and J. L. Berggren. Copenhagen: Netherland: University Library, 3–13.

Hughes, D. 2000. "Brightness during a Solar Eclipse." *Journal of the British Astronomical Association* 110: 203–5.

Imai, Kosuke, Luke Keele, and Dustin Tingley. 2010. "A General Approach to Causal Mediation Analysis." *Psychological methods* 15(4): 309.

Johnson, Todd M., and Brian J. Grim. 2023. "World Religion Database." https://brill.com/display/db/wrdo (November 28, 2023).

Jubier, Xavier. 2023. "Five Millennium Canon of Solar Eclipses Database." http://xjubier.free.fr/en/site_pages/solar_eclipses/5MCSE/xSE_Five_Millennium_Canon.html (November 6, 2023).

Kalyvas, Stathis N. 2006. *The Logic of Violence in Civil War*. New York, NY: Cambridge University Press.

Kalyvas, Stathis N., and Laia Balcells. 2010. "International System and Technologies of Rebellion: How the End of the Cold War Shaped Internal Conflict." *The American Political Science Review* 104(3): 415–29.

Kalyvas, Stathis N., and Matthew Adam Kocher. 2009. "The Dynamics of Violence in Vietnam: An Analysis of the Hamlet Evaluation System (HES)." *Journal of Peace Research* 46(3): 335–55.

Kamenica, Emir. 2012. "Behavioral Economics and Psychology of Incentives." *Annual Review of Economics* 4(1): 427–52.

Keele, Luke, and Randolph T. Stevenson. 2021. "Causal Interaction and Effect Modification: Same Model, Different Concepts." *Political Science Research and Methods* 9(3): 641–49.

Kertzer, Joshua D., and Dustin Tingley. 2018. "Political Psychology in International Relations: Beyond the Paradigms." *Annual Review of Political Science* 21(1): 319–39.

Ketchley, Neil, and Christopher Barrie. 2020. "Fridays of Revolution: Focal Days and Mass Protest in Egypt and Tunisia." *Political Research Quarterly* 73(2): 308–24.

Kikuta, Kyosuke. 2022. "A New Geography of Civil War: A Machine Learning Approach to Measuring the Zones of Armed Conflicts." *Political Science Research and Methods* 10(1): 97–115.

Kikuta, Kyosuke. 2023a. "A Typology of Substitution: Weather, Armed Conflict, and Maritime Piracy." *Political Science Research and Methods* 11(2): 237–53.

Kikuta, Kyosuke. 2023b. "Rainy Friday: Religious Participation and Protests." *Journal of Conflict Resolution*.

Kikuta, Kyosuke, and Mamoru Uesugi. 2023. "Do Politically Irrelevant Events Cause Conflict? The Cross-Continental Effects of European Professional Football on Protests in Africa." *International Organization* 77(1): 179–216.

Kitamura, Shuhei. 2022. "UFOs: The Political Economy of Unidentified Threats." https://osf.io/tme8f/ (October 28, 2023).

Krcmaric, Daniel. 2019. "Information, Secrecy, and Civilian Targeting." *International Studies Quarterly* 63(2): 322–33.

Li, Yadan, Wenjuan Ma, Qin Kang, Lei Qiao, Dandan Tang, Jiang Qiu, Qinglin Zhang, and Hong Li. 2015. "Night or Darkness, Which Intensifies the Feeling of Fear?" *International Journal of Psychophysiology* 97(1): 46–57.

Litina, Anastasia, and Èric Roca Fernández. 2024. "Solar Eclipses and the Origins of Critical Thinking and Complexity." *The Economic Journal* 134(660): 1545–77.

Lowes, Sara, and Eduardo Montero. 2021. "Concessions, Violence, and Indirect Rule: Evidence from the Congo Free State." *The Quarterly Journal of Economics* 136(4): 2047–91.

McAdam, Doug, Sidney Tarrow, and Charles Tilly. 2001. *Dynamics of Contention*. Cambridge: Cambridge University Press.

Miao, Meng, Jacopo Ponticelli, and Yi Shao. 2021. "Eclipses and the Memory of Revolutions: Evidence from China." https://www.nber.org/papers/w29182 (October 24, 2023).

Micah, Ross. 2016. "Eclipses and the Precipitation of Conflict: Deciphering the Signal to Attack." In *The Religious Aspects of War in the Ancient Near East, Greece, and Rome: Ancient Warfare Series Volume 1*, Ancient Warfare, ed. Krzysztof Ulanowski. Leiden: Netherland: Brill, 99–120.

Michalopoulos, Stelios, and Elias Papaioannou. 2016. "The Long-Run Effects of the Scramble for Africa." *American Economic Review* 106(7): 1802–48.

Michalopoulos, Stelios, and Melanie Meng Xue. 2021. "Folklore." *The Quarterly Journal of Economics* 136(4): 1993–2046.

Moscona, Jacob, Nathan Nunn, and James A. Robinson. 2020. "Segmentary Lineage Organization and Conflict in Sub-Saharan Africa." *Econometrica* 88(5): 1999–2036.

Murakami, Daisuke. 2017. "Spmoran: An R Package for Moran's Eigenvector-Based Spatial Regression Analysis." https://cran.r-hub.io/web/packages/spmoran/vignettes/vignettes.pdf (December 23, 2023).

Musharraf, Muhammad Nabeel, and Basheer Ahmad Dars. 2021. "Eclipses, Mythology, and Islam." *Al-Duhaa* 2(02): 01–16.

News 24. 2006. “Eclipse Causes Fear in Nigeria.” https://www.news24.com/news24/eclipse-causes-fear-in-nigeria-20060329 (October 24, 2023).

Nunn, Nathan. 2007. *The Long-Term Effects of Africa’s Slave Trades*. National Bureau of Economic Research. http://www.nber.org/papers/w13367 (October 6, 2015).

Oruru, Bosco, Harriet Najjemba, Caroline Joyce Atim, Ronald Nteziyaremye, and Merciline Nayibinga. 2021. “Cultural Astronomy in Uganda from the Perspectives of the Acholi, Banyankole, Iteso and Lugbara.” *African Journal of History and Culture* 13(2): 88–101.

Oruru, Bosco, Harriet Najjemba, Annet Eva Zawedde, Ronald Nteziyaremye, Merciline Nayibinga, and Florence Mutonyi Dâ€™ujanga. 2020. “The First Track of Cultural Astronomy in Uganda: Perspectives of the Baganda, Bagisu, Banyoro and Langi.” *African Journal of History and Culture* 12(2): 35–48.

Page, Richard A., and Martin K. Moss. 1976. “Environmental Influences on Aggression: The Effects of Darkness and Proximity of Victim.” *Journal of Applied Social Psychology* 6(2): 126–33.

Palmer, James. 2001. “Africa on Riot Alert over First Eclipse of Millennium.” *The Independent*. https://www.independent.co.uk/news/world/africa/africa-on-riot-alert-over-first-eclipse-of-millennium-9222951.html (October 24, 2023).

Paolini, Stefania, Jake Harwood, and Mark Rubin. 2010. “Negative Intergroup Contact Makes Group Memberships Salient: Explaining Why Intergroup Conflict Endures.” *Personality and Social Psychology Bulletin* 36(12): 1723–38.

Parkinson, Sarah E. 2023. “Unreported Realities: The Political Economy of Media-Sourced Data.” *American Political Science Review*: 1–6.

Phillips, Barnaby. 2001. "Eclipse Triggers Nigeria Riot." *BBC News*. http://news.bbc.co.uk/1/hi/world/africa/1110791.stm (October 24, 2023).

Rainey, Carlisle. 2014. "Arguing for a Negligible Effect." *American Journal of Political Science* 58(4): 1083–91.

Raleigh, Clionadh, Andrew Linke, and Caitriona Dowd. 2014. "Armed Conflict Location and Event Data Project (ACLED) Codebook 3." http://www.acleddata.com/wp-content/uploads/2014/08/ACLED_Codebook_2014_updated.pdf (August 22, 2015).

Schafer, Jerome, and John B. Holbein. 2020. "When Time Is of the Essence: A Natural Experiment on How Time Constraints Influence Elections." *The Journal of Politics* 82(2): 418–32.

Schaller, Mark, Justin H. Park, and Annette Mueller. 2003. "Fear of the Dark: Interactive Effects of Beliefs about Danger and Ambient Darkness on Ethnic Stereotypes." *Personality and Social Psychology Bulletin* 29(5): 637–49.

Slough, Tara. 2023. "Phantom Counterfactuals." *American Journal of Political Science* 67: 137–53.

Steel, Duncan. 2001. *Eclipse: The Celestial Phenomenon That Changed the Course of History*. Washington, DC: Joseph Henry Press.

Steidle, Anna, Eva-Verena Hanke, and Lioba Werth. 2013. "In the Dark We Cooperate: The Situated Nature of Procedural Embodiment." *Social Cognition* 31(2): 275–300.

Steidle, Anna, and Lioba Werth. 2013. "Freedom from Constraints: Darkness and Dim Illumination Promote Creativity." *Journal of Environmental Psychology* 35: 67–80.

Steidle, Anna, and Lioba Werth. 2014. "In the Spotlight: Brightness Increases Self-Awareness and Reflective Self-Regulation." *Journal of Environmental Psychology* 39: 40–50.

Steidle, Anna, Lioba Werth, and Eva-Verena Hanke. 2011. "You Can't See Much in the Dark: Darkness Affects Construal Level and Psychological Distance." *Social Psychology* 42(3): 174–84.

Stock, James H, Jonathan H Wright, and Motohiro Yogo. 2002. "A Survey of Weak Instruments and Weak Identification in Generalized Method of Moments." *Journal of Business & Economic Statistics* 20(4): 518–29.

Sun, Chengjiu, and Hongfei Li. 2023. "The Celestial Empire: Solar Eclipses, Political Legitimacy, and Economic Performance in Historical China." *Cliometrica*.

Tajfel, H. 1982. "Social Psychology of Intergroup Relations." *Annual Review of Psychology* 33(1): 1–39.

Tajfel, Henri. 2010. *Human Groups and Social Categories: Studies in Social Psychology*. Cambridge; New York: Cambridge University Press.

Tealde, Emiliano. 2022. "The Unequal Impact of Natural Light on Crime." *Journal of Population Economics* 35(3): 893–934.

Tennakone, Kirthi. 2018. "Historical and Social Aspects of Solar Eclipse Occurrences." *Sri Lanka Journal of Social Sciences* 41(1): 25–37.

Tollefsen, Andreas Forø, Håvard Strand, and Halvard Buhaug. 2012. "PRIO-GRID: A Unified Spatial Data Structure." *Journal of Peace Research* 49(2): 363–74.

Toro, Weily, Robson Tigre, and Breno Sampaio. 2019. "Daylight Saving Lives: The Effect of Daylight Saving Time on Homicides." https://papers.ssrn.com/abstract=2786452 (November 7, 2023).

Tullock, Gordon. 1971. "The Paradox of Revolution." *Public Choice* 11(1): 89–99.

Urama, J. O. 2008. “Astronomy and Culture in Nigeria.” In *African Cultural Astronomy*, eds. Jarita C. Holbrook, Johnson O. Urama, and R. Thebe Medupe. Dordrecht: Netherland: Springer Netherlands, 231–38.

Valentino, Benjamin A. 2014. “Why We Kill: The Political Science of Political Violence against Civilians.” *Annual Review of Political Science* 17(1): 89–103.

Varshney, Ashutosh. 2003. “Nationalism, Ethnic Conflict, and Rationality.” *Perspectives on Politics* 1(1): 85–99.

Vogt, Manuel, Nils-Christian Bormann, Seraina Rüegger, Lars-Erik Cederman, Philipp Hunziker, and Luc Girardin. 2015. “Integrating Data on Ethnicity, Geography, and Conflict: The Ethnic Power Relations Data Set Family.” *Journal of Conflict Resolution* 59(7): 1327–42.

van Weezel, Stijn. 2020. “Local Warming and Violent Armed Conflict in Africa.” *World Development* 126: 104708.

Weidmann, Nils B. 2016. “A Closer Look at Reporting Bias in Conflict Event Data.” *American Journal of Political Science* 60(1): 206–18.

Welsh, Brandon C., and David P. Farrington. 2008. “Effects of Improved Street Lighting on Crime.” *Campbell Systematic Reviews* 4(1): 1–51.

Wennekers, A. M., R. W. Holland, D. H. Wigboldus, and A. Van Knippenberg. 2012. “Prejudice in the Dark: How Darkness Facilitates Negative Associations with a Feared Out-Group.” In *Proceedings of Experiencing Light 2012*, Eindhoven, Metherland, 1–4.

Wilson, Rick K. 2011. “The Contribution of Behavioral Economics to Political Science.” *Annual Review of Political Science* 14(1): 201–23.

Wooldridge, Jeffrey M. 2009. *Introductory Econometrics: A Modern Approach*. Boston, MA: Cengage Learning.

Wuam, Pius Williams, and Kabiru Shehu. 2022. “Hausa People’s Perception of Eclipses: A Natural Phenomena or Superstition?” *International Journal of Intellectual Discourse* 5(2): 355–65.

Xu, Yiqing. 2023. “Causal Inference with Time-Series Cross-Sectional Data: A Reflection.” In *The Oxford Handbook of Methodological Pluralism in Political Science*, eds. Janet M. Box-Steffensmeier, Dino P. Christenson, and Valeria Sinclair-Chapman. Oxford, New York: Oxford University Press.

Zhang, Yu, Zhicheng Phil Xu, and Shahriar Kibriya. 2021. “The Long-Term Effects of the Slave Trade on Political Violence in Sub-Saharan Africa.” *Journal of Comparative Economics* 49(3): 776–800.

Zhong, Chen-Bo, Vanessa K. Bohns, and Francesca Gino. 2010. “Good Lamps Are the Best Police: Darkness Increases Dishonesty and Self-Interested Behavior.” *Psychological Science* 21(3): 311–14.

Zhou, Xiang, and Teppei Yamamoto. 2023. “Tracing Causal Paths from Experimental and Observational Data.” *The Journal of Politics* 85(1): 250–65.

Online Appendix for

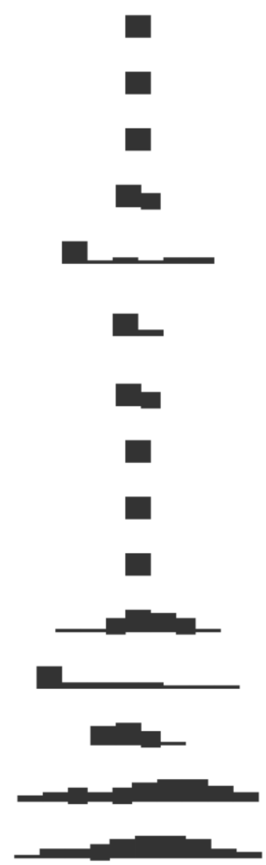
"Eclipse: How Darkness Shapes Violence in Africa"

Table of Contents

A1. Summary Statistics

Table A1-1. Summary Statistics

	Mean	SD	Min	Median	Max	N	Histogram
ΔViolence	0.00	3.18	-100.00	0.00	100.00	274274	
ΔBattle	0.00	2.60	-100.00	0.00	100.00	274274	
ΔProtest	0.00	2.81	-85.71	0.00	100.00	274274	
Eclipse	0.37	0.48	0.00	0.00	1.00	337568	
Christians (prop.)	0.37	0.38	0.01	0.25	0.98	337504	
Excluded groups (prop.)	0.22	0.41	0.00	0.00	1.00	337568	
Conflict zone (dummy)	0.38	0.49	0.00	0.00	1.00	327019	
Night light	0.01	0.04	0.00	0.00	0.97	327019	
GCP	0.05	0.23	0.00	0.01	4.93	335584	
Population	0.06	0.19	0.00	0.01	8.98	337568	
Temperature	24.41	3.92	10.92	24.57	39.07	332384	
Precipitation	0.66	0.62	0.00	0.47	2.55	337568	
Elevation	0.61	0.48	-2.25	0.51	3.02	337568	
Latitude	6.14	17.66	-34.75	8.75	37.25	337568	
Longitude	18.65	15.55	-17.75	20.25	51.25	337568	



The table shows the summary statistics of the main variables and covariates. The last column shows the histograms of those variables. The data of Christian population, excluded groups, and conflict zones are the same as in the main analysis (see p.34). The data on nighttime light come from Li et al. (2020). The data on elevation come from ETOPO05 by NOAA. The other data come from the PRIO GRID. Ref.: Li, Xuecao, Yuyu Zhou, Min Zhao, and Xia Zhao. 2020. “A Harmonized Global Nighttime Light Dataset 1992–2018.” *Scientific Data* 7(1): 168.

A2. Validity Check: Balance Checks

Table A2-1. Balance Checks

	Mean (Treated)	Mean (Control)	Std. difference	Var. ratio	p-value
Christians (prop.)	0.393	0.362	0.059	1.026	0.574
Excluded groups (prop.)	0.232	0.215	0.029	1.056	0.097
Conflict zone (dummy)	0.375	0.382	-0.009	0.994	0.911
Night light (log)	-9.102	-8.924	-0.032	0.933	0.703
GCP (log)	-5.228	-5.198	-0.01	1.012	0.762
Population (log)	-4.735	-4.65	-0.027	0.998	0.584
Temperature	24.208	24.523	-0.057	1.044	0.302
Precipitation (log)	-1.303	-1.282	-0.009	0.969	0.918
Elevation	0.633	0.596	0.055	1.061	0.211
Latitude	4.431	7.15	-0.108	1.16	0.4
Longitude	18.941	18.48	0.021	0.955	0.783

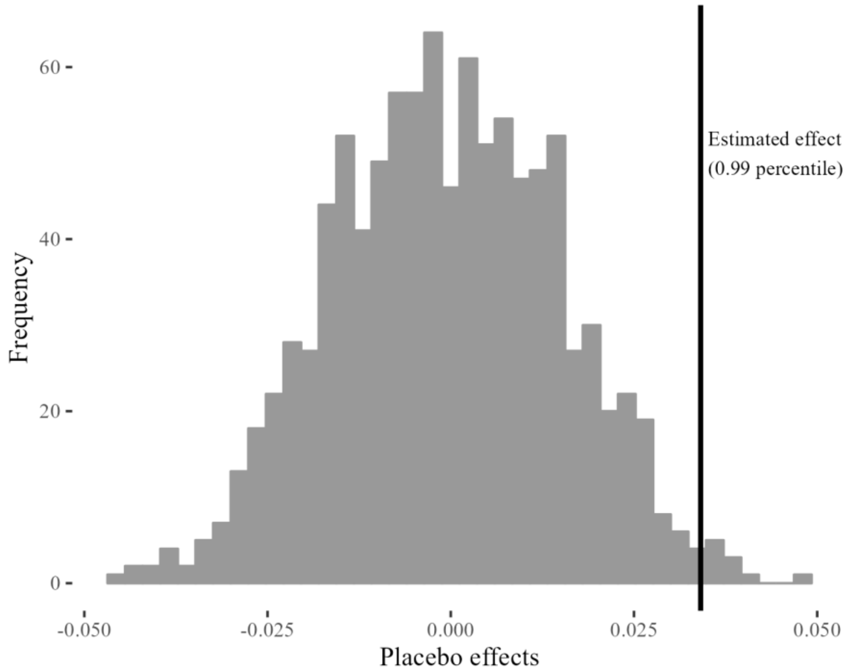
The table shows the results of balance checks, in which the treated and control cells are compared with respect to their values in the covariates. As a rule of thumb, they are considered as balanced if the standardized mean difference (Std. difference) of each covariate is between -0.2 and 0.2, the variance ratio (Var. ratio) is between 0.5 and 2.0, and the p-value of the t-test is above 0.1 or 0.2.

A3. Validity Check: Randomization Test

I check the validity of the analysis by randomly reshuffling the solar eclipses. I reshuffle the 26 solar eclipses in the sample, assign corresponding $eclipse_{ij}$, and estimate the effect of the placebo variable on $\Delta violence$.[1] I repeat this 1,000 times and compare the placebo effects with the treatment effect (i.e., Table 1). As seen in Figure A3-1, the treatment effect is larger than 98.7% of the placebo effects. Moreover, only 4.6% and 9.9% of the placebo effects are statistically significant at a 5% and 10% level, respectively. Thus, it is unlikely that the analysis over-rejects the null.

[1] I resample the data at the level of eclipses. For example, consider a hypothetical sample of two eclipses with four cells, where $eclipse_{ij}$ is $\{(1,1,0,0),(0,1,0,1)\}$. Then, a reshuffled treatment is $\{(0,1,0,1),(1,1,0,0)\}$. The standard errors of placebo effects are clustered by reshuffled eclipse.

Figure A3-1. Randomization Test

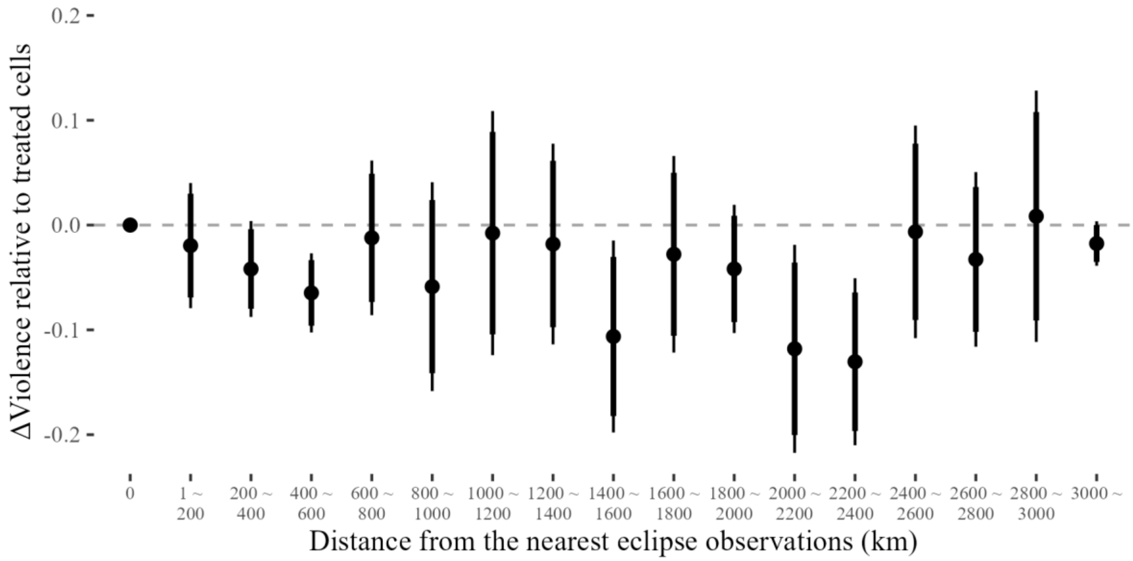


The figure compares the estimated treatment effect (vertical bar) to the placebo effects (histogram) generated from simulation, where the solar eclipses are randomly reshuffled for 1,000 times and the effects are estimated with the reshuffled eclipses. The estimated treatment effect is larger than 98.7% of the placebo effects.

A4. Validity Check: Spatial Displacement of Violence

One concern is that eclipses displaced violence from the control to treated cells. Armed groups might move to the treated cells to attack the crowds of people and those praying. With spatial displacement, the estimate can be biased upward. I check the spatial displacement by disaggregating the control cells to those at different distances from the nearest locations of eclipse observations. Because displacement is likely to occur near the treated cells, the difference should be larger in the control cells near eclipse observations. Figure A4-1 compares the difference in the probabilities of violence in control cells at each distance from eclipse observations, to the difference in the treated cells (0 distance), showing no evidence of spatial displacement. Even compared to the control cells over 2,000 km away from the eclipse observations, the treated cells (0 distance in Figure A4-1) experienced a greater degree of violence.

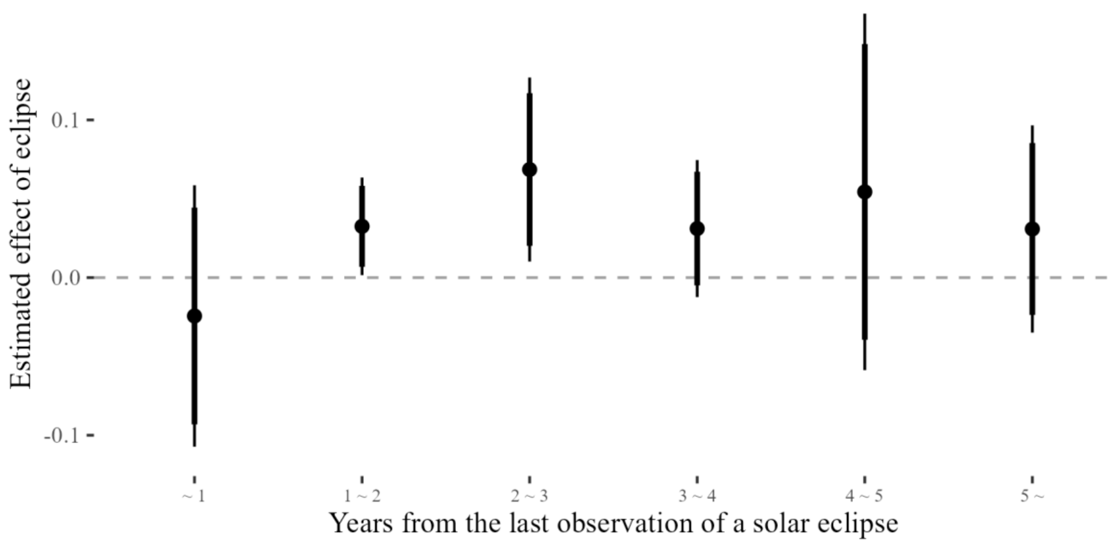
Figure A4-1. Check for Spatial Displacement



The figure shows $\Delta violence$ (changes in the number of violent events after eclipses) for the control cells at each distance from the nearest locations of eclipse observations. Because the effect is positive in the treated cells, the values are negative when the values in the control cells are compared to those in the treated cells. The standard errors are clustered by eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

A5. Mechanism Check: Time from the Last Eclipse

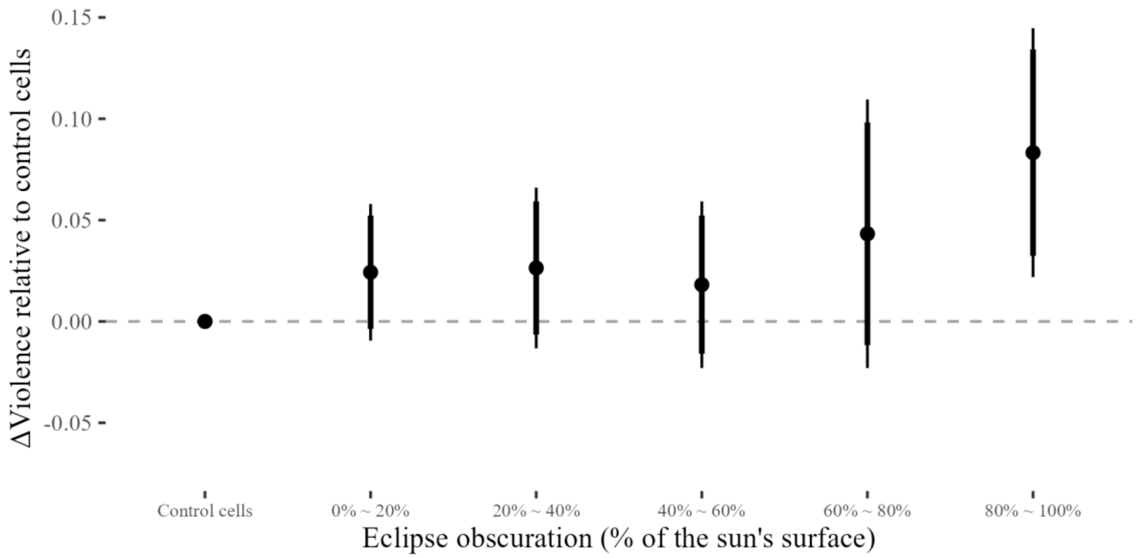
Figure A5-1. Heterogeneous Effects by the Time from the Last Solar Eclipse



The figure shows the effects of solar eclipses on $\Delta violence$ (changes in the number of violent events after eclipses) by the years from the last observation of a solar eclipse. The standard errors are clustered by eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

A6. Mechanism Check: Obscuration Rates of Eclipses

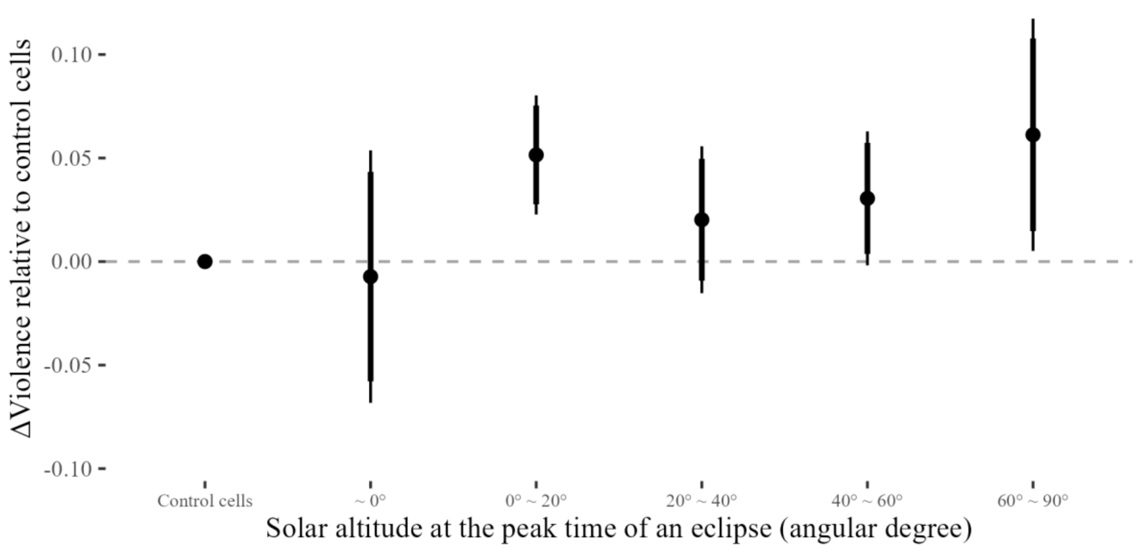
Figure A6-1. Heterogeneous Effects by Obscuration Rates



The figure shows the effects of solar eclipses on $\Delta violence$ (changes in the number of violent events after eclipses) by the percentages of the Sun's surface hidden by the Moon. The results are similar with the visual magnitude of the eclipses (see Table 4 for the visual magnitude). The standard errors are clustered by eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

A7. Mechanism Check: The Sun's Altitudes

Figure A7-1. Heterogeneous Effects by the Sun's Altitudes at the Peaks of Solar Eclipses



The figure shows the effects of solar eclipses on $\Delta violence$ (changes in the number of violent events after eclipses) by the Sun's altitudes at the peaks of solar eclipses (angular degrees). The altitude takes a negative value when an eclipse is not observable at a peak time. The standard errors are clustered by eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

A8. Mechanism Check: Lunar Eclipse

Table A8-1. Results with Lunar Eclipses

	ΔViolence	ΔBattle	ΔProtest
Eclipse	0.013 (0.009)	-0.005 (0.007)	0.018 (0.011)
(Intercept)	-0.004 (0.007)	0.010 (0.006)	-0.016 (0.011)
N	548,548	548,548	548,548

The table shows the estimated effects of lunar eclipses. Because lunar eclipses occur at night, the posttreatment period includes the days of the eclipses and one day after the eclipses. The other specifications are the same as those in the main analysis. The standard errors are clustered by eclipse. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$.

A9. Mechanism Check: Individual-level Surveys

I analyze the psychological impacts of eclipses using the Afrobarometer surveys (2019). I use survey items about respondents' feelings of being unsafe and neighborhood crimes (*sense of insecurity*), willingness to have neighbors of different religions and ethnicities (*outgroup neighbors*), and trust in religious and traditional leaders (*ingroup leaders*). Each variable is the average of two corresponding survey items. Table A9-1 shows the list of the items. I standardize the outcome variables by dividing them by their standard deviations. I use the sixth to eighth rounds of the Afrobarometer (2015–2022), wherein all of the survey items are available.

Table A9-1. Survey Items

Sense of insecurity	Q1: Over the past year, how often, if ever, have you or anyone in your family: Feared crime in your own home? Q2: Over the past year, how often, if ever, have you or anyone in your family: Felt unsafe walking in your neighbourhood? A: 0: Never, 1: Just once or twice, 2: Several times, 3: Many times, 4: Always.
Outgroup neighbors	Q1: For each of the following types of people, please tell me whether you would like having people from this group as neighbours, dislike it, or not care: People of a different religion. Q2: For each of the following types of people, please tell me whether you would like having people from this group as neighbours, dislike it, or not care: People from other ethnic groups. A: 1: Strongly dislike, 2: Somewhat dislike, 3: Would not care, 4: Somewhat like, 5: Strongly like.
Ingroup leaders	Q1: How much do you trust each of the following, or haven't you heard enough about them to say: Religious leaders? Q2: How much do you trust each of the following, or haven't you heard enough about them to say: Traditional leaders? A: 0: Not at all, 1: Just a little, 2: Somewhat, 3: A lot.

With the geocoded versions of the Afrobarometer, I create a treatment variable $eclipse_k$ that takes 1 if a solar eclipse was observed in respondent k's location.[2] This variable is interacted with another treatment variable $after_k$ that takes 1 if respondent k was interviewed on the day of a solar eclipse or later. As in the main analysis, I compare the respondents interviewed on the days of solar eclipses to those interviewed within one week before the eclipses, and supplement it with the event study. Following Goldsmith et al. (2021), I use data only if there are both treated and control respondents for a given country-eclipse, such that I can make a comparison within each country-eclipse. This results in about 2,100 respondents in seven countries for 2015–2021. Similarly, I follow Goldsmith et al. (2021) and include country-eclipse fixed effects to focus on variation *within* each country-eclipse, instead of variation *across* country-eclipses. This is

[2] I merged Afrobarometer data with the main dataset using the PRIO GRID.

important as the proportions of treated and control respondents substantially vary across country-eclipses. Because the sample includes only five solar eclipses, I cluster the standard error by each province-eclipse.[3] Table A9-2 shows the summary statistics of the main variables.

Table A9-2. Summary Statistics (Survey)

	Mean	SD	Min	Median	Max	N	Histogram
Sense of insecurity	0.25	1.09	-0.75	0.12	2.75	2105	
Outgroup neighbors	0.24	0.95	-2.58	0.62	1.08	2100	
Ingroup leaders	0.12	0.98	-2.09	0.49	1.00	2071	
Eclipse	0.17	0.38	0.00	0.00	1.00	2106	
After	0.13	0.34	0.00	0.00	1.00	2106	
Female	0.50	0.50	0.00	1.00	1.00	2106	
Muslim	0.44	0.50	0.00	0.00	1.00	2106	
Unemployed	0.74	0.44	0.00	1.00	1.00	2106	
Age	37.36	14.48	18.00	35.00	96.00	2104	
Primary educ.	0.20	0.40	0.00	0.00	1.00	2106	
Secondary educ.	0.48	0.50	0.00	0.00	1.00	2106	
Media access	1.68	1.16	0.00	1.40	4.00	2104	
Poverty	1.34	0.87	0.00	1.20	4.00	2105	

The table shows the summary statistics of the main variables and demographic covariates. The last column shows the histograms of those variables.

As seen in Table A9-3, solar eclipses decreased respondents’ willingness to have outgroup neighbors, whereas their effects on the sense of insecurity and trust in ingroup leaders are indistinguishable from zero. The results appear to partially support the psychological explanation.

[3] The results hold even with standard errors clustered by country-eclipse or eclipse. Indeed, the standard errors become too small due to the small number of clusters.

Nevertheless, it is also possible that the estimates capture the indirect effects of violence; solar eclipses may incite violence, which in turn elicits hostility toward outgroups.

Table A9-3. The Psychological Effects of Solar Eclipses at an Individual Level

	Sense of insecurity	Outgroup neighbors	Ingroup leaders
Eclipse × After	-0.171	-0.487**	0.063
	(0.111)	(0.177)	(0.129)
After	0.005	-0.033	0.008
	(0.084)	(0.100)	(0.096)
Eclipse	0.394**	-0.152	0.190
	(0.100)	(0.215)	(0.280)
N	2,105	2,100	2,071

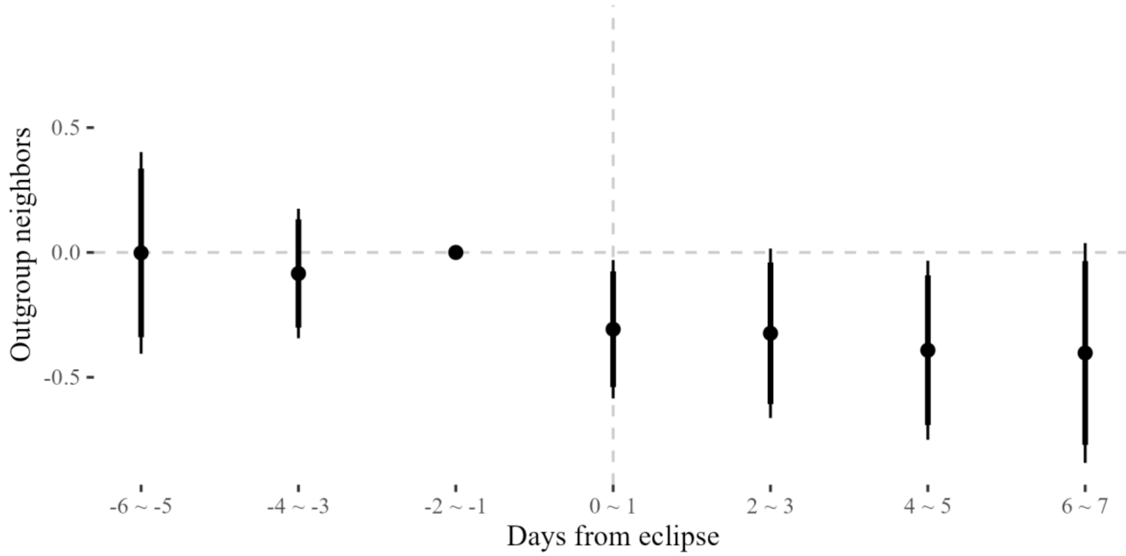
The figure shows the estimated effects of solar eclipses on the sense of insecurity, willingness to have neighbors of different religion and ethnicity, and trust in religious and traditional leaders. The outcome variables are standardized. The sample is based on the sixth to eighth rounds of Afrobarometer and includes only surveys whose periods overlapped with solar eclipses. The sample contains five solar eclipses in seven countries for the period 2015–2021. The models include country-eclipse fixed effects. The standard errors are clustered by province-eclipse. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$.

The results of the event study, presented in Figure A9-1, are more consistent with the latter interpretation; the effects on the attitudes toward outgroup neighbors persist for one week.[4] Unless solar eclipses continue to affect people for a week, the results cannot be explained by the psychological mechanism. Conversely, people remember violence for a longer time, and thus, eclipse-induced violence can affect public opinion for a week (Berrebi and Klor 2008). In addition, consistent with the tactical mechanism, eclipses had a particularly large impact on the hostility toward outgroups and even increased the trust in ingroup leaders on *cloudy* days (Table A9-4). These results suggest that people psychologically reacted even when they could not see eclipses. Admittedly, the effects on the sense of insecurity and trust in ingroup leaders are imprecise, and

[4] Because the number of respondents interviewed on each day is limited, they are grouped into two-day intervals.

thus, the results do not fully support the interpretation (although the tactical explanation itself does not strongly rely on the psychological reactions of individuals). However, it would be premature to interpret Table A9-3 as support for the psychological explanation.[5]

Figure A9-1. Event Study of the Attitudes toward Outgroup Neighbors



The figure shows the results of the event study for the attitudes toward outgroup neighbors. Because the number of respondents interviewed on each day is limited, they are grouped into two-day intervals. The baseline category is respondents who are interviewed on one or two days before solar eclipses. The sample is based on the sixth to eighth rounds of Afrobarometer and includes only surveys whose periods overlapped with solar eclipses. The sample contains 3,221 respondents for five solar eclipses in seven countries, 2015–2021. The sample contains more respondents than those in Table A9-2 as the sample period is extended one week before and after solar eclipses. The models include country-eclipse fixed effects. The standard errors are clustered by province-eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

[5] I do not conduct mediation analysis or compare the effects with and without violent events, as the mediator, violence, is endogenous, and thus, the core assumption, sequential ignorability, is not satisfied (Bansak 2020; Imai, Keele, and Tingley 2010; Keele and Stevenson 2021; Slough 2023; Zhou and Yamamoto 2023). It is implausible to assume that violence only depends on solar eclipses and the remaining variance is (conditionally) ignorable.

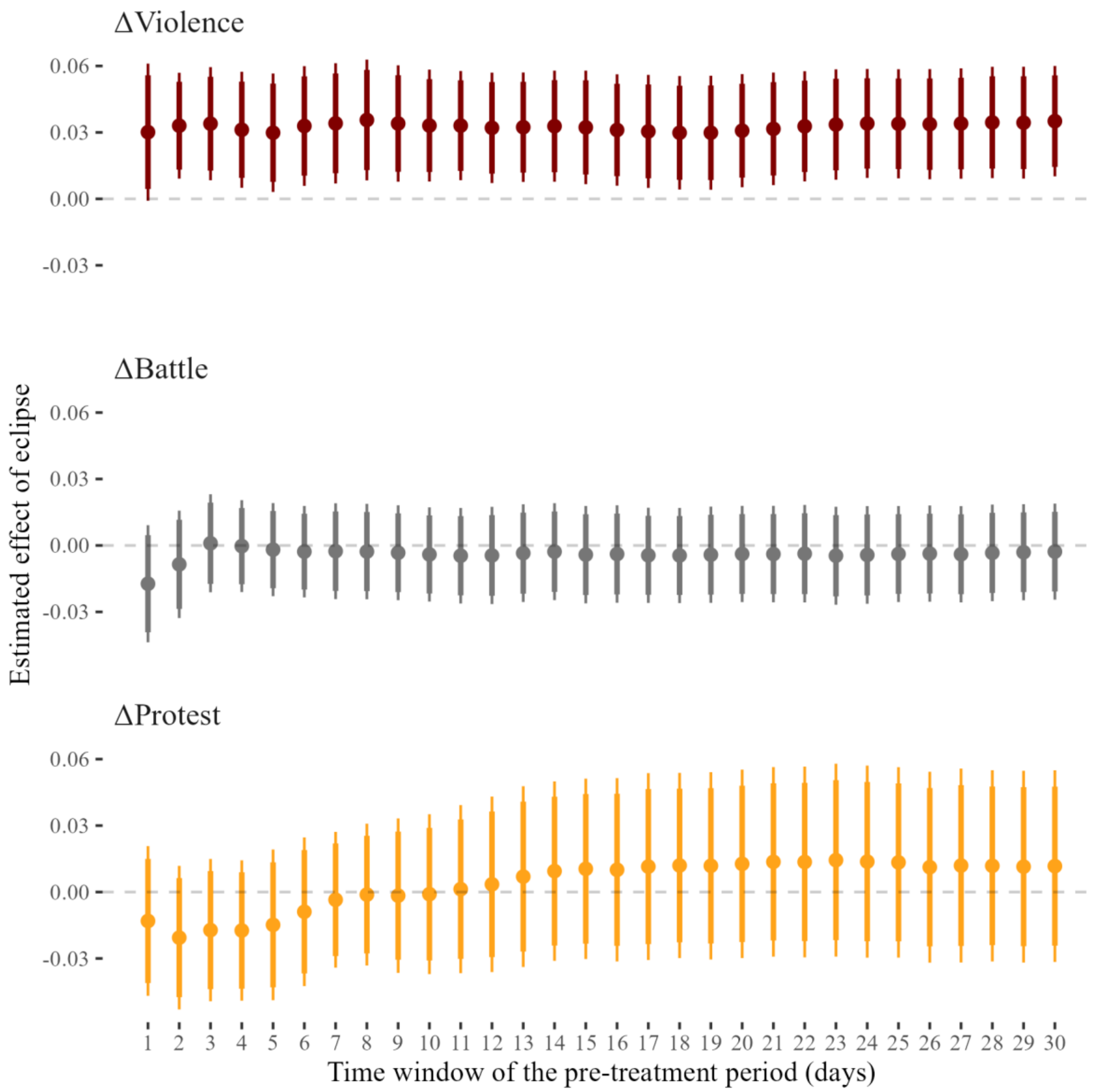
Table A9-4. The Effects of Solar Eclipses Conditional on Cloud Cover (Survey)

	Sense of insecurity		Outgroup neighbors		Ingroup leaders	
	1	2	3	4	5	6
Eclipse × After × Cloud cover	-0.726	-1.642	-2.756**	-1.914*	1.959**	1.161†
	(0.804)	(1.737)	(0.461)	(0.741)	(0.465)	(0.671)
Eclipse × Cloud cover	0.644	0.222	-0.836*	-0.775†	1.258*	1.390*
	(0.482)	(0.496)	(0.407)	(0.423)	(0.533)	(0.603)
After × Cloud cover	0.022	0.237	-0.527*	-0.010	0.325	0.599
	(0.245)	(0.376)	(0.210)	(0.290)	(0.244)	(0.474)
Cloud cover	0.108	0.316	0.330	0.222	-0.658†	-0.927†
	(0.290)	(0.300)	(0.326)	(0.325)	(0.375)	(0.484)
Eclipse × After × Cloud cover a year before eclipse		-4.375		5.768**		-3.041**
		(4.697)		(1.172)		(0.878)
Eclipse × Cloud cover a year before eclipse		0.434†		0.294		0.977**
		(0.260)		(0.195)		(0.354)
After × Cloud cover a year before eclipse		-0.296		-0.528*		-0.217
		(0.314)		(0.231)		(0.445)
Cloud cover a year before eclipse		0.441*		-0.099		-0.456
		(0.212)		(0.150)		(0.329)
Eclipse × After	0.319	1.057	1.904**	0.661	-1.643**	-1.084*
	(0.642)	(1.488)	(0.434)	(0.735)	(0.373)	(0.487)
After	-0.004	0.004	0.098	0.093	-0.057	-0.070
	(0.108)	(0.105)	(0.119)	(0.118)	(0.117)	(0.118)
Eclipse	-0.066	0.554	0.290	0.124	-0.511	-1.038†
	(0.280)	(0.396)	(0.341)	(0.383)	(0.411)	(0.590)
N	2,105	2,105	2,100	2,100	2,071	2,071

The figure shows the estimated effects of solar eclipses on the sense of insecurity, willingness to have neighbors of different religion and ethnicity, and trust in religious and traditional leaders, conditional on cloud cover during the eclipses. The outcome variables are standardized. The cloud cover is based on the weighted average of hourly cloud cover in each cell and eclipse. In Model 1, 3, and 5, the treatment variables are interacted with the cloud cover. In Model 2, 4, and 6, the treatment variables are also interacted with the cloud cover for the same hours but in a year prior to the eclipses to control for geographic, climatic, and other confounders. The models include country-eclipse fixed effects. The standard errors are clustered by province-eclipse. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$.

A10. Robustness Check: Time Windows of the Pretreatment Period

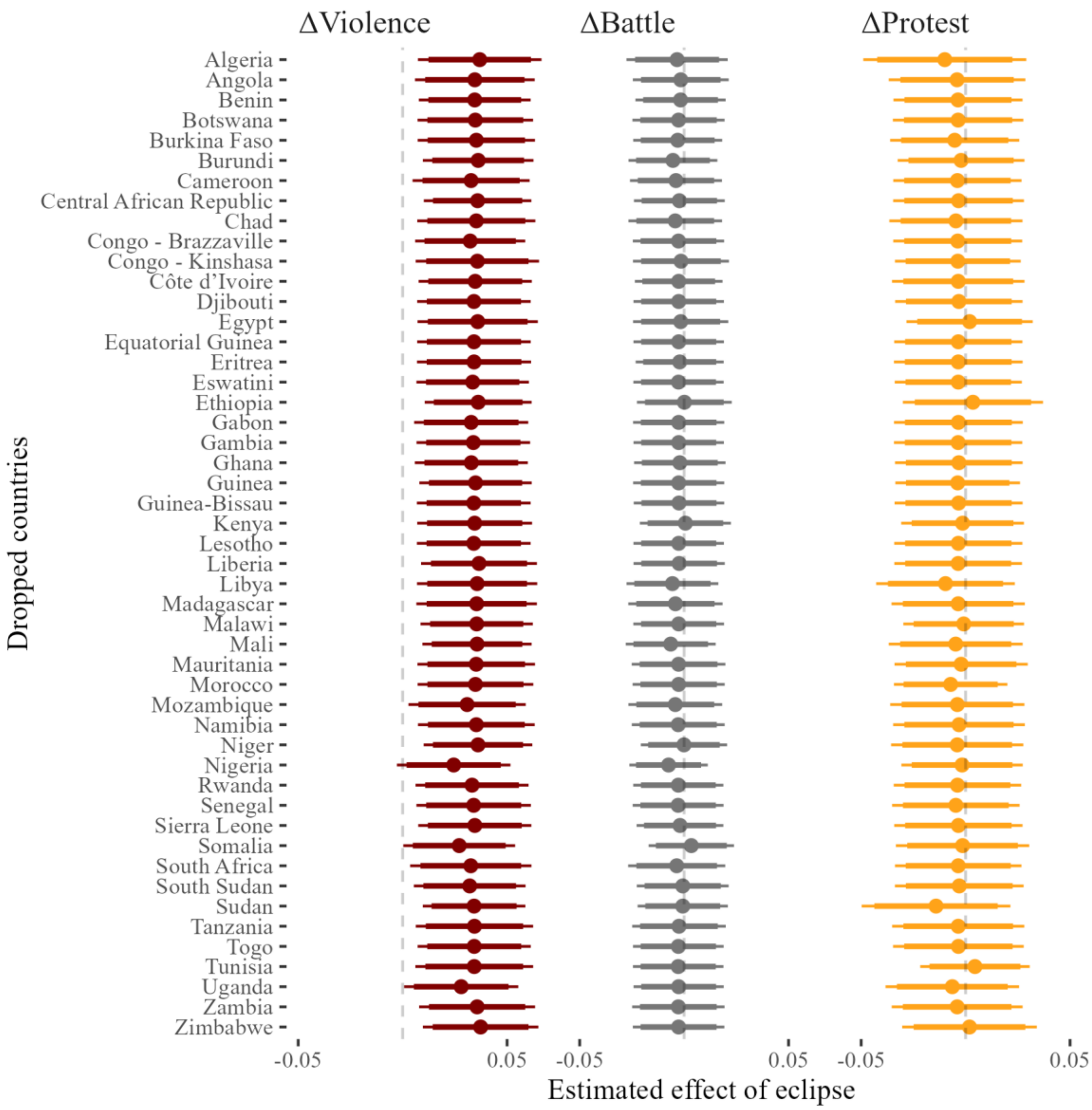
Figure A10-1. Different Time Windows for the Pretreatment Period



The figure shows the estimated coefficients when the time window of the pretreatment period is changed to 1 to 30 days before eclipses. For example, when the time window is set to 3, it means that violence on the days of eclipses is compared to the average probability of violence for the past 3 days from the eclipses. The standard errors are clustered by eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

A11. Robustness Check: Leave-one-country-out Tests

Figure A11-1. Leave-one-country-out Tests



The figure shows the estimated coefficients when each country displayed on the vertical axis is dropped from the sample. The standard errors are clustered by eclipse. The thick and thin vertical intervals are the 90% and 95% confidence intervals, respectively.

A12. Robustness Check: UCDP GED and SCAD

Although the UCDP GED and SCAD contain much fewer violent events and thus the power of analysis is weaker, the results are mostly similar. With the UCDP GED, I find that solar eclipses increased non-state actors' violence against civilians, while eclipses did not affect states' violence or battles. Similarly, with the SCAD, the point estimate remains positive, although the estimate becomes imprecise. However, when I disaggregate violence by issues (religious, ethnic, and other issues), I find that solar eclipses increased violence unrelated to religious or ethnic issues. This is consistent with the main analysis and the tactical explanation.

Table A12-1. The Results with the UCDP GED

	Violence		Battle	
	Non-state	State	State vs Non-state	Non-state vs Non-state
Eclipse	0.008†	-0.002	-0.004	0.003
	(0.005)	(0.003)	(0.007)	(0.004)
(Intercept)	-0.001	0.002	-0.002	-0.003
	(0.003)	(0.003)	(0.006)	(0.002)
N	337,568	337,568	337,568	337,568

The table shows the results with the UCDP GED. The outcome variables are the changes in the incidences of violence against civilians by non-state and state actors, and battles between state and non-state actors, and non-state actors. The standard errors are clustered by eclipse. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$.

Table A12-2. The Results with the SCAD

		Violence by the issue at stake		
	Violence	Religious	Ethnic	Other
Eclipse	0.003	-0.002	0.000	0.005†
	(0.002)	(0.002)	(0.000)	(0.002)
(Intercept)	-0.004†	0.000	-0.001**	-0.002
	(0.002)	(0.001)	(0.000)	(0.001)
N	274,274	274,274	274,274	274,274

The table shows the results with the SCAD. The outcome variables are the changes in the incidences of violence and violence related to religious, ethnic, and other issues. The standard errors are clustered by eclipse. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$.

A13. Robustness Check: Spatial Regression

I implement two parametric models: spatial error model (SEM), where an error term auto-correlates among spatial neighbors, and spatial autoregressive model (SAR), where a spatial lag of an outcome variable appears on the right-hand side of a regression. Because of the large sample size, I use the low-rank approximation with spatial eigenvectors and the four nearest neighbors (Murakami 2017). I also implement a semiparametric approach: the eigenvector spatial filtering (ESF), which flexibly approximates any spatial dependency (Griffith, Chun, and Li 2019; Murakami 2017). Because the estimation takes a long time, I only estimate the effects on violence. As seen in Table A13-1, the main result holds across all of the models. Although the outcome variable has a strong negative dependency with no indirect effect (SAR), the error term has zero autocorrelation (SEM), and the spatial filtering nearly eliminated spatial dependency (ESF).

Table A13-1. Spatial Regression

	SEM	SAR	ESF
Eclipse	0.034* (0.012)	0.035* (0.012)	0.035* (0.012)
(Intercept)	-0.018* (0.008)	-0.018* (0.008)	-0.019* (0.008)
Indirect effect		-0.000	
λ	0.000		
ρ		-0.995	
Moran's *I*			0.030
eigenvectors	100	100	69
BIC	1,413,001	1,413,000	1,413,665
N	274,274	274,274	274,274

SEM: Spatial error model. SAR: Spatial autoregressive model. ESF: Eigenvector spatial filtering. The SAR model also shows the indirect effect of eclipse on neighboring locations. λ refers to the autocorrelation of error terms among spatial neighbors. ρ refers to the coefficient of a spatial lag. Moran's I of the residuals is standardized to 0-1. As a rule of thumb, spatial dependency is weak if Moran's I is 0.25~0.50, moderate if it is 0.50~0.70, and strong if it is 0.70~1.00. The table also shows the numbers of eigenvectors used in the analyses and the Bayesian Information Criteria (BIC). The outcome variable is the changes in the incidences of violence. The standard errors are those corresponding to each model. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$.

A14. Robustness Check: Other

Table A14-1. Other Robustness Checks (Violence)

		Measurement & Sample				GLM			Control & FE								Standard error	
	Main	Including Day1	Over 1,000 pop	Count	Logged count	Logit	Poisson	Negative binomial	Control variables	Country × Eclipse FE	Province × Eclipse FE	Time FE	Calendar FEs	Islamic calendar	Differential time trends	Spatial controls	Two-way clustering	Conley SE
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Eclipse× After	0.034*	0.023*	0.042*	0.036*	0.025*	0.034*	0.348*	0.348*	0.025*	0.034*	0.034*	0.034*	0.026†	0.035**	0.034*	0.034*	0.034*	0.034*
	(0.013)	(0.011)	(0.016)	(0.015)	(0.010)	(0.013)	(0.141)	(0.141)	(0.010)	(0.013)	(0.013)	(0.013)	(0.014)	(0.012)	(0.013)	(0.013)	(0.013)	(0.014)
After	-0.018	-0.012	-0.022	-0.021	-0.014	-0.018	-0.179	-0.179	-0.009	-0.018	-0.018		-0.019	-0.010	-0.018	-0.018	-0.018	-0.018*
	(0.012)	(0.009)	(0.014)	(0.013)	(0.009)	(0.012)	(0.116)	(0.116)	(0.008)	(0.012)	(0.012)		(0.013)	(0.012)	(0.012)	(0.012)	(0.012)	(0.009)
Eclipse	-0.039	-0.039	-0.048	-0.044	-0.029	-0.039	-0.427	-0.427	-0.015	-0.003	-0.022	-0.039	-0.020	-0.040	-0.028	-0.038	-0.039	-0.039**
	(0.028)	(0.028)	(0.033)	(0.030)	(0.020)	(0.028)	(0.281)	(0.281)	(0.016)	(0.023)	(0.026)	(0.028)	(0.016)	(0.029)	(0.148)	(0.027)	(0.027)	(0.014)
Christians (prop.)									0.088**									
									(0.025)									
Excluded groups (prop.)									0.001									
									(0.010)									
Conflict zone (dummy)									0.092**									
									(0.014)									
Night light (log)									0.017**									
									(0.002)									
GCP (log)									0.007									
									(0.004)									
Population (log)									0.047**									
									(0.009)									
Temperature									0.008**									
									(0.002)									
Precipitation (log)									-0.037**									
									(0.006)									
Elevation									0.024									
									(0.019)									
Latitude									0.000									
									(0.001)									
Longitude									0.000									
									(0.000)									
(Intercept)	0.115**	0.115**	0.140**	0.127**	0.084**	0.115**	-6.666**	-6.666**	0.174**						0.080	-0.196	0.115**	0.115**
	(0.024)	(0.024)	(0.029)	(0.026)	(0.017)	(0.024)	(0.204)	(0.204)	(0.049)						(0.475)	(0.122)	(0.024)	(0.025)
N	2,194,192	2,468,466	1,788,176	2,194,192	2,194,192	2,194,192	2,194,192	2,194,192	2,065,800	2,194,192	2,193,776	2,194,192	2,194,192	8,502,494	2,194,192	2,194,192	2,194,192	2,194,192

The table shows the results of the robustness checks. All models are estimated with the "long-format" dataset, which has a row for each cell i, eclipse j, and t day from the eclipse. Model 1: The results with the long-format dataset, which are identical to the main estimates. Model 2: One day after the eclipses is also included as a treated observation. Model 3: The cells are limited to those over 1,000 population. Model 4: The outcome variable is changed to the count of violence. Model 5: The outcome variable is changed to the logged count of violence. Model 6: The model is changed to the logit model. Model 7: The outcome variable is changed to the count of violence, and the model is changed to the Poisson model. Model 8: The outcome variable is changed to the count of violence, and the model is changed to the negative binomial model. Model 9: Control variables are included. Model 10: Country and eclipse fixed-effects are included. Model 11: Province and eclipse fixed-effects are included. Model 12: Fixed effect for t is included. Model 13: Year, month, day-of-the-week, and day fix-effects are included. Model 14: Fixed effect for each day of the Islamic calendar is included. To mitigate multicollinearity, the pretreatment period includes 30 to 1 days before the eclipses. Model 15: Pretreatment time trend is removed (Goodman-Bacon 2021). Model 16: Cubic splines of latitude and longitude and their full interactions are included. Model 17: Standard errors are two-way clustered by eclipse and cell. Model 18: Conley spatial HAC standard errors are used with a cutoff of 500km. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$. Ref.: Goodman-Bacon, Andrew. 2021. "Difference-in-Differences with Variation in Treatment Timing." *Journal of Econometrics* 225(2): 254–77.

Table A14-2. Other Robustness Checks (Battle)

	Measurement & Sample					GLM			Control & FE								Standard error	
	Main	Including Day1	Over 1,000 pop	Count	Logged count	Logit	Poisson	Negative binomial	Control variables	Country × Eclipse FE	Province × Eclipse FE	Time FE	Calendar FEs	Islamic calendar	Differential time trends	Spatial controls	Two-way clustering	Conley SE
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Eclipse× After	-0.003	-0.002	-0.004	-0.006	-0.003	-0.003	-0.120	-0.120	-0.004	-0.003	-0.003	-0.003	-0.008	-0.003	-0.003	-0.003	-0.003	-0.003
	(0.011)	(0.010)	(0.013)	(0.013)	(0.008)	(0.011)	(0.165)	(0.165)	(0.011)	(0.011)	(0.011)	(0.011)	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)	(0.012)
After	-0.002	0.000	-0.002	-0.004	-0.002	-0.002	-0.040	-0.040	0.001	-0.002	-0.002		-0.003	-0.006	-0.007	-0.002	-0.002	-0.002
	(0.009)	(0.007)	(0.011)	(0.013)	(0.008)	(0.009)	(0.134)	(0.134)	(0.009)	(0.009)	(0.009)		(0.009)	(0.010)	(0.011)	(0.009)	(0.009)	(0.008)
Eclipse	-0.025	-0.025	-0.030	-0.030	-0.019	-0.025	-0.363	-0.363	-0.011	-0.040	-0.031	-0.025	-0.013	-0.025	0.069	-0.019	-0.025	-0.025**
	(0.017)	(0.017)	(0.020)	(0.021)	(0.013)	(0.017)	(0.249)	(0.249)	(0.013)	(0.029)	(0.024)	(0.017)	(0.015)	(0.017)	(0.095)	(0.016)	(0.017)	(0.009)
Christians (prop.)									-0.045†									
									(0.025)									
Excluded groups (prop.)									0.008									
									(0.010)									
Conflict zone (dummy)									0.101**									
									(0.012)									
Night light (log)									0.008**									
									(0.002)									
GCP (log)									0.011*									
									(0.004)									
Population (log)									0.017**									
									(0.004)									
Temperature									0.014**									
									(0.003)									
Precipitation (log)									-0.002									
									(0.002)									
Elevation									0.032*									
									(0.013)									
Latitude									-0.001									
									(0.000)									
Longitude									0.002**									
									(0.001)									
(Intercept)	0.084**	0.084**	0.102**	0.097**	0.063**	0.084**	-6.935**	-6.935**	-0.144**						-0.258	-0.301**	0.084**	0.084**
	(0.014)	(0.014)	(0.017)	(0.018)	(0.011)	(0.014)	(0.180)	(0.180)	(0.048)						(0.355)	(0.099)	(0.015)	(0.022)
N	2,194,192	2,468,466	1,788,176	2,194,192	2,194,192	2,194,192	2,194,192	2,194,192	2,065,800	2,194,192	2,193,776	2,194,192	2,194,192	8,502,494	2,194,192	2,194,192	2,194,192	2,194,192

See the note of Table A14-1.

Table A14-3. Other Robustness Checks (Protest)

		Measurement & Sample				GLM			Control & FE								Standard error	
	Main	Including Day1	Over 1,000 pop	Count	Logged count	Logit	Poisson	Negative binomial	Control variables	Country × Eclipse FE	Province × Eclipse FE	Time FE	Calendar FEs	Islamic calendar	Differential time trends	Spatial controls	Two-way clustering	Conley SE
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Eclipse× After	-0.003 (0.015)	-0.001 (0.013)	-0.004 (0.018)	0.001 (0.018)	-0.001 (0.011)	-0.003 (0.015)	0.006 (0.198)	0.006 (0.198)	-0.005 (0.016)	-0.003 (0.015)	-0.003 (0.015)	-0.003 (0.015)	0.011 (0.015)	0.011 (0.021)	-0.033 (0.020)	-0.003 (0.015)	-0.003 (0.015)	-0.003 (0.014)
After	-0.001 (0.015)	0.005 (0.008)	-0.001 (0.019)	-0.004 (0.017)	-0.002 (0.011)	-0.001 (0.015)	-0.042 (0.173)	-0.042 (0.173)	-0.005 (0.016)	-0.001 (0.015)	-0.001 (0.015)		-0.007 (0.014)	0.013 (0.023)	0.013 (0.017)	-0.001 (0.015)	-0.001 (0.015)	-0.001 (0.009)
Eclipse	-0.020 (0.026)	-0.020 (0.026)	-0.025 (0.032)	-0.021 (0.030)	-0.015 (0.020)	-0.020 (0.026)	-0.231 (0.335)	-0.231 (0.335)	-0.005 (0.022)	0.004 (0.021)	-0.002 (0.016)	-0.020 (0.026)	0.021 (0.020)	-0.036 (0.023)	-0.516† (0.279)	-0.013 (0.026)	-0.020 (0.026)	-0.020 (0.013)
Christians (prop.)									0.077** (0.021)									
Excluded groups (prop.)									0.034** (0.012)									
Conflict zone (dummy)									-0.002 (0.018)									
Night light (log)									0.016** (0.003)									
GCP (log)									0.012** (0.004)									
Population (log)									0.055** (0.013)									
Temperature									-0.017* (0.006)									
Precipitation (log)									-0.045** (0.009)									
Elevation									-0.119** (0.032)									
Latitude									0.003* (0.001)									
Longitude									-0.001* (0.000)									
(Intercept)	0.094** (0.023)	0.094** (0.023)	0.114** (0.028)	0.102** (0.026)	0.068** (0.017)	0.094** (0.023)	-6.887** (0.252)	-6.887** (0.252)	0.935** (0.258)						1.186† (0.617)	0.747* (0.287)	0.094** (0.024)	0.094** (0.023)
N	2,194,192	2,468,466	1,788,176	2,194,192	2,194,192	2,194,192	2,194,192	2,194,192	2,065,800	2,194,192	2,193,776	2,194,192	2,194,192	8,502,494	2,194,192	2,194,192	2,194,192	2,194,192

See the note of Table A14-1.

A15. Violence During the 2001 Lunar and 2006 Solar Eclipses

Table A15-1. Violence Stories in the 2001 Lunar and 2006 Solar Eclipses

The 2001 Lunar Eclipse
- Hundreds of Muslim youths went on the rampage burning churches and beer parlours late Tuesday in Maiduguri, after sighting the eclipse which appeared across Africa. Many non-Muslims fled to a nearby military barracks for safety. Riot policemen used teargas to disperse them.
- FESCI students take up arms and drive out immigrants from poor neighbourhoods
- Many fled the town of Ngabu which was attacked by unidentified armed men.
The 2006 Solar Eclipse
- LRA kills 4 civilians while they were hunting in Atiak.
- Karamojong ambush people at Singila trading center; 2 killed, 2 injured.

The table shows the violence descriptions recorded in the ACLED that occurred in the areas of eclipse observations on the days of the eclipses. The events during the 2001 lunar eclipse also include those a day after the eclipse.