Agricultural Shocks and Conflict in the Short- and Long-Term: Evidence from Desert Locust Swarms

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Abstract

Civil conflict inflicts many harms on economies and society, and a growing literature links agricultural shocks to incidence of violent conflict. This paper tests whether destruction of agricultural production by desert locust swarms affects the long-term risk of violent conflict and how income-related mechanisms commonly cited in the literature explain impacts on conflict risk over time. I use difference-in-differences and event study approaches to identify causal impacts of exposure to a locust swarm—effectively an agriculture-specific natural disaster—on conflict across 0.25° grid cells in Africa and the Arabian peninsula from 1997-2018. Swarms do not increase the probability violent conflict in the year of exposure, with results indicating that reduced returns to predatory attacks over agricultural output in affected areas offset reduced opportunity costs of fighting related to agriculture. Average long-term effects are large, however: cells affected by the 2003-2005 major desert locust upsurge are 58% more likely to experience violent conflict on average over the following 10-15 years, driven by growing season swarms in areas with cropland. Reduced cereal yields after swarm exposure are consistent with a wealth shock leading to persistent decreases in agricultural productivity. Effects of swarm exposure are concentrated in years and areas with groups actively engaged in civil conflict, indicating that the long-term decrease in opportunity costs of fighting following the initial wealth shock makes affected areas more likely to engage in violent conflict following its onset due to other proximate causes. This long-term wealth channel is a potentially important mechanism relating economic shocks to conflict risk.

JEL codes: Q54; D7; Q10; O13; N57
Keywords: desert locusts; natural disasters; conflict; agriculture; Africa

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1 Introduction

Conflict between states has been rare in recent decades but the number of civil conflicts—between actors within states and sometimes spilling over—has been generally increasing, especially in Africa and the Middle East.[1] Civil conflict can ultimately benefit certain populations but causes significant suffering in the process as time and investment are allocated to destruction rather than production. Violent conflict harms lives, health, and living standards of affected populations and can slow or reverse economic growth and development (Blattman and Miguel 2010; Fang et al. 2020), while also having broader impacts through economic instability and migrant flows, among other effects. Understanding the drivers of conflict therefore has important implications for policy.

Economic factors could affect the onset and incidence of civil conflict in a variety of ways, but a large literature exploring this relationship is largely inconclusive (McGuirk and Burke 2020). Within this literature, a rapidly growing number of studies explores the impacts of agricultural shocks on conflict risk—a primary concern given the prominence of agricultural livelihoods in many of the areas most affected by civil conflict and the threat to agriculture posed by climate change. Several studies have found that shocks to agricultural prices increase conflict incidence,[2] and impacts on agricultural productivity are speculated to explain the widely-studied relationship between climate or weather deviations and conflict risk.[3] These studies have focused on short-term impacts on conflict, and the evidence linking decreases in agricultural production to conflict risk is mixed and limited by identification challenges.

This paper tests whether destruction of agricultural production affects the risk of violent

[1]See Cederman and Pengl (2019) for a review of recent conflict trends using data from the Uppsala Conflict Data Program.

[2]See for example, Dube and Vargas (2013), Fjelde (2015), McGuirk and Burke (2020), and Ubilava, Hastings, and Atalay (2022).

[3]See Burke, Hsiang, and Miguel (2015), Carleton, Hsiang, and Burke (2016), Dell, Jones, and Olken (2014), Hsiang and Burke (2013), Koubi (2019), and Mach et al. (2019) for reviews. The evidence generally shows that weather deviations increase the likelihood of conflict, though many studies also report no effects (e.g., Buhaug et al. 2015; Ciccone 2013) or results that are not consistent with effects through agricultural productivity (e.g., Bollfrass and Shaver 2015; Sarsons 2015).

conflict in the long-term, and how income-related mechanisms commonly cited in the literature explain short- and long-term impacts on conflict risk. I identify agricultural production shocks using outbreaks of desert locusts, the world's most dangerous and destructive migratory pest (Cressman, Van der Elstraeten, and Pedrick 2016; Lazar et al. 2016). Variation in exposure and agricultural destruction comes from differences in locust breeding conditions over time and flight patterns over space. Desert locusts form cohesive swarms—with billions of locusts covering tens of square kilometers—in years when population density increases in desert breeding areas, typically after periods of above-average rainfall. Swarms make daily flights downwind and consume all forms of vegetation after they land, often leading to complete destruction of agricultural production. (Symmons and Cressman 2001; Thomson and Miers 2002). Swarm movements can be predicted but with a great deal of uncertainty and there are no effective means for farmers to prevent damages even with awareness of the potential threat of locust swarms. Locust swarms continue migrating until they are controlled by pesticides or follow winds to areas with scarce vegetation, at which point they die out. Impacts of locust swarms are limited to damages to agriculture and vegetation, without the effects on infrastructure or human physiology which may result from weather shocks. These characteristics make locust swarms a useful natural experiment for analyzing how agricultural production shocks affect the risk of conflict, particularly in the long-term as effects may be more persistent following such a severe shock.

Using data on the location and timing of desert locust swarm observations from the Food and Agricultural Organization of the United Nations and of conflict events from the Armed Conflict Location & Event Data Project (ACLED) and Uppsala Conflict Data Program (UCDP) I estimate a model of conflict at the annual level for 0.25° (around 28×28km) grid cells between 1997-2018 across Africa and the Arabian peninsula.[4] The identification exploits

[4]I include all countries where at least 10 locust swarms are reported during the sample period. Torngren Wartin (2018), an unpublished master's thesis from Stockholm University, estimates short-term impacts of desert locusts on conflict in Africa using similar data. Torngren Wartin (2018) focuses on potential measurement issues around short-term impacts which I address in Section 6.4. He does not consider long-term impacts of locust swarms or mechanisms that are the main contributions of this paper.

quasi-random variation in locust swarm exposure over time and space driven by conditions in locust breeding areas and swarm flight patterns to identify causal impacts.

As severe agricultural shocks may have persistent effects on wealth and productivity, I analyze the impacts of locusts using difference-in-difference and event study designs. This is a departure from the literature on weather shocks and conflict using an annual grid cell data structure where the analyses implicitly assume that the shocks only affect conflict risk in the short term. I use the first year in which cells are exposed to a locust swarm to define 'treatment' and compare changes in outcomes over time in affected cells to those that do not experience any locust swarms. First, I estimate average impacts on conflict of locust swarm exposure in two-way fixed effects regressions with cell and country by year fixed effects, controlling for annual rainfall, temperature, and population to account for potential time-varying differences in cells affected by locust swarms. I test for parallel pre-trends and estimate impacts over time using event study models from the recent literature on difference-in-differences with staggered treatment timing (Borusyak, Jaravel, and Spiess 2021; Callaway and Sant'Anna 2021). Then, I explore patterns over time and mechanisms using an event study of the 2003-2005 major desert locust upsurge, which accounts for 60% of swarm observations in the sample period. I control for baseline differences in which areas were affected by the upsurge by applying inverse propensity weights calculated using pre-upsurge characteristics.

While a relationship between weather deviations and conflict has been repeatedly demonstrated the mechanisms driving this impact are not fully understood (Mach et al. 2020). Studies generally point to income-related mechanisms through impacts of weather on agricultural production, but are unable to test this mechanism because weather shocks affect a variety of economic and social outcomes in addition to reducing agricultural labor productivity and agricultural output (Dell, Jones, and Olken 2012, 2014; Mellon 2022). Some papers cast doubt on this mechanism by finding that impacts of weather on conflict do not vary by sensitivity or presence of agricultural production (Bollfrass and Shaver 2015; Sarsons

2015). This paper addresses these limitations by testing the impacts on conflict risk of locust swarms, an agricultural shock that does not affect other economic outcomes. I further isolate effects through agricultural production by comparing impacts by land cover and timing of locust swarm exposure relative to crop calendars.

I interpret the results through the lens of a commonly used model of individual occupation choice between production and conflict (Chassang and Padró i Miquel 2009; Dal Bó and Dal Bó 2011; McGuirk and Burke 2020). In the model, agricultural shocks affect the short term risk of conflict by changing the returns to engaging in agricultural production and the returns to fighting over agricultural output. The former channel is the 'opportunity cost' mechanism commonly cited in the climate-conflict literature. The latter channel, sometimes referred to as the 'predation' mechanism, is more commonly discussed in studies of price shocks and conflict. Little attention is given to the predation mechanism in the climate-conflict literature given the generally positive estimated effects of weather shocks on conflict.[5] I test the importance of the predation mechanism over time for a severe agricultural shock by analyzing differences in impacts of locust swarms on different types of conflict and by the activity of armed groups in surrounding areas. I also extend the model to allow for long-term impacts of agricultural production shocks through a third mechanism, effects on wealth, and test for this channel by examining long-term impacts of desert locust swarms on conflict risk and measures of agricultural productivity. This furthers our understanding of the drivers of conflict (e.g., Bazzi and Blattman 2014; Blattman and Miguel 2010; Cervellati, Esposito, and Sunde 2022; Collier and Hoeffler 1998; Hodler and Raschky 2014; McGuirk and Burke 2020; Miguel, Satyanath, and Sergenti 2004), and the role of agricultural production in particular (e.g., Crost et al. 2018; Guardado and Pennings 2021; Harari and La Ferrara 2018; McGuirk and Nunn 2021; Von Uexkull et al. 2016).

[5] Studies showing evidence of opportunity cost and predation mechanisms in agriculture have primarily explored impacts on conflict risk of changes in global prices of agricultural goods (e.g., Dube and Vargas 2013; Fjelde 2015; McGuirk and Burke 2020) rather than shocks to local agricultural production. McGuirk and Nunn (2021) is an exception, analyzing impacts of drought on conflict between pastoralists and farmers. Changing the quantity of local agricultural output may have different effects on violent conflict than changing its value, particularly when much of production is for household consumption.

Studies of the impacts of climate or weather on conflict have focused on the short-term—impacts in the same year and potentially the following year.[6] But a negative shock to agricultural production may have persistent effects on wealth and agricultural productivity, affecting opportunity costs of conflict in the long-term. Many papers have explored the dynamics of poverty traps, including the impacts of environmental shocks (e.g., Carter and Barrett 2006; Carter et al. 2007; Lybbert et al. 2004), but these have not been related to conflict risk. More generally, the evidence on long-term impacts of disasters such as hurricanes and droughts is limited, inconclusive, and focused on a small number of outcomes (see Botzen, Deschenes, and Sanders (2019) and Klomp and Valckx (2014) for reviews). I study how the impacts on conflict risk of desert locusts swarms—an extreme shock to agricultural production akin to a natural disaster—evolve over time and test whether patterns are consistent with a productivity trap.

The paper also contributes to a small literature studying economic impacts of desert locusts beyond immediate crop destruction and costs of control operations (see e.g., Thomson and Miers 2002). The range of many agricultural pests is expanding due to climate change and globalization, and though locust outbreaks have become less frequent in recent decades due to increased monitoring desert locusts are ideally situated to benefit from climate change (ASU 2020). Marending and Tripodi (2022) use panel data from the Ethiopia Socioeconomic Survey and find that exposure to desert locust swarms in Ethiopia decreases farm profits by 20-48% two harvest seasons after swarm arrival. De Vreyer, Guilbert, and Mesple-Somps (2015) report long-term decreases in school enrollment and educational attainment of children born or under age 4 during the 1986-1989 locust upsurge among Demographic and Health Survey (DHS) households in Mali. Another three papers similarly use DHS data and variation in locust swarm exposure across birth cohorts and over space, and find negative

[6] Crost et al. (2018) and Harari and La Ferrara (2018) estimate effects of weather shocks on conflict 2 and 4 years afterward. Iyigun, Nunn, and Qian (2017) is an exception, considering long-run effects on conflict risk of a *positive* agricultural productivity shock from the introduction of the potato to the Eastern Hemisphere. To my knowledge, no study has explored long-term impacts on conflict risk of a negative shock to agricultural production.

long-term impacts on child anthropometric outcomes (Conte, Tapsoba, and Piemontese 2021; Le and Nguyen 2022; Linnros 2017). These papers all illustrate how locust swarm exposure can adversely affect long-term productivity and human capital, but I am not aware of any study considering the impacts of a pest shock on conflict. I use locust swarm exposure to test for a wealth mechanism linking a severe agricultural income shock to long-term conflict risk.

Locust swarms nearly double the probability of any violent conflict event occurring in a 0.25° grid cell—from 2.4% to 4.5%—on average in years after exposure to the swarm, compared to unaffected areas. This result is robust to a variety of alternative specifications. Impacts are entirely driven by agricultural cells with crop or pasture land as expected if swarms affect conflict risk through destruction of agricultural production, with impacts on cells with any crop land particularly important. The estimated effects of having been affected by a locust swarm are large relative to the effects of annual weather deviations. Experiencing 100mm higher rainfall than average in a year increases the risk of violent conflict by 13% while having a 1°C higher maximum temperature increases it by 21%.

Event study analyses accounting for staggered swarm treatment timing show no significant differences in the risk of violent conflict between areas affected by locust swarms and unaffected areas in the years before the arrival of a swarm, supporting the argument for parallel trends in the absence of swarm exposure. Average effects of swarms in the years post-treatment are similar to the two-way fixed effects estimates. The patterns over time show no significant impacts of locust swarms on conflict in the year they arrive or the following year. The increase in conflict risk is largest 8-12 years after swarm arrival and remains significant 14 years after exposure. Results are similar with different event study estimators and specifications.

Cells exposed to a locust swarm during the 2003-2005 desert locust upsurge in particular are 58% more likely to experience any conflict in a given year afterward on average relative to cells that were not affected by the upsurge. This result is robust to various specifications, restrictions on the set of unaffected cells included in the analysis, and to weighting observations based on the estimated propensity to be exposed to any swarm during the upsurge. Impacts of the upsurge are driven by swarms that arrived during the crop growing season in cells with cropland, consistent with a persistent wealth shock following destruction of agricultural output. The pattern of impacts of the upsurge on conflict risk over is similar to the pattern in the event studies averaging across different swarm treatments, though short-term impacts are more muted. There are no significant effects on conflict risk during the year of the upsurge or in the first seven years afterward, but from 2013-2018 areas affected by the upsurge are 67% more likely to experience a violent conflict than unaffected areas.

A naive approach to estimating short-term impacts of locusts swarms that ignores the possibility that effects may persist results in downward bias. I show that this also holds for analyzing short-term impacts of a severe drought, as this shock also increases the long-term risk of violent conflict. Studies of short-term effects of other shocks on the risk of conflict may also be biased downward to the extent those shocks affect conflict over the long term.

Null effects of locust swarms on conflict risk in the short term contrast with the effects of rainfall or temperature deviations but have two main potential explanations. First, as discussed in the climate-conflict literature, weather deviations could be affecting conflict risk through mechanisms other than agricultural productivity such as impacts on physiology, psychology, and infrastructure.[7] Second, locust swarms are effectively a natural disaster solely affecting agricultural production, and the level of destruction may have different implications for short-term conflict risk

Reduced returns to fighting over agricultural output could make fighting sub-optimal even with reduced opportunity costs, as shown in the simple model. Point estimates for the impact on violent conflict risk in the year of exposure are negative but not significant, while protests and riots—where participation is also affected by opportunity costs but not by reduced agricultural output available to capture—increase in the year of exposure. This

[7] Dell, Jones, and Olken (2012, 2014) and Mellon (2022) document a wide variety of channels through which temperature and rainfall can affect the economy and society.

indicates that null short-term impact of locust swarm exposure on violent conflict risk is due at least in part to the predation mechanism offsetting the opportunity cost mechanism. The fall in opportunity costs may also be limited by relief efforts. I find evidence that international agricultural aid flows increase to countries after exposure to locust swarms, which could dissuade affected individuals engaging in civil conflict.

Long-term average increases in violent conflict risk following exposure to locust swarms are consistent with predictions in the simple model based on a wealth mechanism. A negative shock to agricultural production—particularly in contexts characterized by incomplete financial markets—is also a shock to household wealth which decreases assets in following periods and therefore also agricultural productivity. I show that impacts on conflict are concentrated in crop cells exposed to locust swarms during the growing season, where agricultural destruction and the shock to wealth should be greatest. Using geospatial data from the Demographic and Health Survey (DHS) AReNA database (IFPRI 2020), I show that NDVI falls in the first year of swarm exposure and that cereal yields decrease by 6% on average in years after exposure relative to unaffected areas, indicating a persistent decrease in agricultural productivity consistent with a wealth mechanism. This evidence supports the argument that long-term impacts of locust swarm exposure on the risk of violent conflict are due to a persistent reduction in the opportunity cost of fighting.

Differences in impacts across types of conflict events are also consistent with a wealth mechanism. The impacts are larger for violent conflict events recorded by ACLED than the larger-scale battles recorded by UCDP, and primarily involve non-state actors such as identity/ethnic militias, rebel groups, and terrorist groups. The 2003-2005 upsurge has no effect on conflict that does not involve non-state actors or on UCDP conflict events. In contrast, locust swarms increase the probability of any protest or riot event in a year by 1.8 percentage points on average in years after the swarm relative to unaffected areas, similar to the effect on violent conflict. Swarm exposure thus only increases the risk of types of conflict that would be expected to be affected by changes in individuals' opportunity costs related to agricultural production.

The variation over time in impacts of exposure to locust swarms and the 2003-2005 upsurge in particular indicates an additional mechanism beyond the wealth effect. I find that long-term impacts are driven entirely by cells and periods where there are groups actively engaged in civil conflict in the surrounding area or in the cell the previous year. As the prevalence of civil conflict in the sample countries is low in the beginning of the study period before increasing starting around 2011 and the majority of swarm exposure comes from the 2003-2005 upsurge, this explains the pattern of increased risk of violent conflict in swarm-affected areas many years after exposure. This result indicates that persistent reductions in productivity and opportunity cost of fighting in areas affected by locust swarms are not sufficient to increase conflict risk until other factors precipitate the onset of conflict.[8] The formation of fighting groups in such conflict reduces the cost to individuals of engaging in fighting and indicates higher expected benefits, making it more likely that a switch from agriculture to fighting for individuals with a persistently lower agricultural productivity is optimal. Impacts of swarm exposure on violent conflict risk being concentrated in periods of elevated conflict is consistent with prior studies suggesting agricultural shocks primarily affect conflict incidence but not conflict onset (e.g., Bazzi and Blattman 2014).

The remainder of the paper is organized as follows. Section 2 provides background on desert locusts and summarizes the literature on agricultural shocks and conflict. Section 3 presents a conceptual framework of how agricultural shocks affect occupational choice and the decision to fight through income-related mechanisms. Section 4 discusses the data used in the analyses and Section 5 outlines the empirical approaches. Section 6 shows and discusses the results for the impacts of locust swarm exposure on conflict, first considering all locust swarm events in the study period and then focusing on the major 2003-2005 locust upsurge. Section 7 discusses the results in light of the conceptual framework and presents additional analyses testing the mechanisms behind the estimated effects. Section 8 concludes.

[8]Global food price shocks, the Arab Spring, and the spread of terrorist organization in many sample countries are among the proximate causes of conflict onset in the study period.

2 Background

2.1 Desert locusts

Desert locusts (*Schistocerca gregaria*) are a species of grasshopper always present in small numbers in desert 'recession' areas from Mauritania to India.[9] They usually pose little threat to livelihoods but favorable climate conditions—periods of repeated rainfall and vegetation growth overlapping with the breeding cycle—can lead to exponential population growth. Unique among grasshopper species, after reaching a particular population density desert locusts undergo a process of 'gregarization' wherein they mature physically and begin to move as a cohesive unit (Symmons and Cressman 2001). In the hopper stage (pre-flight), locusts at high density form 'bands' which march together. In the adult stage after developing wings, gregarization leads to the formation of 'swarms'. In this paper I focus exclusively on locust swarms, which are much more mobile and destructive than hopper bands or non-gregarious groups of adult or hopper locusts.

Locust swarms vary in density and extent. The average swarm includes around 50 locusts per m^2 and can cover tens of square kilometers, including billions of locusts (Symmons and Cressman 2001). About half of swarms exceed 50km^2 in size (FAO and WMO 2016). Damages from locust swarms can be extreme: a small swarm covering one square kilometer can consume as much food in one day as 35,000 people. Locusts consume any available vegetation, and swarms frequently lead to the total destruction of local agricultural output (Showler 2019).

The threat from desert locusts is most severe during 'outbreaks' or 'upsurges' where locusts spread from their desert breeding areas. The most recent upsurge took place from 2019-2021 in East Africa and the Arabian Peninsula, following repeated cyclones in 2018 that lead to rapid population growth in breeding areas in Yemen and Saudi Arabia. Locust swarms spread from there, taking advantage of favorable breeding conditions to continue

[9] Additional detail on desert locusts is included in Appendix B. Any time I use 'locusts' in this paper I am referring exclusively to desert locusts.

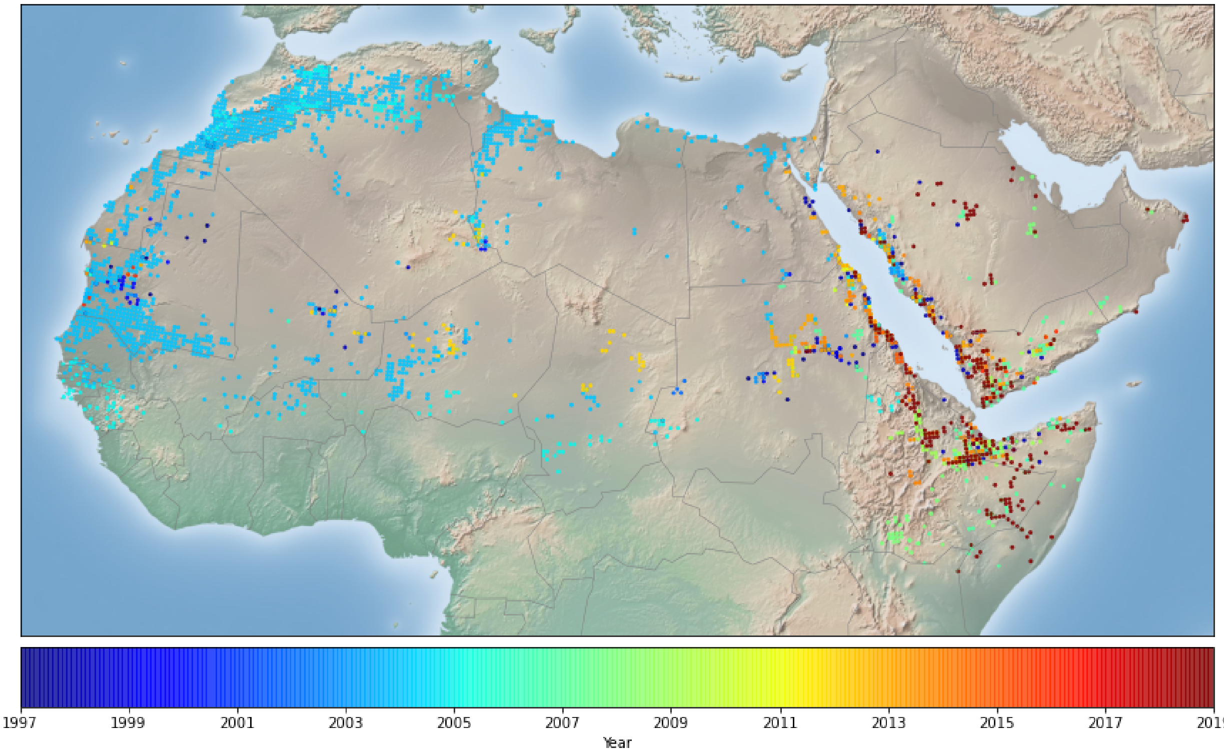
breeding and reaching parts of East Africa not affected by locusts in several decades. Over 40 million people in 10 countries faced severe food insecurity due to crop destruction as a result of this upsurge (Food and Agriculture Organization of the United Nations (FAO) 2022a), and the World Bank estimates that 8 million people were internally displaced and over 2 million hectares were treated with pesticides (The World Bank 2020). During the previous major locust upsurge in 2003-2005 in North and West Africa, 100, 90, and 85% losses on cereals, legumes, and pastures respectively were recorded, affecting more than 8 million people (Renier et al. 2015; Brader et al. 2006).

Few locust swarms are observed outside of major upsurges, as conditions favoring swarm formation tend to produce large swarms which reproduce and spread rapidly. Figure 1 displays the locations of desert locust swarm observations recorded in the FAO Locust Watch database by year for the sample countries and years for this analysis. As illustrated by the figure, locust swarms are not observed with any regularity over time. The countries affected by the 2003-2005 upsurge are not the same as those that have experienced more recent outbreaks and very few locations have been exposed to more than one swarm. Desert locusts are migratory, moving on after consuming all available vegetation, rather than becoming endemic. Locust swarms therefore do not permanently change local agricultural pest risk.

Which locations are affected by locust swarms during an upsurge depends on which breeding areas fostered initial swarm formation and on wind patterns in the months following swarm formation. The 2003-2005 upsurge resulted from multiple small outbreaks in breeding areas from Mauritania to Niger in Summer 2003, followed by unusually heavy rainfall in late October in winter breeding areas in Western Sahara which supported further breeding. Wind patterns typically lead swarms to cycle through breeding areas in time for seasonal breeding. Swarms fly downwind and can easily move 100km or more in a day even with minimal wind (FAO and WMO 2016).[10] After leaving breeding areas, locust swarms fly for 9-10 hours each

[10]Swarms do not always fly with prevailing winds and may wait for warmer winds which lead to seasonal breeding areas (FAO and WMO 2016). Small random deviations in the positions of individuals in the swarm can also sometimes alter the course of the swarm's flight.

Figure 1: Desert locust swarm observations by year, study period



Note: Map created by authors using data from the FAO Locust Watch database for 1997-2018. Figure B2 shows the locations and timing of all recorded desert locust swarms from 1985-2020.

day, from a few hours after sunrise to an hour or so before sunset when they land and feed. Outside of breeding areas, these swarm flight patterns result in some areas in the flight path being spared any damages, even in the context of a major locust upsurge (Figure B4 shows an example of local variation in exposure to the 2003-2005 upsurge in Mali).

An important result of the local variation in locust swarm damages during upsurges is that macro level impacts may be muted, since upsurges occur in periods of positive rainfall shocks in breeding areas which tend to be associated with better agricultural conditions in surrounding countries. Several studies find that impacts of locust upsurges on national agricultural output and on prices are minimal, despite devastating losses in affected areas (Joffe 2001; Krall and Herok 1997; Showler 2019; Zhang et al. 2019).

Locusts live 2-6 months and upsurges end due to a combination of migration to unfavorable habitats, limited vegetation in breeding areas, and control operations (Symmons and

Cressman 2001). Farmers have no proven effective recourse when faced with the arrival of a locust swarm (Dobson 2001; Hardeweg 2001; Thomson and Miers 2002). The only current viable method of swarm control is direct spraying with pesticides (Cressman and Ferrand 2021, which can take days to have effects as well as being slow and costly to organize and requiring robust locust monitoring infrastructure. Control operations are most effective before locust bands reach the adult stage and form swarms, but this requires extensive monitoring activities. Knowledge of locust breeding patterns and swarm flight characteristics inform efforts to predict locust swarm formation and movements, but forecasts remain highly imprecise (Latchininsky 2013). Farmers in affected areas report viewing locust swarms as an unpredictable natural disaster that is the government's responsibility to address (Thomson and Miers 2002).

The characteristics of desert locust swarms make them a useful natural experiment for analyzing the impacts of agricultural production shocks on the risk of conflict. The arrival of a swarm is effectively a locally and temporally concentrated natural disaster where all crops and pastureland are at risk (Hardeweg 2001), but other aspects of the economy are importantly unaffected. Whereas impacts of temperature or rainfall deviations on conflict might go through channels other than agricultural production, such as effects on infrastructure or physiology, impacts of locust swarms should be restricted to this channel. The level of damage to agriculture from swarms arriving during the crop growing season and lack of tools for farmers to prevent damages imply more severe reductions in agricultural production than moderate weather deviations. Decreased wealth following such a catastrophic shock may be more likely to persist and affect agricultural labor productivity in following seasons, increasing the potential for long-term impacts on conflict through the opportunity cost channel.

2.2 Agricultural production shocks and conflict

A variety of proximate and underlying causes has contributed to the increase in civil conflict in recent decades. A growing literature explores the impacts of climate or weather on conflict (see Burke, Hsiang, and Miguel (2015), Carleton, Hsiang, and Burke (2016), Dell, Jones, and Olken (2014), Hsiang and Burke (2013), Koubi (2019), and Mach et al. (2019) for reviews), primarily analyzing impacts of deviations of rainfall or temperature from historical norms. Most studies find that weather shocks increase short-term conflict risk, with meta-analyses finding a mean increase in the risk of conflict of between 5-10% for a one standard deviation increase in a weather shock variable and more consistent positive effects of temperature increases (Burke, Hsiang, and Miguel 2015; Carleton, Hsiang, and Burke 2016). These meta-analyses conclude that these results would be very unlikely if the true effect were zero or negative, and most studies reporting such effects use country-level data (e.g., Buhaug et al. 2015; Ciccone 2013; Couttenier and Soubeyran 2014; Klomp and Bulte 2013). These results have important implications for conflict risk as climate change increases the frequency and severity of weather shocks.

The majority of papers in the climate-conflict literature focus on income-related mechanisms for impacts of weather on conflict risk, following early work in Miguel, Satyanath, and Sergenti (2004). Arguments typically follow the models in Chassang and Padró i Miquel (2009) and Dal Bó and Dal Bó (2011), discussing how weather affects agricultural labor productivity and therefore the opportunity costs of engaging in conflict for agricultural producers. Many studies use variation by land cover or timing relative to show support for this mechanism (e.g., Caruso, Petrarca, and Ricciuti 2016; Crost et al. 2018; Harari and La Ferrara 2018; McGuirk and Nunn 2021; Von Uexkull 2014). Discussion of offsetting changes in the returns to conflict from capture of agricultural output is typically limited. If the predation or rapacity mechanism is mentioned it is presented as being outweighed by the opportunity cost mechanism.

Although the evidence in studies of weather and conflict is generally consistent with an opportunity cost mechanism through decreased agricultural labor productivity, other channels may also be important given the many ways in which weather affects the economy and society (Dell, Jones, and Olken 2012, 2014; Mellon 2022). For example, Sarsons (2015) shows that rainfall shocks in India predict riot incidence similarly across districts where rainfall has different effects on income due to access to irrigation dams, indicating a role of channels outside of income and opportunity cost effects. Bollfrass and Shaver (2015) find that positive temperature deviations increase conflict even in areas without significant agricultural production. Studies have pointed to physiological, psychological, and infrastructural effects of weather shocks in explaining impacts on conflict (Baysan et al. 2019; Carleton, Hsiang, and Burke 2016; Chemin, De Laat, and Haushofer 2013; Dell, Jones, and Olken 2014; Hsiang and Burke 2013; Sarsons 2015; Witsenburg and Adano 2009),

Because of these various possible mechanisms connecting weather shocks to an increase in conflict, these studies are not definitively able to test the impact of a shock to agricultural production on conflict risk. Reviews of the climate-conflict literature agree that the mechanisms remain unclear and deepening insight into them is highlighted as the first priority for future climate-conflict research in Mach et al. (2020). The main advantage of analyzing the effects of locust swarms is that the only active mechanism should be the income channel through agricultural destruction, allowing a cleaner identification of the importance of the agricultural production and income mechanism.

Income mechanisms have been discussed and tested in the literature on the drivers of conflict more generally (see e.g., Blattman and Miguel 2010; Buhaug et al. 2021; Collier and Hoeffler 1998, 2004; Fearon 1995; Hodler and Raschky 2014), including studies looking at changes in the value of agricultural labor or output not related to production shocks. Several studies have shown that plausibly exogenous changes in prices of agricultural commodities affect the risk local conflict in areas producing the affected goods (e.g., Bazzi and Blattman 2014; Dube and Vargas 2013; Fjelde 2015; McGuirk and Burke 2020; Ubilava, Hastings, and Atalay 2022). A recent literature explores how the onset of harvest season in agricultural areas affects economic incentives to fight (Guardado and Pennings 2021; Hastings and Ubilava 2023).

Importantly, these studies illustrate different ways in which agricultural shocks affect both the opportunity cost of fighting related to agricultural labor productivity and the returns to predatory capture of agricultural output. These papers largely focus on conflict initiated by non-state actors, as the opportunity cost mechanism matters for individuals generally engaged in agricultural production while the predation mechanism is most relevant for militants or insurgents. Which of the two effects dominates to determine the effect on conflict risk appears to vary with the nature of the agricultural shock. Dube and Vargas (2013) and Fjelde (2015) find that decreases in global agricultural prices increase the risk of conflict in areas growing the affected crops in Colombia and Africa, respectively, consistent with reduced opportunity costs outweighing reduced returns to predation. McGuirk and Burke (2020) and Ubilava, Hastings, and Atalay (2022) find that increases in global food prices increase predatory conflict over output in food-producing areas of Africa indicating that increased returns to predation outweigh increased opportunity costs, though McGuirk and Burke (2020) also find reductions in conflict for control of territory which they attribute to increased opportunity costs. Guardado and Pennings (2021) find that harvest season decreases insurgent attacks in agricultural areas of Afghanistan, Iraq, and Pakistan, while Hastings and Ubilava (2023) find that it decreases protests and riots in Southeast Asia, both consistent with increased opportunity costs of agricultural producers. Hastings and Ubilava (2023) further report that harvest onset increases violence against civilians, consistent with predation against rice producers and showing how the two mechanisms interact.

It is striking that different studies show that both decreases and increases in agricultural prices increase conflict risk through similar mechanisms. Effects on opportunity costs related to agricultural labor productivity appear to dominate for decreases in the value of agricultural production, while effects on returns to predation are more important for increases in value of agricultural output. It is not clear, however, whether this would be the case for direct shocks to agricultural production, although findings from the climate-conflict literature are generally consistent with decreased agricultural production reducing opportunity costs. Destruction of a crop may have more serious implications for producers than a reduction in crop prices, particularly in areas where much of agricultural production is for own consumption as for most farm households across Africa, and lead to different responses. Locust swarms in the growing season can entirely destroy agricultural output, sharply affecting both within-season agricultural labor productivity and the returns to predation over agricultural output. I return to this in the conceptual framework in Section 3.

The majority of studies of the impact of agricultural shocks on conflict focus on impacts within the same time period, with a few exceptions. Crost et al. (2018) and Harari and La Ferrara (2018) find that growing season weather shocks have inconsistent effects on conflict in the same year, but consistently increase conflict risk the following year. Harari and La Ferrara (2018) finds some persistence of impacts up to 4 years afterward, but results are not always statistically significant. Crost et al. (2018) argue that lagged effects of rainfall on conflict could be due to storage and savings offsetting effects in the same year, though this appears inconsistent with effects driven by reduced opportunity costs as impacts on agricultural labor productivity should be realized in the same year as the rainfall shock, not in the following year, unless wealth effects reduce subsequent productivity. To my knowledge, only Iyigun, Nunn, and Qian (2017) consider how an agricultural shock impacts conflict in the long term, though they stand out in studying impacts of a permanent increase to agricultural productivity. They find that introducing potatoes to Europe, the Near East, and North Africa led to a large and permanent reduction in the risk of conflict in subsequent centuries by comparing changes in areas with different suitability for potato cultivation. A paucity of evidence on long-term impacts is a limitation of the literature on natural disasters more generally (Botzen, Deschenes, and Sanders 2019), and particularly in low-income countries (Baseler and Hennig 2023).

3 Conceptual framework

The primary models cited in the climate-conflict literature are Chassang and Padró i Miquel (2009) and Dal Bó and Dal Bó (2011). Both are models of occupational choice where actors allocate their labor between productive activities and fighting—over land in Chassang and Padró i Miquel (2009) and over output in Dal Bó and Dal Bó (2011).[11] The former considers only agricultural production while the latter includes a labor-intensive sector and a capital-intensive sector, but both illustrate how shocks to these sectors affect the risk of conflict through changes in opportunity costs of fighting and returns to predation. McGuirk and Burke (2020) further develops this model to illustrate these mechanisms for both factor and output conflict and incorporates consumers who may also engage in fighting.

I present a stylized model of occupational choice similar to these models to build intuition and generate hypotheses about the effect of agricultural shocks—and locust swarms in particular—on conflict through income-based mechanisms. The conflict modeled here should be thought of as civil conflict initiated by non-state actors, the main focus of the literature on agriculture shocks and conflict. [12]

Consider a simple model where two actors i and j make occupation decisions to maximize net returns in a given time period. Actor i allocates one unit of labor L_i to either agricultural production with net returns $F^A(L^A, i, S_i, W_i, X_i)$, non-agricultural work with net returns $F^N(L_i^N, X_i)$, or fighting to capture output or factors of production with net returns $F^C(L_i^C, X_i, I_j, W_j, X_j)$, where j indexes the other party. For simplicity I discuss the case of exclusive occupation decisions, such that labor allocations are either 0 or 1 and there are no returns from activities with no labor. Returns to all activities are affected by actor and location characteristics X such as land quality, level of education, and fighting ability.

Net returns to agricultural production are affected by agricultural shocks S, which may

[11] Becker (1968) present an early application of the Roy (1951) model to occupational choice between productive activities and crime, which relates closely to conflict in terms of mechanisms.

[12] The implications would be similar for interpersonal conflict such as theft, as the predation mechanism outlined is effectively a form of organized theft, but data limitations preclude empirical analysis of impacts of locust shocks on interpersonal conflict.

vary across actors. Let S take values between -1 and 1 with $S = 0$ indicating no shock, $S = -1$ indicating a strongly positive shock to agricultural production, and $S = 1$ indicating a strongly negative shock. Agricultural production is a concave function of S, with $\frac{\partial F^A}{\partial S} < 0$ and $\frac{\partial^2 F^A}{\partial S^2} < 0$: more severe shocks decrease agricultural production by a greater amount. A larger S therefore reduces agricultural labor productivity—the *opportunity cost mechanism*.

Agricultural production also depends on wealth W with $\frac{\partial F^A}{\partial W} > 0$ as wealth allows more investment in inputs and productive assets. Wealth in period t is a function of income I from activities in period $t-1$, with $\frac{\partial W_t}{\partial I_{t-1}} > 0$. Wealth is therefore decreasing in agricultural shocks since these reduce returns to agricultural production. Effects on wealth create a relationship between past agricultural shocks S_{t-s} on agricultural labor productivity in period t, where $s \in [1, \tau]$ for some τ. We can write $F_t^A = F^A(L_t^A, S_t, W_t(\{S_{t-s}\}_{s=1}^{\tau}), X_t))$, with $\frac{\partial F_t^A}{\partial W_t} > 0$ and therefore $\frac{\partial F_t^A}{\partial S_{t-s}} < 0$. I refer to this long-term impact on agricultural labor productivity as the *wealth mechanism*. This mechanism has not been discussed in the literature on agricultural shocks and conflict, which focuses on short-term effects.

Net returns to non-agricultural work F^N are based on the most productive activity available outside of own agricultural production, including activities that might require migrating. As a simplifying assumption, I suppress the dependence of non-agricultural returns on S and W. Returns to non-agricultural work thus set a lower bound on how far the opportunity cost of fighting may fall following a negative agricultural shock.

The potential net returns to i of deciding to fight j, $F^C(L_i^C, X_i, I_j, W_j, X_j)$, depend on j's income $I_j = F^A(L_j^A, S_j, W_j, X_j) + F^N(L_j^N, X_j)$ and wealth W_j. We can think of these as output and factors of production, respectively. Returns are received only if i is successful in fighting j where this probability depends on characteristics X_i and X_j. Costs of fighting are incurred with certainty and include economic, social, and emotional costs as well as risk of injury or death. If i decides to fight, j also incurs costs regardless of their own occupation decision. An agricultural shock S_j affects i's returns to fighting in the same period by changing j's agricultural output, with $\frac{\partial F^C}{\partial S_j} < 0$ and $\frac{\partial^2 F^C}{\partial S_j^2} < 0$. This is the *short-term predation mechanism.* Past agricultural shocks will affect j's wealth through the wealth mechanism. This will reduce both the output and the factors that i can capture, with $\frac{\partial F_t^C}{\partial S_{j,t-s}} < 0$. This is the *long-term predation mechanism.*

The actor's problem can be presented as choosing their labor allocation L_i to maximize returns in period t given some current and past shock realizations S_i, S_j. For simplicity and intuition I ignore uncertainty in returns and suppose that decisions are made (or equivalently, updated) after the agricultural shocks in the period are realized.

$$\begin{aligned}
\max_{L_{i,t}^A, L_{i,t}^N, L_{i,t}^C} I_{i,t} =& F^A(L_{i,t}^A, S_{i,t}, W_{i,t}(\{S_{i,t-s}\}_{s=1}^{\tau}), X_{i,t}) + F^N(L_{i,t}^N, X_{i,t}) \\
&+ F^C(L_{i,t}^C, X_{i,t}, I_{j,t}, W_{j,t}(\{S_{j,t-s}\}_{s=1}^{\tau}), X_{j,t}) \\
\text{subject to } & L_{i,t}^O \in \{0,1\}, \quad F^O(0,.) = 0, \quad \text{and } \sum_O L_{i,t}^O = 1 \text{ for } O \in \{A, N, C\} \\
& \frac{\partial F^A}{\partial S_{i,t}} < 0; \quad \frac{\partial^2 F^A}{\partial S_{i,t}^2} < 0; \quad \frac{\partial F^C}{\partial S_{j,t}} < 0; \quad \frac{\partial^2 F^C}{\partial S_{j,t}^2} < 0 \\
& \frac{\partial F^A}{\partial S_{i,t-s}} < 0; \quad \frac{\partial F^C}{\partial S_{j,t-s}} < 0
\end{aligned}$$

This yields

$$\begin{aligned}
L_{i,t}^C = 1 \text{ iff } & F^C(1, X_{i,t}, I_{j,t}, W_{j,t}(\{S_{j,t-s}\}_{s=1}^{\tau}), X_{j,t}) \\
& > \max(F^A(1, S_{i,t}, W_{i,t}(\{S_{i,t-s}\}_{s=1}^{\tau}), X_{i,t}), F^N(1, X_{i,t}))
\end{aligned}$$

In words: actor i chooses to engage in violent conflict if the net returns from fighting exceed their opportunity cost: the highest net returns they could receive from choosing another occupation.

If i and j are located in the same area (in this paper, a grid cell), either actor deciding to fight will lead to conflict in the area. If they are located in different areas, conflict occurs in the location of the actor being attacked. In the analysis I test sensitivity of the results to using larger grid cells to capture such spillovers of conflict from the areas affected by agricultural shocks.

3.1 Effects of agricultural shocks on the decision to fight

The effect of an agricultural shock on the decision to fight in the same time period is ambiguous, particularly if there is a strong positive correlation between the two actors' shocks, as in most agricultural shocks. In the data for this paper, the correlation between a grid cell being exposed to a desert locust swarm and the share of neighboring cells exposed in a given year is 0.76, smaller than the correlation in annual total rainfall or maximum temperature (both nearly 1) but still large.

In this case, larger $S_{i,t}$ will decrease i's returns to agricultural production but also be associated with a decrease in the returns to fighting as $S_{j,t}$ is also large. Which effect dominates will depend on the share of agricultural output in the returns to fighting. If conflict is primarily over factors of production (wealth), the correlated shock $S_{j,t}$ will not significantly affect returns to fighting in the same time period so the opportunity cost effect from $S_{i,t}$ should dominate and the probability of conflict will increase. If conflict is primarily over output, the correlated shock $S_{j,t}$ could decrease returns to fighting sufficiently to make this unattractive even in a situation with decreased agricultural labor productivity, potentially decreasing the probability of fighting.

Capture of agricultural output may represent a significant share of the returns to fighting in the sample countries. Banditry and raiding are common, notably targeting livestock but also high-value and easy to steal crops, across different African countries and particularly in periods of conflict. For example, 17% of households surveyed in the Mopti region of Mali in 2012 report banditry attacks (Masset et al. 2019). McGuirk and Burke (2020) summarize multiple examples of raiding and looting of food in different countries following food price spikes in 2008 and 2010-11 which are captured in the ACLED conflict data used in this paper. They also show that the cell level measures of output conflict used in this paper are significantly correlated with micro-level measures of conflict from Afrobarometer household surveys.

In the case of desert locust swarms, the destruction of agricultural production is extreme, meaning returns to agricultural production fall to nearly 0 and the optimal decision will be to shift occupation out of agriculture. Importantly, swarms consume all types of vegetation and there are effective methods for farmers to limit damage to their output. Levels of agricultural destruction will therefore be similar across individuals with different characteristics in affected areas.

Flight patterns create some variation in the shock to agricultural production over space so affected individuals may still perceive some returns to fighting over agricultural output in neighboring areas. But the net returns to fighting will still fall on average due to agricultural destruction in nearby affected areas. Even if agricultural prices increase as a result, this may not increase returns to fighting if the quantity available to capture is low. This implies that for some individuals, switching to non-agricultural work will offer higher net returns than switching to fighting. In addition, individuals for whom fighting was previously optimal may switch out of fighting to non-agricultural work. In many cases, this transition may involve temporary migration, a common response to desert locust swarms (Thomson and Miers 2002; The World Bank 2020). National and international relief efforts may also prevent individuals switching into fighting. Together, these offsetting mechanisms suggest we might expect a null effect on the risk of conflict in the same year a locust swarm arrives, which would likely extend at least until after the following season's harvest when there is again agricultural output available and the returns to fighting over output increase.

An increase in conflict may be more likely for less catastrophic agricultural production shocks, such as deviations from average rainfall and temperature. These will cause less damage to agricultural production on average and also potentially more variation in damages in affected areas. Different crops may be affected differently, and farmers may have various tools to reduce exposure such as irrigation or planting drought-resistant varieties. Consequently, even if the weather shock is common over a large area there will likely be variation in the shock to agricultural production across farmers. Returns to fighting over output in affected areas will not fall as much as in the case of locusts swarms. Farmers who are most affected by the shock may then perceive that switching to fighting is optimal, increasing average conflict risk.

A price shock increasing agricultural prices would increase the returns to both agricultural production and to fighting over agricultural output. Individuals for whom agriculture or fighting was previously optimal are unlikely to switch occupation, but the risk of conflict will increase if any individuals for whom non-agricultural work was optimal decide to switch to fighting.

The long-term effects of past shocks $S_{i,t-s}$ on the decision to fight in period t also involve offsetting mechanisms. The returns to both agricultural production and to fighting will be higher than in the short-term, but may be lower than before in affected areas as the wealth mechanism decreases agricultural labor productivity. Marending and Tripodi (2022) show evidence of reduced farm profits two years after exposure to locusts in Ethiopia.

Which effect is stronger will depend on the correlation between the shocks and the relative recovery trajectories of affected individuals. Although locust swarms damage agricultural output similarly across individuals with different characteristics, those characteristics may affect the strength of the wealth mechanism. Some individuals will have access to more resources allowing them to recover their agricultural productivity, while others will fall into a low-productivity trap. Individuals with persistently lower agricultural productivity will be more likely to switch to fighting if the returns to fighting increase in a given period. Productivity traps may be particularly likely following desert locust swarm exposure due to the severity of the income shock and lack of access to financial markets for many farm households in countries affected by locusts. This suggests we should expect an increase in long-term conflict risk in areas exposed to locust swarms.

Agricultural price shocks should not affect long-term conflict risk as the wealth and long-term predation mechanisms would likely be limited, though large price increases might lead to persistent wealth decreases for non-producers. Weather shocks could have similar long-term effects on conflict as locust shocks if they are severe enough to lead to productivity traps.

Based on this discussion, the main predictions I investigate empirically are:

1. Locust swarms do not significantly increase the risk of civil conflict in the year of exposure.
2. Exposure to locust swarms increase the long-term risk of civil conflict.

4 Data

The Locust Watch database (FAO 2022) reports observations of desert locust swarms as well as smaller concentrations of locusts from 1985 to the present. These data include latitude, longitude, and date of observations.Observations of locusts are recorded by national locust control and monitoring officers on the ground, but incorporate reports from agricultural extension agents, government officials, and other sources. Local farmer scouts are often trained in locust monitoring and reporting (Thomson and Miers 2002). I consider only data on locust swarms, high density groups of gregarious locusts that move as a unit, and do not consider observations of locusts at lower density as these pose less of a threat to agriculture. Locust swarm presence is also less likely to be unreported than smaller locust groupings.

A concern might be that violent conflict reduces the probability that locust swarms are recorded, since insecurity could limit locust monitoring or prevent local observations from being passed on in areas where locusts may be active. This concern is the focus of Torngren Wartin (2018)'s analysis of the impact of locusts on conflict, which uses the same data but ignores the potential long-term effects of desert locust swarms, modeling them as temporary shocks.

Showler and Lecoq (2021) review how insecurity has affected national and international desert locust control operations from 1985-2020 across countries where locusts are active.

They mention Chad, Mali, Somalia, Sudan, Western Sahara, and Yemen as countries with areas where insecurity has constrained locust control operations in certain periods since 1997. Insecurity is likely less of a constraint for recording locust swarms as FAO locust monitoring guideliness discuss conducting aerial surveys and using reports from local scouts, agricultural extension agents, security forces, and other sources (Cressman 2001). None of the monthly FAO locust swarm bulletins published during the 2003-2005 upsurge—the major locust event in the sample period—mention issues related to insecurity affecting locust monitoring efforts. The Locust Watch data includes observations of locust swarms even in countries and periods where the authors indicate control operations have not been possible due to insecurity. For example, the authors mention that control operations in Western Sahara have been largely infeasible due to Polisario activity over the whole sample period, but 166 swarms have been recorded there in 9 different years from 1996-2018.

Locust swarms may yet be underreported in insecure areas. The share of cells within 50km of a locust swarm observation in a given year that experienced violent conflict that year and also were exposed to a locust swarm is 27% in the set of countries Showler and Lecoq (2021) indicate created locust control challenges, compared to 34% in all other countries. Underreporting would imply that some insecure areas will be incorrectly included in the set of cells not exposed to locust swarms, which could bias the analysis. I discuss how such bias might affect estimates and test the sensitivity of the results to excluding the countries listed in the report as potential locations of locust swarm underreporting.

Data on conflict events come from the Armed Conflict Location & Event Data Project (ACLED) database (Raleigh et al. 2010). The database records the location, date, actors, and nature of conflict events globally starting from 1997 by compiling and validating reports from traditional media at different levels, from institutions and organizations, from local partners in each country, and from verified new media sources. The analysis focuses on events categorized by ACLED as "violent conflict," which includes battles, explosions, and violence against civilians. I test robustness to analyzing protest and riot events and to using data on larger-scale violent conflicts from the Uppsala Conflict Data Program (UCDP; Sundberg and Melander 2013), which records conflicts worldwide since 1989 involving at least one "organized actor" and resulting in at least 25 battle-related deaths in a calendar year. ACLED has no organized actor or minimum death threshold requirements. McGuirk and Burke (2020) characterizes ACLED events as more likely to represent conflict over outputs and UCDP events as more likely to represent conflict over territory and factors of production. These different types of conflict may engage different mechanisms.

I collapse the data to a raster grid with annual observations for cells with a 0.25° resolution (15 arcminutes, approximately 28×28km). Analyzing impacts at this spatial level reduces potential measurement error about the specific areas affected by swarm and conflict events and allows me to leverage local variation in swarm presence created by their flight patterns. About half of locust swarms exceed 50km^2 in extent. Most swarms will be contained within 0.25° cells (∼784km^2), except those near cell boundaries. I test for robustness to analyzing data at the level of 0.5° and 1° cells. In each cell and year I measure whether any locust swarm and conflict event was recorded.

I determine the country and highest sub-national administrative level in which each cell lies using country boundaries from the Global Administrative Areas (2021) database v3.6. I use sub-national boundaries to create a set of 170 regions, all of which include at least 32 individual grid cells. These regions are either existing sub-national administrative units or combinations of adjacent units within the same country. I cluster standard errors at the level of these regions.

Given the role of weather in desert locust biology and its importance in determining agricultural production, all analyses control for local weather to isolate the impact of the locust swarm exposure. I measure total annual precipitation (in mm) and maximum temperature (in °C) using high-resolution monthly data from WorldClim available through 2018.[13] I also incorporate raster population data for every 5 years from CIESIN 2018, linearly interpolat-

[13] CRU-TS 4.03 (Harris et al. 2014) downscaled with WorldClim 2.1 (Fick and Hijmans 2017).

ing within cells between years where the population is estimated, and raster data on land cover in 2000 from CIESIN, giving the share of land cover that is cropland and pasture (Ramankutty et al. 2010). I include additional cell characteristics from the PRIO-GRID dataset (Tollefsen, Strand, and Buhaug 2012), assigning all 0.25° cells the values for the 0.5° cell in which they are located.

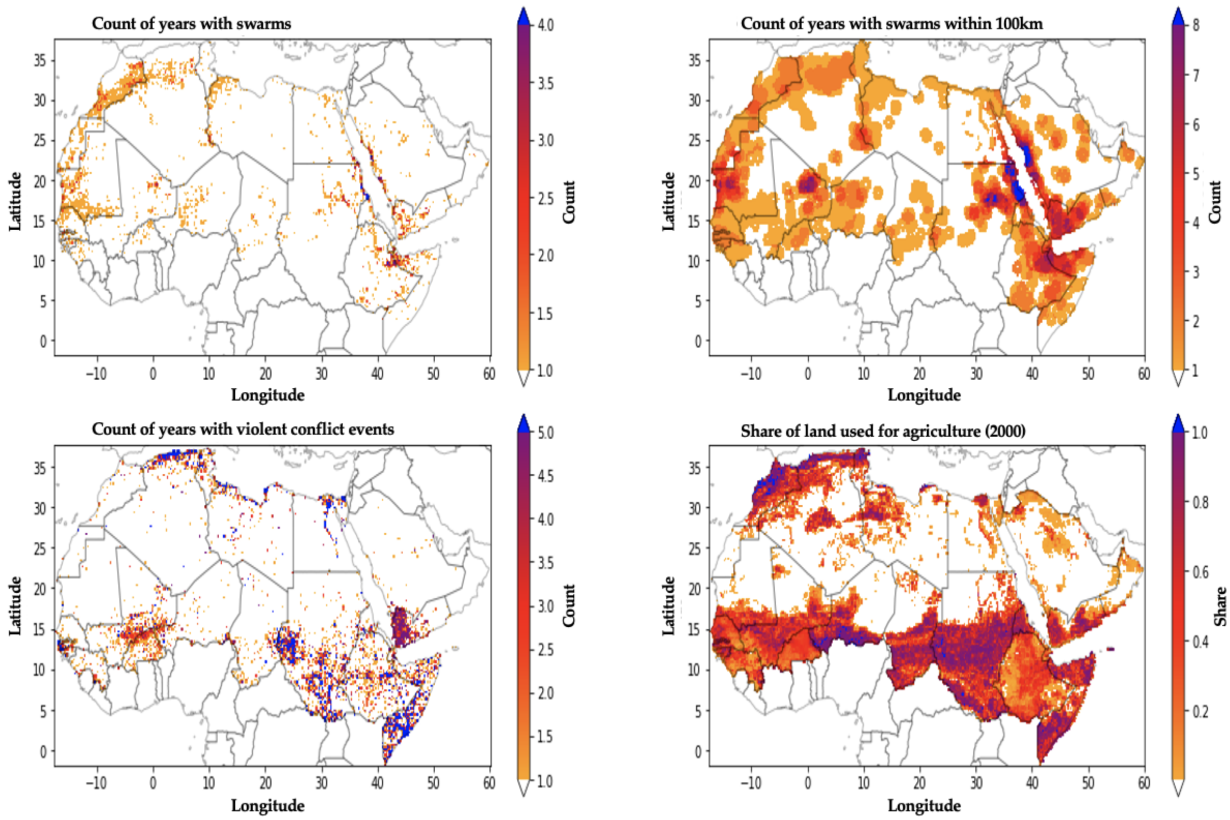
Since ACLED records conflicts beginning in 1997 and the weather data are available until 2018, I retain only data from 1997 to 2018. I restrict the analysis to countries with at least 10 locust swarm observations in this period. These countries include all of North Africa, most of the Arabian Peninsula, and most countries along the Sahel. The resulting analysis sample covers 22 years across 24,459 cells, for a total of 538,098 observations. Among these are 2,634 cell-years with a locust swarm event and 10,265 with a violent conflict event. Ten percent of cells in the sample were exposed to at least one locust swarm, but just 1.4% experience swarms in multiple years. Fifty-six percent of cells were within 100km of at least one locust swarm event. Fourteen percent of cells experienced at least one violent conflict event. About half the cells (53%) in the sample include some agricultural land: 52% have pasture land while 28% have crop land. Across all cells, mean pasture area is 19% of the cell and mean crop area is 5% of the cell. These variables are displayed in Figure 2, and summary stats are included in Table A1.

5 Empirical approach

I estimate the causal impacts of locust swarms on conflict using a difference-in-differences approach allowing for long-term effects of this agricultural shock. For each grid cell, I identify the first year after 1989 in which a locust swarm is recorded in the Locust Watch database.[14] I define a cell as exposed to a locust swarm in each year starting from the first year a swarm

[14] A major locust upsurge occurred from 1985-1989. 1,195 cells where a locust swarm was recorded between 1985 and 1989 but in no year afterward are treated as not exposed to locust swarms during the 1998-2018 sample period. Treatment timing for another 997 cells where a locust swarm was recorded between 1985 and 1989 is based on the first year after this period that a locust swarm was recorded. The results are robust to basing treatment timing on the first year any swarm is recorded in a cell in the Locust Watch database.

Figure 2: Distribution of swarm and violent conflict observations over sample countries



Note: Land used for agriculture includes crop land and pasture land. This panel shows most clearly which countries in West, Central, and East Africa are excluded from the study sample.

is observed, and not exposed in all other years or if no locust swarm is ever observed.[15] I first estimate average effects of locust swarm exposure in the following years using a two-way fixed effects (TWFE) linear probability model, which takes the form:

$$Conflict_{ict} = \alpha + \beta Exposed_{ict} + \delta X_{ict} + \gamma_{ct} + \mu_i + \epsilon_{ict} \quad (1)$$

where i indexes cells, c indexes countries, and t indexes years. $Conflict$ is a dummy variable for observing any conflict event and $Exposed$ is a dummy variable for having been exposed to a locust swarm. γ_{ct} are country by year fixed effects, and μ_i are cell fixed effects. X_{ict} is a vector of time-varying controls at the cell level. Standard errors (SEs) are clustered at the

[15]I treat cases where locust swarms are observed in more than one year with cases where they are observed only once, defining treatment only by the first year a swarm is observed. 8.7% percent of cells with any locust exposure in the sample period are exposed in two different years, 2.6% are exposed in three years, and 1.3% are exposed in four or more years.

sub-national region level (170 clusters) to allow for correlation in the errors within nearby areas over time.[16]

I then estimate event study models using the staggered treatment difference-in-differences Stata packages *did_imputation* and *csdid* which implement the methods in Borusyak, Jaravel, and Spiess (2021) and Callaway and Sant'Anna (2021), respectively. These approaches deal with concerns with a static TWFE estimators when there is heterogeneity in treatment effects over time, which can lead to 'forbidden' comparisons between late- and early-treated groups and negative weighting of effects for certain treatment groups or periods. Both methods effectively estimate an average treatment effect on the treated in each time period separately for groups exposed in a year g. Event study estimates are then calculated by taking weighted averages of the treatment effect in different periods relative to the timing of exposure across groups exposed in different years. The main difference is that Callaway and Sant'Anna (2021) compare differences between years t and $g-1$—the year prior to exposure—for the group exposed at g to the difference for groups not yet exposed at g, while the Borusyak, Jaravel, and Spiess (2021) imputation estimator makes comparisons between t and the average over all periods before g (Roth et al. 2023). The methods imply different assumptions about parallel trends but generally give quite similar results. I use these methods to estimate differences between cells exposed to desert locust swarms and not yet exposed cells over the 14 years before and after swarm exposure, using the same fixed effects, controls, and clustering as in Equation 1. I generate event study plots using Stata's *event_plot* package developed by Borusyak, Jaravel, and Spiess (2021).

To further explore mechanisms and the impacts of swarm exposure over time, I then specifically analyze impacts of exposure to the 2003-2005 major desert locust upsurge on conflict risk. This is the only major locust upsurge in the sample period (1997-2018), and

[16] This is likely more restrictive than necessary and will lead to a conservative interpretation of the results. Patterns of statistical significance are largely unchanged when using two-way clustered errors at the year and region level and using Conley (1999) Heteroskedasticity and Autocorrelation-Consistent (HAC) SEs allowing for spatial correlation over 100 and 500km and serial correlation over 0 or 10 time periods, following Hsiang (2010)'s approach.

accounts for 73% of first cell locust swarm exposure. I estimate the TWFE difference-in-differences regression in Equation 1 where swarm exposure is defined as previously but cells first exposed to desert locusts outside of 2003-2005 during the sample period are omitted from the sample. This is a 'canonical' difference-in-differences analysis with the upsurge 'treatment' occurring in the same period for all treated units and a comparison group that never receives this treatment. In this case the treatment period is 2003-2005 and I treat 2004 as the year of first exposure as the small number of swarms in 2003 at the beginning of the upsurge arrived in the last months of the year.[17] I then conduct an event study analysis of the upsurge interacting exposure to any upsurge swarm with individual year dummies to explore how impacts on conflict risk evolve over both relative and calendar time.

To test for heterogeneity in the impacts of swarms, I estimate Equation 1 fully interacting the right-hand side variables with another variable of interest. I test robustness of the results to different controls and fixed effects, restrictions of the analysis sample, cell sizs, and clustering of SEs. Results of robustness tests are included in Appendix C. I also present results of a 'naive' approach to estimating short-term impacts of locust swarm exposure that does not account for persistent effects of exposure on conflict risk following the methods commonly used in the climate-conflict literature with panel grid cell data, and discuss the resulting bias.

The long-term impact of locust swarms is identified by comparing the difference in conflict risk before and after swarm exposure in affected cells to differences over time in unaffected cells. The key identifying assumption of this design is that trends in conflict risk would be parallel over time in affected and unaffected areas in the absence of locust swarm exposure. This assumption is supported by the quasi-random variation in locust exposure over space during locust outbreaks due to wind speed, direction, and flight duration.

To explore the validity of the parallel trends assumption, I first test for balance in baseline or mean cell characteristics. Cells exposed to a desert locust swarm during the sample period

[17] Results are similar using the staggered treatment timing estimators.

are similar to unexposed cells in timing of the main rainy season, total annual precipitation, and area allocated to crop production but differ in other characteristics (Table A2). Cells with locust exposure had significantly higher populations and share of land area allocated to pasture in 2000, higher mean cell nightlight radiance from 1996-2012, and lower maximum annual temperature from 1997-2018. Differences are similar when restricting the definition of locust exposure to just the 2003-2005 upsurge. These differences are consistent with desert locusts rarely being observed in the interior of the Sahara desert, as their breeding areas are closer to the boundaries of the Sahara and wind patterns generally keep them from entering the interior.

Baseline differences are not a concern if they only affect levels of civil conflict and not trends in civil conflict. Cell fixed effects control for time invariant cell characteristics that might affect the risk of conflict such as distance to major cities or country boundaries, topography, and agricultural suitability, as well as factors affecting risk of locust exposure such as distance from locust breeding areas and typical seasonal wind patterns. Country by year fixed effects flexibly control for factors varying over time at the country that might affect conflict risk and the impact of agricultural shocks, such as food price shocks, weather patterns, the policy environment and national economic and social conditions. Importantly, they also control for trends in violent conflict incidence, which increases over the sample period.

To isolate impacts of locust swarm exposure from other potentially time-varying factors affecting conflict risk, I include controls for characteristics that differ between exposed and unexposed cells. In particular, my preferred specification includes total annual precipitation (in mm), the maximum annual temperature (in °C), and annual population.[18] I do not have time-varying data on land cover, but results are not sensitive to accounting for changes in crop land over time as documented in Xiong et al. (2017). Effects of locust swarms are therefore identified from variation in exposure within cells over time controlling for time-

[18]Results are robust to including squared temperature and rainfall terms or used logged versions.

varying national conditions as well as cell-specific variation in population and weather.

I use the event study analyses to test for differences in violent conflict risk by exposure to desert locusts in periods prior to exposure. I find no significant differences in the pre-periods, indicating no differential conflict risk pre-trends (Figure 3, Figure 4). Though this does not preclude the possibility that trends would differ in the years after swarm exposure for reasons unrelated to agricultural destruction, it is an encouraging sign that the parallel trends assumption may be likely to hold.

For the analysis of the 2003-2005 upsurge, I test the robustness of the results to efforts to increase the plausibility of the parallel trends assumption by imposing different constraints on the areas included in the comparison sample and to using inverse propensity weights based on the estimated probability of reporting a locust swarm during the upsurge.[19] The main results for the 2003-2005 upsurge include these inverse propensity weights.

Another identification assumption relevant to the event study designs with staggered treatment timing is the no anticipation assumption: knowledge of future treatment timing does not affect current outcomes (Roth et al. 2023). Swarm formation in breeding areas determines whether any cells are exposed in a given year, and variation in wind direction and typical locust flight duration create quasi-random variation in areas where swarms land. The FAO Desert Locust Watch publishes monthly forecasts of areas predicted to be at risk of locust swarm exposure but the predictions include a great deal of uncertainty due to unpredictable variation in swarm flight patterns. Consequently, areas forecast to be at risk are generally quite large, the majority of which end up not being affected by locusts.[20] Populations may expect a higher probability of swarm exposure in years of major outbreaks

[19] I calculate propensity scores using a logit regression with a dummy for being exposed to a locust swarm during the upsurge on baseline (pre-2004) cell characteristics and country fixed effects. I calculate inverse propensity weights as $\frac{1}{p}$ for cells that were exposed during the upsurge and $\frac{1}{1-p}$ for cells that were not, where p is the estimated probability of reporting a swarm during the upsurge. I assign cells with estimated probabilities outside the range of common support and cells exposed to a locust swarm during the sample period but outside of the upsurge a weight of 0.

[20] Monthly forecasts during the major upsurge in 2004 on average covered 40.6% of 0.25° cells in sample countries. 78% of recorded swarms across were in areas forecast to be at risk in the month the swarm was observed, and being mentioned in a monthly forecast is associated with a significant 2% increase in the likelihood of being exposed to a locust swarm.

but cannot perfectly anticipate timing of exposure. Anticipation may also have limited effects as there are no effective methods of defending vegetation against locust swarms, and farmers in at-risk areas typically describe locust prevention and control as out of their hands and the responsibility of governments (Thomson and Miers 2002).

6 Results

6.1 Average long-term impacts of swarm exposure

Table 1 presents estimates of Equation 1 analyzing average impacts of having been exposed to a desert locust swarm in the years following exposure. Column (1) shows that cells exposed to locust swarms are 2.1 percentage points more likely to experience any violent conflict in a given year in the period after swarm exposure, an 88% increase over the mean probability of any violent conflict event in a year for cells not exposed to locusts. This effect is large compared to the effects of weather deviations. An increase in annual precipitation of 100mm relative to the average in the cell increases the probability of violent conflict in the same year by 0.3 percentage points (13%), while an increase in the maximum annual temperature of 1°C relative to the average increases conflict risk in the same year by 0.5 percentage points (21%). These effects fall in the upper middle range of estimates reported in Burke, Hsiang, and Miguel (2015)'s meta-analysis of the impacts of weather deviations on conflict. Cell population is also positively associated with conflict risk, with an increase of 10,000 people associated with a 0.5 percentage point (21%) increase in the probability of any violent conflict event in a year.

The impact of locust exposure remains statistically significant at the 99% confidence level under other forms of standard error clustering, including two-way clustering at the region and year level and using Conley (1999) SEs allowing for spatial correlation within 100 and 500km and serial correlation over 0 or 10 years (Figure C1). Associations between weather deviations and population and violent conflict risk are also statistically significant at the

95% confidence level or greater under all clustering choices. Clustering at the region level consistently leads to SEs at least as large as Conley SEs allowing for spatial correlation within 500km and serial correlation over 10 years, implying the main SEs I report with region clustering may understate statistical significance of certain estimates.

Table 1: Average impacts of exposure to locust swarms on conflict risk

Outcome: Any violent conflict event	(1) All land	(2) Any crop or pasture land	(3) Any crop land
Affected by any locust swarm	0.021***	0.006	0.010**
	(0.006)	(0.005)	(0.005)
Total annual rainfall (100 mm)	0.003***	0.003	0.003*
	(0.001)	(0.002)	(0.001)
Max annual temperature (deg C)	0.005***	0.003**	0.003**
	(0.002)	(0.001)	(0.001)
Population (10,000s)	0.005***	0.004**	0.010***
	(0.001)	(0.002)	(0.003)
Affected by any locust swarm × Land =1		0.018**	0.027***
		(0.007)	(0.009)
Total annual rainfall (100 mm) × Land =1		0.000	0.001
		(0.002)	(0.002)
Max annual temperature (deg C) × Land =1		0.002	0.005**
		(0.002)	(0.002)
Population (10,000s) × Land =1		0.002	-0.004
		(0.002)	(0.003)
Observations	505679	499651	499651
Outcome mean, no swarms	0.024	0.023	0.023
Country-Year FE	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes

Note: The dependent variable is a dummy for any violent conflict event observed. Cells are regarded as 'affected' by locust swarms for all years starting from the first year in which a swarm is recorded in the cell. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Columns (2) and (3) show results interacting the right-hand side variables with dummy variables for whether a cell has any agricultural (crop or pasture) land or any crop land, respectively, using measures of land cover from 2000 (Ramankutty et al. 2010).[21] Locust swarm exposure in non-agricultural cells (46% of the sample) has no significant effect on

[21] Southward expansion of the Sahara desert, anti-desertification efforts, deforestation, changing seasonal distribution of precipitation, and expansion of farming in traditional pastureland have all contributed to changing land cover over the study period (Davis 2022; Liu and Xue 2020; Rahimi et al. 2021). Xiong et al. (2017) report that from 2003-2014 croplands increased by 1 Mha per year on average. As a result, some areas with cropland will be inaccurately classified as non-agricultural in this analysis based on land cover in 2000, which would reduce the estimated difference in impact by cell land cover. Results in Tables 1 and 2 are similar when defining crop cells as those with any cropland in either Ramankutty et al. (2010) or Xiong et al. (2017).

subsequent conflict risk, while in agricultural cells conflict risk increases by 2.4 percentage points (104%). Locust swarms increase conflict risk by 3.7 percentage points (161%) in crop cells (29% of the sample) compared to 1.0 percentage points in non-crop cells (35% of which have pasture land), indicating that impacts on crop production drive most of the effect on conflict risk but impacts on pasture also explain part of the total effect. These results are consistent with locust swarms representing shocks that affect the economy and society solely through their impacts on agricultural production.

There is no significant difference in the effects of rainfall deviations by land cover, consistent with previous work questioning whether agricultural mechanisms explain the relationship between rainfall and conflict (Bollfrass and Shaver 2015; Sarsons 2015). Impacts of temperature deviations on conflict risk are larger in by cells with crop land, where a 1°C hotter year increases conflict risk by 0.8 percentage points. The association between population and conflict risk does not vary significantly with land cover.

The estimated average impact of locust swarm exposure on conflict risk in subsequent years is robust to a variety of specifications (Figure C2). The magnitudes of the estimated effects do not differ significantly and remain statistically significant when dropping controls, replacing country by year fixed effects with year or region by year fixed effects, conducting the analysis at the level of 0.5° or 1° grid cells, and excluding countries in North, West, and East Africa, Arabia, and the list of insecure countries affecting locust control in Showler and Lecoq (2021) from the analysis. Most estimates are slightly larger in magnitude, with the exception of using year fixed effects and excluding Arabian countries[22] and those listed in Showler and Lecoq (2021).

Using larger grid cells limits the potential for spillovers outside a cell and the possibility that the area exposed to a locust swarm recorded in a cell exceeds the boundaries of the

[22] Cells in the Arabian peninsula first exposed to locust swarms during an outbreak in 2007 experienced a much larger increase in subsequent conflict risk than other cells first exposed to swarms during the sample period. The 2003-2005 locust upsurge largely did not affect Arabian cells, so estimates from the analysis of the impact of locust exposure during that upsurge will not be affected by the factors influencing the differential effect of locust exposure in Arabia.

cell. Despite larger estimated magnitudes, the proportional effect relative to unexposed cells is lower—a 34-38% increase in conflict risk—when using larger grid cells. The smaller proportional effect will partly reflect dilution of treatment intensity as only one 0.25° cell in the broader cell need have been exposed to a locust swarm for the broader cell to be considered exposed, but part of the difference could also be due to spillovers. Nearby cells not exposed to locust swarms may end up better off if they take advantage of potential price increases of sale of assets following agricultural destruction in exposed cells, and therefore experience a wealth increase and be less likely to engage in conflict in the long-term. To the extent such spillovers are occurring, smaller relative estimated impacts of locust swarm exposure on violent conflict risk from 1° cells may more accurately capture the effect of agricultural destruction from locusts.

Excluding countries listed in Showler and Lecoq (2021) as areas where insecurity limited desert locust control operations during the sample period slightly decreases the absolute estimated impact of locust exposure to a 1.5 percentage point increase in conflict risk, but increases the relative effect to a 111% increase due to lower conflict incidence in the remaining countries. This would be consistent with the more insecure countries having some unreported swarm exposure which increased subsequent conflict risk, biasing the estimated impact of reported swarm exposure downward.

I also estimate effects weighting observations by the inverse of the estimated propensity to have been exposed to a locust swarm during the study period. Characteristics of exposed and unexposed cells are well-balanced after including these weights (Table C1), suggesting the parallel trends assumption may be more likely to hold. The pattern of results is similar, with smaller estimated magnitudes except for impacts in cells with crop land (Table C2). On average, locust swarm exposure significantly increases conflict risk by 0.8 percentage points (62%) in subsequent years. There are no significant effects in cells without pasture or crop land, and impacts are driven particularly by cells with any cropland where the risk of violent conflict increases by 3 percentage points (230%), compared to an increase of 1.5 percentage points (115%) in cells with either crop or pasture land.

Impacts of swarm exposure on conflict risk are larger in both absolute and relative terms using ACLED data on violent conflict events than UCDP data, which imposes a threshold of 25 battle-related deaths in a calendar year between groups engaged in conflict (Table A3). Impacts are largest in magnitude for ACLED violent conflict events involving non-state actors (such as rebel groups, identity militias, etc.) and violence against civilians, though I also find significant increases in the probability of conflict involving the state. The largest proportional effect—a 1.8 percentage point (257%) increase—is for the probability of any protest or riot event in cells affected by locust swarms in the years after exposure. These differences by conflict type are consistent with individuals with lower agricultural productivity having lower opportunity costs of engaging in conflict as discussed in the conceptual framework.

6.2 Impacts of swarm exposure over time

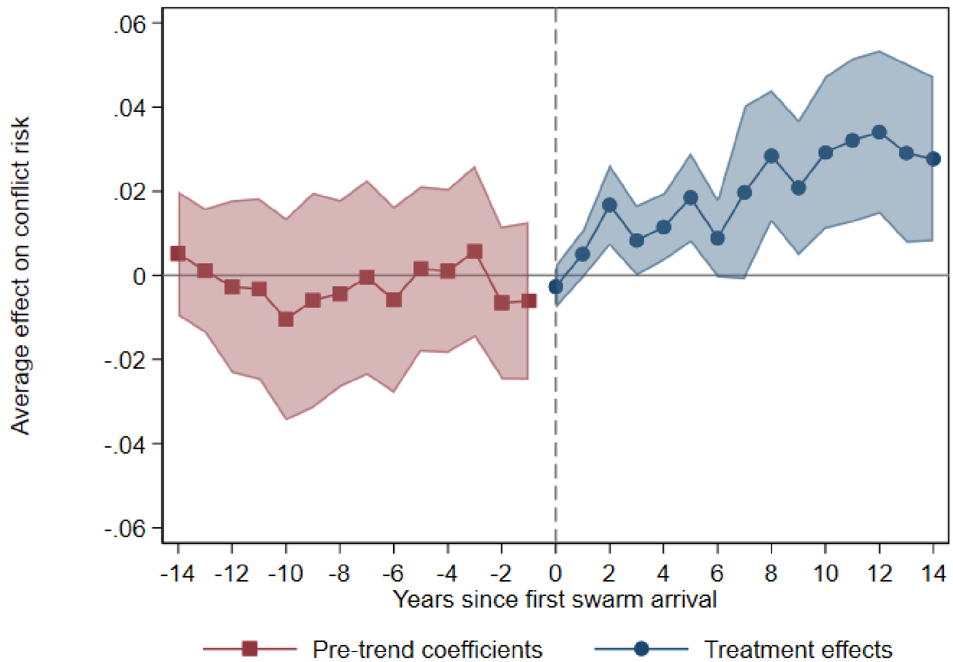
The previous results estimate average impacts of locust exposure in over the following years, relative to unexposed areas. Figure 3 presents event study estimates of the impacts of swarm exposure over time using the staggered treatment timing difference-in-differences approach developed in Borusyak, Jaravel, and Spiess (2021).[23] There is no significant difference in conflict risk between cells that are and are not exposed to locusts in the years prior to exposure.[24].

The point estimate for the effect on conflict risk in the year locusts arrive is close to 0 (-0.002) and not statistically significant. All other estimated treatment effects are positive and statistically significant,. Impacts in years 1-6 post-exposure are relatively smaller—the average effect is a 1.2 percentage point increase in conflict risk—and are only marginally statistically significant for 3 of the years. The impacts are larger in years 7-14 post-exposure

[23]The main estimates do not include weather or population controls due to challenges getting the estimates to converge with the BJS *did_imputation* package. I focus on results from the BJS approach because of challenges getting the estimates to converge when including country by year FE in the CS *csdid* package. I present results from both packages with different fixed effects and controls in Figure C3.

[24]The average difference in the pre-exposure period is -0.005. None of the 14 pre-exposure period differences are significantly different from 0 and I fail to reject that pre-period differences are jointly equal to 0 (p=0.191).

Figure 3: Impacts of exposure to locust swarms on conflict risk over time



Note: Event study results for impacts of exposure to any locust swarm on conflict risk over time using the Borusyak, Jaravel, and Spiess (2021) approach. All regressions include country by year and cell fixed effects. Locust swarm exposure is based on the first year a locust swarm is observed in a cell; cells with locust swarms observed before the start of the sample period are not included in the analysis. Estimated impacts in each time period are weighted averages across effects for swarm exposure in particular years. The time period 0 is the year of swarm exposure. The shaded areas represent 95% confidence intervals. The reference year for treatment effects is the year prior to exposure, and coefficients are based on comparisons against the pre-exposure period. A joint test that the pre-exposure coefficients equal 0 gives $p = 0.191$. Observations are grid cells approximately 28×28km by year. SEs are clustered at the region level.

and are highly significant after year 7 even as the standard errors are larger with more time since exposure. Swarm exposure causes an average increase in conflict risk in a given year of 2.8 percentage points over these periods.

The pattern of results in the event study is similar in alternative specifications (Figure C3). Estimated treatments effect sizes are similar but standard errors are smaller when using region-by-year fixed effects. Using year fixed effects results in a similar pattern of treatment effects with larger magnitudes particularly in years 8-10, but estimated treatment effects in years 12-14 are smaller and not statistically significant. Treatment effects and significance are similar using the event study method in Callaway and Sant'Anna (2021), though the effect in year 3 is no longer statistically significant. Pre-trend estimates are more precise due to the different estimation method (taking differences in adjacent years). Pre-trend coefficients are nearly identical using this method and including weather and population controls. Treatment effects for years 0-11 post-exposure are smilar though the effect in years 6 and 11 are no longer statistically significant. Estimates for years 12-14 are close to 0. The pattern of treatment effects over time is similar at the 1° cell level. Estimated magnitudes are larger (though not in proportion to mean conflict risk at this level) but the standard errors are as well, particularly for the pre-trend coefficients. The negative effect in the year of exposure becomes statistically significant, while estimated treatment effects in years 1-6 are not significant. Effects for years 7-14 are statistically significant and largest for years 7-10. Standard errors on the treatment effects are slightly larger when clustering at the country instead of the sub-national region level, and the effects in periods 3 and 6 are no longer significant at a 90% confidence level.[25]

Long-term increases in conflict risk are driven by violent conflict involving non-state actors, with consistently smaller impacts on conflict involving state actors (Figure C4). The pattern of impacts of swarm exposure is similar for protest and riot events: smaller increases in the risk of any such event in years 2-8 after exposure and much larger increases afterward, though the estimates for years 13 and 14 are noisy.

In summary, after null effects on conflict risk in the short-term immediately following swarm exposure (with a negative point estimate), the probability of any violent conflict event is significantly higher than in unaffected cells in the years post-exposure. In some specifications the effect is limited to the first 10 years after exposure before losing significance, but across all specifications the largest impacts on conflict risk are realized around 7-11 years after swarm exposure.

[25] The CS and BJS event study packages in Stata are not compatible with two-way clustering of SEs; additional treatment effects may lose statistical significance if also clustering SEs by year but most effects are likely to remain significant.

6.3 Impacts of the 2003-2005 desert locust upsurge

I further test effects of locust swarm exposure over time by analyzing the major locust upsurge in 2003-2005. This is the main outbreak in the sample period which affected 6.6% of cells and accounts of 73% of first cell locust swarm exposure. Trends for violent conflict events and locust swarms prior to the upsurge are similar across cells that were and were not affected by the 2003-2005 upsurge supporting the parallel trends assumption, and locust swarm presence is similar following the upsurge (Figure A1). Differences in characteristics of cells exposed to locusts during this upsurge to unexposed cells are similar to the differences when considering cells exposed to any locust swarm (Table A2). Cells exposed to an upsurge swarm have 65% more area allocated to pasture land and are 1.2°C cooler on average. Weighting based on the inverse of the estimated propensity to have been exposed to a locust swarm during the upsurge and dropping cells outside the region of common support for the propensities of affected and unaffected cells results in well-balanced samples (Table C1). The main results I present for the upsurge include these inverse propensity weights.

Table 2 shows the TWFE estimates for the average impact of upsurge swarm exposure. The patterns and magnitudes of results are similar to the estimates for exposure to any swarm using inverse propensity weights (Table C2)—not surprising since the 2003-2005 upsurge was the main swarm exposure event in the sample period. Column (1) shows that upsurge exposure is associated with a 1.1 percentage point (58%) increase in conflict risk over the following years on average. Columns (2) and (3) show that there are again no impacts in cells with no crop or pasture land, and that impacts are particularly large in cells with crop land: a 3.1 percentage point (163%) increase in the probability of any violent conflict event.

Figure 4 shows the results of an event study analysis of the 2003-2005 upsurge. Effects are all estimated relative to 2003, when a few locust swarms were observed near the end of the year. There are no significant differences in the risk of conflict between areas exposed to locust swarms during this upsurge and areas that were not in the years preceding the upsurge, though the coefficient for 2000 is large. I cannot reject the joint hypothesis that

Table 2: Average impacts of exposure to 2003-2005 upsurge swarms on conflict risk

Outcome: Any violent conflict event	(1) All land	(2) Any crop or pasture land	(3) Any crop land
Affected by 2003-05 upsurge	0.011*	0.002	-0.001
	(0.006)	(0.007)	(0.005)
Total annual rainfall (100 mm)	0.004*	0.006	0.004
	(0.002)	(0.006)	(0.003)
Max annual temperature (deg C)	0.007***	0.006**	0.006**
	(0.003)	(0.003)	(0.003)
Population (10,000s)	0.007***	0.001	0.004
	(0.001)	(0.002)	(0.003)
Affected by 2003-05 upsurge		0.014*	0.032**
× Land=1		(0.008)	(0.013)
Total annual rainfall (100 mm)		-0.003	-0.001
× Land=1		(0.006)	(0.003)
Max annual temperature (deg C)		0.002	0.003
× Land=1		(0.002)	(0.004)
Population (10,000s)n		0.006**	0.003
× Land=1		(0.003)	(0.003)
Observations	419748	419748	419748
Outcome mean, no swarms	0.019	0.019	0.019
Country-Year FE	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes
Inverse Propensity Weights	Yes	Yes	Yes

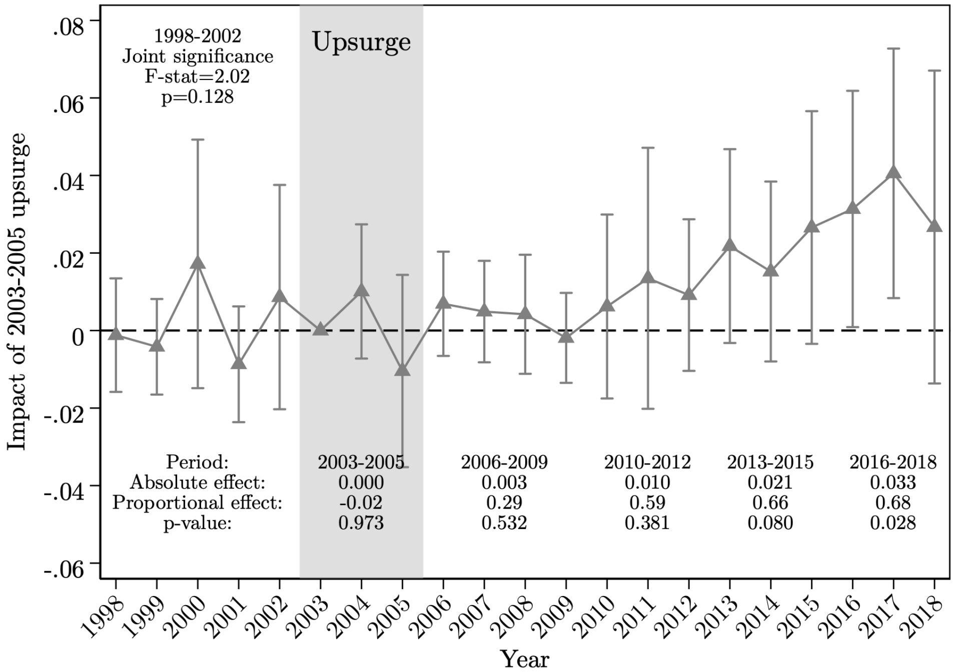
Note: The dependent variable is a dummy for any violent conflict event observed. Cells are regarded as 'affected' by a 2003-2005 upsurge swarm for all years starting from the first year in which a swarm is recorded in the cell. Cells exposed in other years are not included. Inverse propensity weights calculated based on estimates of the propensities of cells to have been exposed to any swarm during the upsurge are included. Controls include annual total rainfall, maximum temperature, and population, and their interactions with the land variables. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

the pre-trend coefficients are equal to 0 (p=0.128). This supports the assumption of parallel trends between these areas if not for the upsurge.

There is no significant impact of locust exposure on the risk of conflict in the main years of the upsurge, 2004 and 2005. The point estimate for 2005 is slightly negative, as in the exposure year estimates in the main event study. Estimated impacts of the 2003-2005 upsurge on conflict in the following years are almost all positive (the coefficient for 2009 is slightly negative), and become larger in magnitude over time starting after 2009.

The estimated effects for individual years are only statistically significant at a 90% confidence level or greater for 2013 and 2015-2017. Looking at average estimates over bins of years leads to more precise estimates. Being exposed to a 2003-2005 upsurge swarm does not significantly affect conflict risk from 2006-2012, but increases the risk of conflict by 2.1

Figure 4: Impacts of exposure to 2003-2005 locust upsurge swarms on conflict risk over time



Note: The dependent variable is a dummy for any violent conflict event observed. Coefficients are for the interaction of a dummy for being exposed to a locust swarm between 2003-2005 with year. The reference year is 2003, the first year of the upsurge period which is shaded in gray. Bars represent 95% confidence intervals using SEs clustered at the country level. The regression includes controls for rainfall, temperature, population, and cell and country-by-year FE. Observations are grid cells approximately 28×28km by year, weighted by the inverse of the propensity to have been exposed to a swarm during the 2003-2005 upsurge. Estimates from the same specification with binned years are reported at the bottom of the figure. Proportional effects are relative to the probability of observing any violent conflict during the particular time period. *p*-values are for tests of the null of 0 impact of the upsurge in each period. In the top left are the results from a joint test of the hypothesis that all pre-upsurge coefficients equal 0.

percentage points on average between 2013-2015 and by 3.3 percentage points between 2016-2018, and these effects are statistically significant. This is similar to the time frame for the largest swarm exposure treatment effects in the main event study. As civil conflict in the sample countries increased over time due to a variety of factors (Figure A1 Panel A), the effect of the upsurge represents around a 67% increase in conflict risk relative to unaffected areas over these periods.

Upsurge event study results are qualitatively similar across different specifications (Figure C5). Without inverse propensity weights the treatment effect magnitudes are larger, statistically significant starting in 2009, and significant for all post-exposure year bins with exposure increasing conflict risk by 75% on average from 2010-2018. Clustering standard errors at the sub-national region level instead of the country level results in the coefficients for 2000 and 2014 becoming statistically significant at the 90% confidence level but the interpretation is otherwise unchanged. The results are almost identical when interacting the weather and population controls with year, with slightly smaller treatment effect magnitudes leading to an estimated increase of 55% in conflict risk on average from 2013-2018 in cells exposed to the upsurge. Replacing country by year with year fixed effects slightly increases the magnitude of the treatment effects but does not affect statistical significance. Restricting the sample of control cells to those within 100km of a locust swarm observation during the upsurge serves a similar purpose as including inverse propensity weights: excluding or downweighting cells that are not good comparisons for cells exposed to the upsurge. The results are noisier given the smaller sample size. Only the treatment effects in 2016 and 2017 statistically significant, and the impact on conflict risk in exposed cells is significant in the 2016-2018 period only: a 54% increase. The estimated coefficients are larger in magnitude and noisier when using 0.5° instead of 0.25° cells, with a significant increase in conflict risk of 51% in the 2016-2018 period only.[26]

In summary, the pattern of long-term effects of exposure to the 2003-2005 upsurge on the probability of violent conflict is largely similar to the pattern in the event study for all swarm exposure groups (Figure 3). No significant differences in the pre-exposure periods indicate the parallel trends assumption may be likely to hold, particularly as I also include controls for time-varying characteristics that differ at baseline and weight observations by their estimated propensity to have been exposed to a locust swarm during the upsurge. Short-term effects during and in the few years immediately following swarm exposure are not statistically significant, with a small negative point estimate on average for effects during the upsurge. While the event study for all swarm exposure events shows significant increases in conflict risk in all years starting 2 years after exposure, effects of upsurge exposure are not realized until 2013.

[26] A hypothesis test of the null that the pre-exposure coefficients are jointly 0 is rejected with p=0.046, though no individual pre-exposure coefficient is close to statistically significant (the closest is 1999 with p=0.398) and the average effect from 1998-2002 is 0.004 and also not significant (p=0.796). Patterns are similar but much noisier when conducting the analysis at the 1° level.

The large and statistically significant increases in conflict risk in areas affected by the upsurge from 2013-2018 (8-14 years after the event) align with the periods of highest estimated effects in the main event study. The average increases in conflict risk over the 8-14 years post-exposure are nearly identical: 2.7 percentage points for exposure to an upsurge swarm and 2.8 percentage points for any swarm exposure. Importantly, analyzing the 2003-2005 upsurge in particular allows me to characterize how these effects relate to conflict risk in unaffected cells over this period. I find this effect represents a 67% increase in conflict risk in my preferred specification and between a 42% and 83% increase in alternative specifications.

Long-term impacts on conflict risk are driven by conflict involving non-state actors, which includes groups such as identity/ethnic militias, rebel groups, and terrorist organizations. There is no significant effect of the upsurge on conflict involving no non-state actors in any year and the estimates are all close to 0 (Figure A2 Panels A and B). These results are consistent with the conflict over output by individuals determining whether to join non-state groups following a wealth shock presented in the conceptual framework. Reduced opportunity costs related to agricultural production following a persistent wealth shock should also make individuals more willing to engage in protest activities. In line with this expectation, impacts of the locust upsurge on protest and riot events over time follow a similar pattern to the impacts on violent conflict events recorded by ACLED (Figure A2 Panel C). Exposure to an upsurge swarm increase the probability of any protest or riot event by 2.7 percentage points (over 100%) on average between 2013-2018.

Long-term increases in conflict risk following exposure to locust swarms are consistent with predictions in the conceptual framework based on the wealth mechanism. The delays in the realization of significant impacts and in the timing of the largest magnitude impacts in both the event study across all swarm exposure events and the event study of the 2003-2005 upsurge are somewhat surprising. This pattern indicates that areas affected by locust swarms are made more vulnerable to engaging in future conflicts precipitated by other proximate factors—of which many emerged in the sample countries during the sample period—rather than directly contributing to onset of new conflicts. I explore this interpretation further in section 7.

6.4 Naive estimation of short-term impacts

The results show a large and persistent long-term increase in conflict risk in the years following locust swarm exposure. Central to this analysis is the recognition that swarm exposure may have long-term effects through a wealth mechanism. If we did not recognize the potential for these long-term impacts, we might be tempted to consider cells as affected by locust swarms only in the years in which swarms are recorded, rather than in all subsequent years.

This is effectively the approach used in studies of weather or price shocks and conflict which also use grid cell panel data.[27]. This literature has overwhelmingly focused on short-term effects. The most common empirical approach is a distributed lag model with two-way fixed effects which takes the form:

$$Conflict_{ict} = \alpha + \beta_1 Shock_{ic,t} + \beta_2 Shock_{ic,t-1} + \delta X_{ict} + \gamma_{ct} + \mu_i + \epsilon_{ict} \tag{2}$$

where i indexes cells, c indexes countries, and t indexes years. $Conflict$ is a dummy variable for observing any conflict event and $Shock$ is a variable representing a particular shock which enters for both current and previous year. γ_{ct} are country by year fixed effects, and μ_i are cell fixed effects. X_{ict} is a vector of controls at the cell level. This is similar to Equation 1 with the exception that instead of the $Shock$ variable representing a permanent treatment status over subsequent years, in this model years after the shock is experienced in a cell are treated as unaffected by the shock. I illustrate the potential bias in estimates from this approach when shocks have persistent effects on conflict risk using the cases of exposure to locust swarms and to severe drought.

[27] See for example Fjelde (2015), Harari and La Ferrara (2018), McGuirk and Burke (2020), McGuirk and Nunn (2021), and Ubilava, Hastings, and Atalay (2022). These studies analyze the impact of various shocks on conflict in Africa, and vary in their choice of controls and in the size of grid cells they analyze but all use a similar econometric specification.

I first estimate Equation 2 using observations of locust swarms in a particular year as the *Shock* variable. I include as controls total annual rainfall and the maximum annual temperature for the current and previous year as well as total cell population. The country by year fixed effects flexibly control for factors varying over time at the country that might affect conflict risk across the sample and be correlated with locust exposure, while the cell fixed effects control for time invariant cell characteristics that could be correlated with both locust swarm exposure and conflict. Short-term effects of locust swarms are therefore identified from variation in swarm presence within cells over time controlling for national time-varying conditions and local weather variation, where swarm presence is based only on whether swarms are recorded in the particular year and not on prior exposure.

Table 3 presents the results comparing the impacts of locust swarms estimated using Equations 1 and 2. Column (1) presents naive estimates of the impacts of locust swarms on conflict risk in the year of exposure and following year, ignoring potential long-term impacts. A locust swarm is associated with a highly significant 1.5 percentage point *decrease* in the probability of any violent conflict in the same year relative to unaffected cells. Locust swarm exposure the previous year does not significantly affect conflict risk, but the point estimate is also negative.

Importantly, with cell fixed effects these impacts are estimated relative to conflict risk in other years in the same cell where locust swarms are not observed, including years after exposure to a locust swarm. If locust swarm exposure increases conflict risk on average in subsequent years, as shown again in Column (2), this implies that the estimate from Column (1) will be biased downward as a result of comparing conflict risk in the year locusts are observed against later years with no locust swarms but higher conflict risk. The event study analysis gives a non-significant point estimate of -0.002 for the impact on conflict risk in the year of swarm exposure (Figure 3). This is larger than the estimate in Column (1) and I can reject equality with high confidence (p=0.009), consistent with downward bias of the naive estimate.

Table 3: Impacts of agricultural shocks on the conflict risk, treating shocks as temporary vs. persistent

	(1) Naive swarms	(2) Long-term swarms	(3) Naive drought	(4) Long-term drought
Any swarm in cell	-0.015***			
	(0.004)			
Any swarm in cell previous year	-0.006			
	(0.004)			
Affected by any locust swarm		0.021***		
		(0.005)		
Any drought in year			0.004	
			(0.003)	
Any drought previous year			0.002	
			(0.002)	
Affected by any drought				0.005**
				(0.002)
Observations	508269	482691	408744	408752
Country-Year FE	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes

Note: The dependent variable is a dummy for any violent conflict event observed. Locust swarms and droughts in columns (1) and (3) are based on these shocks being observed in a particular year. Cells are considered 'affected' by any locust swarm or any drought in columns (2) and (4) for all years after these shocks are first observed in the cell. Controls in all regressions include total cell population and current and prior year measures of total rainfall and maximum annual temperature. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Torngren Wartin (2018) estimates a version of Equation 2 with a similar sample as in this paper to analyze the impact of desert locusts on conflict.[28] He finds that locust swarms are associated with a significant 1.3 percentage point decrease in the probability of any violent conflict event in the year of locust swarm arrival, similar to the 1.5 percentage point effect I estimate in Table 3. He interprets the result as suggesting endogenous underreporting of locust swarm presence correlated with violent conflict, and does not consider potential bias from ignoring long-term impacts of swarm exposure on conflict risk. The much larger event study estimate for the impact of swarms on conflict in the same year suggests a large share of the magnitude of the negative estimate from the naive regression can instead be attributed to downward bias from ignoring long-term impacts.

Endogenous underreporting of locust swarms as discussed by Torngren Wartin (2018)

[28]His analysis is at the level of 0.5° and 0.1° cells with somewhat different controls for lagged locust presence and weather. He considers locust swarms and bands together while I focus on more destructive swarms alone, and includes some African countries with very few locust swarm observations over time while excluding Arabian countries with extensive locust activity.

may be a potential source of additional downward bias, as indeed the event study point estimate for impact on conflict risk the year of swarm exposure is negative—though small and not statistically significant. As discussed in section 4, insecurity appears to create more of a challenge for desert locust control operations than for locust monitoring, as swarms are regularly reported in countries where Showler and Lecoq (2021)—henceforth SL2021—indicate insecurity has prevented control operations, and the share of cells experiencing violent conflict that experience a locust swarm when nearby cells also experience locust swarm is similar in these insecure countries and in the other sample countries: 27% compared to 34%.

Violent conflict the previous year is associated with a lower probability of reporting a locust swarm in the current year (Table C3, Column 1), so I test the sensitivity of the results in Table 3 Column (1) to controlling for any violent conflict in the previous year, dropping cells which experienced conflict the previous year, and dropping the countries where SL2021 indicate insecurity has prevented control operations (Table C3). The estimated effect is similar across all specifications—between a 1 and 1.5 percentage point decrease in conflict risk for a locust swarm in the same year. In addition, in a simulation exercise I find that 23% of cells experiencing conflict within 50km of a locust swarm observation would need to have been affected by but not reported a locust swarm for the estimated impact of locust swarms on violent conflict in the same year in the naive specification to no longer be statistically significant (Figure C6). This seems to be implausibly large relative to the share of cells within 50km of a locust swarm observation where both violent conflict and locust swarms are reported in the same year in the data. These results together indicate that while insecurity which affects locust control operations as documented in the locusts literature may also limit monitoring activities, measurement error in locust observations correlated with conflict does not drive the negative effect of locust swarms on conflict in the naive specification, though it may contribute some downward bias. To the extent locust exposure is underreported, this would tend to bias downward the long-term estimates as well.

I conduct a similar test of bias in naive short-term estimates of the impact of agricultural shocks on conflict for a measure of drought based on the Standardized Precipitation and Evapotranspiration Index (SPEI, Begueria et al. 2014), using data from 1996-2014 included in the PRIO-GRID database. I define a cell as experiencing a drought shock in a particular year if there are at least 4 consecutive months where the SPEI is below -1.5 (deviations within 1 indicate near normal conditions). This could be considered a severe drought. As with locust swarm exposure, I identify the first year in which a cell experiences such a drought and consider cells to be 'affected' in all subsequent years.

Table 3 Column (3) shows that a naive estimate gives no significant impact of a drought in the same year on the probability of any violent conflict, with a point estimate of 0.4 percentage points. Column (4) shows that on average conflict risk increases by a significant 0.5 percentage points in years following a severe drought. If this impact is not entirely concentrated in the short-term, this implies that the naive estimate will be biased downward.

I estimate an event study of drought exposure using the Borusyak, Jaravel, and Spiess (2021) approach accounting for staggered treatment timing (Figure A3). Pre-exposure coefficients are small in magnitude and not statistically significant, with the exception of the period 8 years before exposure to a drought. Conflict risk increases by a statistically significant 0.9 percentage points in the year of exposure. Point estimates for years 1-7 post-exposure are not statistically significant except for year 5, while effects in years 8-10 post-exposure are large and statistically significant. Consistent with downward bias in the naive estimate, the event study estimate for impact of drought on conflict risk in the year of exposure is larger, though I cannot reject that the difference is 0 (p=0.198). This result provides some evidence that studies analyzing impacts of weather shocks on conflict using specifications similar to Equation 2 and ignoring possible long-term effects of shocks in a particular year may generate downward-biased short-term impact estimates to the extent the long-term effect is an increase in conflict risk.

7 Mechanisms

7.1 Short-term

The short-term impacts of locust swarm exposure provide strong evidence that negative agricultural productivity shocks need not increase the risk of conflict in the same year. This contrasts with much of the economic literature on this topic, though Crost et al. (2018) and Harari and La Ferrara (2018) both find that growing season weather shocks have inconsistent effects on conflict in the same year while increasing conflict risk the following year, which is the result they emphasize. Null effects on conflict in the year of swarm exposure and the following year in both event study analyses align with the first prediction from the conceptual framework. In these years, decreases in agricultural productivity that lower the opportunity cost of fighting would tend to increase the risk of violent conflict but are offset by a reduction in the returns to fighting over agricultural output that would tend to decrease the risk of violent conflict.

Larger impacts of swarm exposure on ACLED measures of violent conflict compared to UCDP measures (Table A3), categorized by McGuirk and Burke (2020) as more likely to represent conflict over output and over factors of production, respectively, are consistent with capture of agricultural output being a primary motivation and source of returns for fighting in this setting. Offsetting mechanisms—a decrease in opportunity costs of fighting from reduced agricultural productivity and a decrease in the returns to fighting from a decrease in agricultural output available to capture—would suggest different impacts of locust exposure on different types of conflict. Protests or riots do not explicitly target capture of output, so should be less affected by the predation mechanism than violent conflict.

Differences in the event study results between these two types of conflict in the year of exposure are consistent with this prediction. The event study point estimate for the impact on violent conflict risk in the year of swarm exposure is -0.002 compared to +0.002 for protests and riots (Figure C4). Though neither effect is statistically significant and I cannot reject that they are the same (p=0.232), the difference in sign aligns with expectations. For upsurge swarm exposure, the estimated effect in 2005 is -0.010 for violent conflict risk compared to +0.004 for protests and riots, the latter of which is statistically significant (Figure A2). I can reject that the effects are the same (p=0.048). These results support the argument that the null short-term impact of locust swarm exposure on conflict risk is due at least in part to the predation mechanism offsetting the opportunity cost mechanism.

Other factors may also make switching from farming to fighting suboptimal immediately following swarm exposure and help explain why the short-term increase in protests and riots is not larger in comparison to the long-term impact. One possibility is that relief efforts increase the opportunity cost of fighting by providing another source of livelihood that is presumably not available to fighters. Country-level annual data on international development flows to agriculture (which includes food aid) from FAOSTAT (2023) provide some indication of temporarily increased relief following exposure to desert locust swarms. I estimate a two-way fixed effects model at the country level and find that locust swarms are associated with an increase in aid, though with a short delay. Agricultural development flows increase by 205 million USD (22%) the year after a country experiences any locust swarm, and by 371 million USD (39%) for locust swarms during the major 2003-2005 locust upsurge which drew significant international attention and support (Table A4). This additional aid, assuming it is targeted to the areas affected by desert locusts, may serve to support livelihoods and deter individuals from engaging in conflict.

Migration, both to urban areas and to surrounding agricultural areas, is a common response to locust crop destruction. Over 8 million people were displaced across East Africa as a result of the 2019-2021 locust outbreak (The World Bank 2020). This indicates that short-term migration is a better outside option following an agricultural shock than fighting for many households. The departure of people from locust-affected areas may also decrease the risk of conflict as there are fewer people to potentially engage in fighting. Though violent conflict does also occur in many low-density parts of Africa, cell population is positively and significantly correlated with the risk of violent conflict in the sample (Table 1).[29]

Psychological mechanisms may also explain part of the null short-term impact of locust swarms on conflict risk, particularly through religious connotations. The dominant religion in the sample countries is Islam, where locusts are mentioned as both a punishment from Allah and as a sign of Judgment Day (*Qayamat*). Future research could evaluate whether locust swarms increase religiosity, which may affect the perceived returns to fighting by increasing social, emotional, and supernatural costs.

7.2 Long-term

The two-way fixed effects and event study results align with the second prediction from the conceptual framework that locust swarm exposure would increase the long-term risk of civil conflict. The heterogeneity in TWFE results by land cover further indicate that the mechanism operates through agricultural destruction given the concentration of impacts in cells with agricultural land, and crop land in particular (Figures 1 and 2), as expected.

Impacts of swarms on conflict should also vary by the timing of swarm arrival relative to the local crop calendar. Crop destruction—and therefore the magnitude of the wealth shock—will be largest for swarms arriving during the crop growing season. Off-season swarms may also affect livelihoods through destruction of livestock pasture, tree and perennial crops, and forest resources, but I expect the wealth reduction from such damages to be less important than from crop destruction.

I categorize swarms as arriving during particular stages of the crop production cycle by matching the month in which a swarm is observed to country-level crop calendars for staple grains and main cash crops from The United States Department of Agriculture (USDA) (2022).[30] The off season—between harvesting and planting—lasts between 3 and 6 months

[29] While out-migration may increase the likelihood of conflict in nearby areas if it increases competition over local output and resources (as in McGuirk and Nunn (2021)), to the extent locusts are driving out-migration the evidence indicates that this is not leading to conflict spillovers.

[30] Figure A4 shows example crop calendars from Libya and Mali. In countries with different agricultural cycles by crop, I identify the crop activity associated with the most commonly grown crops each month.

in most of the sample countries, with an average of slightly over 4 months.[31] I test for differences in long-term impacts of exposure to the 2003-2005 upsurge by whether upsurge swarms arrived during the main growing season and by presence of cropland. Most upsurge swarms were recorded during months of the main growing season, which covers a greater share of the year, and the majority of swarms were in cells with no crop land, unsurprising as only 29% of cells have any crop land (Figure A6).

I modify TWFE Equation 1 to include separate terms for exposure to 2003-2005 upsurge swarms during the off and growing seasons for a given country, with the same set of controls and fixed effects. All right-hand side variables are interacted with a dummy for whether the cell includes any crop land. Table 4 presents the results for average long-term impacts of the upsurge on violent conflict risk by cell land cover and the season of swarm exposure, using Stata's *xlincom* command to estimate standard errors for the sum of the base and interaction terms for crop cells. The pattern of results is similar for the full sample (Column 1) and when restricting control cells to those within 100km of an upsurge swarm observation (Column 2); I discuss the results for the full sample.

As shown in Table 2, impacts are larger for crop cells than for non-crop cells, and the difference is driven by exposure to upsurge swarms that arrived during the country's crop growing season (p=0.012). Areas affected by upsurge swarms that arrived during the growing season are 3.1 percentage points more likely to experience violent conflict in a given year after the upsurge ended, a large and statistically significant effect. The estimated impact of growing season upsurge swarms in crop cells is approximately double that of off season upsurge swarms but I cannot reject equality (p=0.343), as the estimates are somewhat imprecise due to the small numbers of crop cells exposed to the upsurge in different seasons. Exposure to upsurge swarms during the off season or in cells with no crop land does not significantly affect conflict risk, though point estimates for impacts of off season swarms in

[31] Figure A5 shows the share of sample cells at different stages of agricultural cycle by month and the counts of locust swarms during the sample period observed by season and region. I do not distinguish between planting, growing, and harvest season swarms in the analysis as the months assigned to these periods are approximate and effects should largely be similar.

crop and non-crop cells are relatively large indicating potential impacts on pasture land.

Table 4: Average impacts of exposure to 2003-2005 upsurge swarms on conflict risk, by timing of upsurge swarms and land cover

Outcome: Any violent conflict event	(1) All cells	(2) W/in 100km of upsurge
Affected by off season upsurge swarm Non-crop cell	0.010 (0.010)	0.009 (0.010)
Affected by off season upsurge swarm Crop cell	0.016 (0.013)	0.016 (0.013)
p, diff. in off season upsurge swarm effect	0.604	0.526
Affected by growing season upsurge swarm Non-crop cell	-0.004 (0.004)	-0.005 (0.004)
Affected by growing season upsurge swarm Crop cell	0.031** (0.013)	0.040*** (0.012)
p, diff. in growing season upsurge swarm effect	0.012	0.001
p, non-crop off season = growing season	0.176	0.171
p, crop off season = growing season	0.343	0.145
Observations	400668	180999
Outcome mean post-2005, no upsurge	0.019	0.023
Country-Year FE	Yes	Yes
Cell FE	Yes	Yes
Controls	Yes	Yes
Inverse propensity weights	Yes	Yes

Note: The results in each column are from a single regression of a dummy for any violent conflict event on indicators of 2003-2005 upsurge swarm exposure by season and controls all interacted with a dummy for any crop land cover in a cell. The columns indicate the subset of cells considered. For each interaction, I show the coefficient for the swarm variable when there is no cropland, the sum of this coefficient and the interaction with land cover (with standard errors calculated using Stata's *xlincom* command), and the p-value for the test that the coefficient on the interaction is equal to 0. I also include p-values for the tests that the effects of upsurge swarm exposure in different seasons are the same by land cover. Cells are regarded as 'affected' by a 2003-2005 upsurge swarm for all years starting from the first year in which a swarm is recorded in the cell. Cells exposed in other years are not included. Inverse propensity weights calculated based on estimates of the propensities of cells to have been exposed to any swarm during the upsurge are included. Controls include annual total rainfall, maximum temperature, and population, and their interactions with the crop land indicator. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

These results are consistent with long-term impacts of the upsurge driven by destruction of agricultural production by swarms arriving in crop cells during the main growing season. The finding relates to recent studies showing that the impact of weather shocks on conflict risk varies depending on whether the timing of the shock is such that it is likely to decrease agricultural productivity (Caruso, Petrarca, and Ricciuti 2016; Crost et al. 2018; Harari and La Ferrara 2018) and that show seasonality in the form of harvest timing also affects conflict risk by changing opportunity cost for agricultural producers (Guardado and Pennings 2021; Hastings and Ubilava 2023).

Agricultural destruction by locusts would result in a severe wealth shock for many affected households for several reasons. Adoption of agricultural insurance is very low in the sample countries, access to credit is constrained, and local risk sharing networks may be insufficient to help affected households recover from the extent of damage caused by locust swarms. Households use a variety of measures to cope with short-term food security and livelihood effects of locust outbreaks (Thomson and Miers 2002). In addition to seeking help from social networks and food aid, households commonly report selling animals and other assets, consuming less food, sending household members away, taking loans and cutting expenses, and consuming seed stocks as coping strategies. These strategies lead to a decrease in wealth which reduces the resources available for agricultural production in following years, decreasing agricultural productivity and the opportunity cost of fighting. Studies of the long-term impacts of locust swarm exposure on children find lasting negative effects on children's education (De Vreyer, Guilbert, and Mesple-Somps 2015) and health (Conte, Tapsoba, and Piemontese 2021; Le and Nguyen 2022; Linnros 2017), illustrating additional consequences of the wealth shock for human capital which could also affect labor productivity.

Impacts on measures of agricultural productivity included in the DHS AReNA database (IFPRI 2020) provide suggestive evidence of the wealth mechanism affecting long-term productivity following swarm exposure. The DHS AReNA database includes geolocated data on cereal yields at the level of household survey clusters for 40 surveys from 9 countries in the study sample conducted between 1992 and 2018, as well as monthly Normalized Difference Vegetation Index (NDVI) measures at the cluster locations over this time frame. NDVI is a commonly-used satellite-based measure of vegetation greenness which in crop land can be considered a rough proxy for agricultural production. I collapse these data to the level of annual $0.25°$ cells.

Table 5 Column (1) shows that in cells where DHS surveys have been conducted in the sample countries between 2000-2019, NDVI falls significantly in years where a locust swarm is observed in a cell. The magnitude of the effect is similar to the effect of a 1°C increase in annual maximum temperature. The effect is likely an underestimate of the level of local agricultural destruction as not all parts of a 0.25° (28×28km) cell will be affected by a locust swarm, and because locust swarms may arrive and damage crops after peak crop growth and NDVI, unlike a temperature increase which could prevent crops reaching peak growth over a broader area. The average effect of locust swarm exposure on maximum NDVI in subsequent years is a fairly precise 0, consistent with locust swarms not affecting agricultural productivity fundamentals (Column 2).

While this might suggest no persistent impacts on agricultural labor productivity, Column 4 shows that household reports of cereal yields over the agricultural season completed prior to the survey fall by a statistically significant 5.4% on average in years after locust swarm exposure, a larger absolute magnitude effect that an increase of 100mm of rainfall in the same year or a 1°C increase in maximum temperature. This decrease emerges from the first year after locust swarm arrives (though it is not statistically significant), but is not observed in the year of exposure where there is no significant effect on yield (Column 3). No change in the year of exposure may be a result of two factors. First, in some countries and years survey timing may involve asking about cereal yields over a season that ended before swarms arrived. Second, yield is typically reported as output over area harvested, and consequently will not capture damages on plots where crops are completely destroyed so there is no harvest.

This result aligns with Marending and Tripodi (2022) which finds that exposure to desert locust swarms in Ethiopia decreases farm profits by 20-48% two harvest seasons after swarm arrival. A significant average decrease in cereal yield in areas exposed to locust swarms in the following years relative to unexposed areas is consistent with the wealth mechanism described in the conceptual framework. A decrease in agricultural production in the year of locust exposure would result in an income and wealth shock. Reduced wealth would decrease

Table 5: Impacts of locust swarm exposure on NDVI and cereal yield

	(1) Max annual NDVI	(2) Max annual NDVI	(3) Cereal yield (kg/ha)	(4) Cereal yield (kg/ha)
Any swarm in cell during the year	-0.011***		12.089	
	(0.003)		(56.931)	
Any swarm in cell previous year	0.001		-92.298	
	(0.004)		(63.350)	
Affected by any locust swarm		0.000		-108.396*
		(0.002)		(60.008)
Total annual rainfall during the year (100 mm)	-0.000	-0.000	13.121**	17.176**
	(0.001)	(0.001)	(5.936)	(7.036)
Total annual rainfall previous year (100 mm)	0.002***	0.002***	11.869	7.626
	(0.000)	(0.000)	(8.912)	(8.851)
Max annual temperature during the year (deg C)	-0.012***	-0.012***	-61.194	-86.411*
	(0.002)	(0.002)	(47.327)	(48.322)
Max annual temperature previous year (deg C)	-0.001	-0.001	41.207	57.616
	(0.002)	(0.002)	(45.119)	(43.341)
Population (10,000s)	-0.000***	-0.000***	0.045	0.119
	(0.000)	(0.000)	(1.264)	(1.379)
Observations	54412	51961	4181	3750
Outcome mean, no swarms	0.537	0.551	1942.460	1987.031
Country-Year FE	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes

Note: Outcome variables are from the DHS AReNA database (IFPRI 2020) at the level of the clusters where DHS surveys are conducted. Maximum NDVI is measured based on satellite data for the location of each survey cluster each month from 2000-2019; I take the maximum value each year. Cereal crop yield in kg/ha is measured based on survey reports and averaged at the cluster level for years in which surveys are conducted in specific clusters. I collapse these data to the level of 28×28km grid cells by year taking means of the outcome variables. All regressions include country by year and location fixed effects. SEs are clustered at the sub-national region level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

access to productive inputs in subsequent years, which would explain a persistent decrease in cereal yields. A null long-term effect on maximum NDVI despite decreased cereal yields may reflect an increase in area cultivated within a cell or substitution to crops with higher NDVI levels. But reduced cereal yields implies lower agricultural productivity and therefore a lower opportunity cost of fighting in areas exposed to locust swarms, which would increase the probability of violent conflict.

The long-term wealth mechanism should also increase the probability of protests and riots, as participation in these activities is also determined by individuals based on the returns and their opportunity costs. On the other hand, it should not affect the probability of state-based violent conflict as the engagement of the state in conflict is not directly determined by individual laborers. Figures A2 and C4 show that long-term increases in conflict risk in areas exposed to locust swarms during the 2003-2005 upsurge are driven by violent conflict involving non-state actors. Increase in conflict involving state actors are significant but much smaller in the event study pooling all swarm exposure and are much smaller and not significant in the event study of the 2003-2005 upsurge. In both event studies, impacts on protests and riots follow a similar pattern as for violent conflict involving non-state actors. The types of conflict affected by locust swarm exposure are therefore those we would expected based on the wealth mechanism persistently reducing individuals' agricultural productivity and opportunity costs of engaging in conflict.

The fact that long-term impacts of swarm exposure are not consistent over time and are largest in a period starting around 8 years after exposure suggests some heterogeneity in impacts by time-varying conditions. The largest effects of upsurge swarm exposure coincide with the years when the general risk of conflict increased across the sample countries (Figure A1), indicating that the broader conflict environment shapes the returns to fighting. While the 2003-2005 locust upsurge is unlikely to be directly causing any of the spreading violent conflicts after 2010, by decreasing agricultural productivity in the long term it may have made affected areas more vulnerable to engaging in these conflicts given some other more proximate precipitating events increasing the returns to fighting and making the switch to engaging in civil conflict optimal.

The net returns to fighting are likely to be greater when fighting with a group. Having a group increases attacking power and also reduces the social and emotional costs of fighting relative to fighting alone. A reduction in opportunity costs of fighting or increase in the returns to fighting over output following an agricultural shock may thus primarily induce affected individuals to switch to fighting in periods when engaging in fighting is more accessible. Hastings and Ubilava (2023) find evidence of this in Southeast Asia. They show that the onset of rice harvest in Southeast Asia—a temporary increase in the returns to fighting over agricultural output—only increases violence against civilians in years and areas with active fighting groups. They argue that in the absence of such groups, the costs of engaging in predatory conflict during the rice harvest remain too high relative to the potential returns from fighting without a group.

Table 6 shows the estimates from testing whether long-term impacts of the 2003-2005 upsurge vary by the presence of groups active in civil conflict the previous year or in the surrounding cells. Results are similar in the full sample of cells and restricting control cells to those within 100km of an upsurge swarm so I focus the discussion on the full sample. The results show that positive impacts of the upsurge on conflict risk in the years following the upsurge are driven entirely by effects in areas with generally greater conflict risk, consistent with Figure 4 showing impacts delayed until years when conflict risk was greatest in the sample countries. Upsurge exposure has no significant effect on conflict risk in years with no fighting groups engaged in civil conflict either around the cell or in the cell the previous year.

The point estimates for the correlations in violent conflict activity over time and space are very large but noisy, so the association is only statistically significant for the correlation between conflict within a cell and in the surrounding 1° cell. Upsurge exposure magnifies these correlations. Cells exposed to the upsurge are 16 percentage points more likely to have any violent conflict if there was violent conflict in the cell the previous year, relative to unexposed cells. Cells exposed to the upsurge are 16 percentage points more likely to have any violent conflict if there was violent conflict in the cell the previous year and 5.6 percentage points more likely if there is violent conflict in any of the cells in the surrounding 1° cell, relative to unexposed cells.

Because the upsurge affects long-term conflict risk, it is not orthogonal to conflict in the previous year nor likely to surrounding conflict in the same year, though I reject that the interacted terms are jointly equal to 0 with a high level of confidence. These results should

Table 6: Average impacts of exposure to 2003-2005 upsurge swarms on conflict risk, by presence of groups active in civil conflict

Outcome: Any violent conflict event	(1) All cells	(2) W/in 100km of upsurge	(3) All cells	(4) W/in 100km of upsurge
Affected by 2003-05 upsurge	0.003	0.003	0.002	0.003
	(0.004)	(0.003)	(0.004)	(0.003)
Any violent conflict in cell previous year	0.275	0.491		
	(0.274)	(0.478)		
Affected by 2003-05 upsurge	0.160^{***}	0.143^{***}		
× Any violent conflict in cell previous year	(0.031)	(0.038)		
Any violent conflict elsewhere in 1 degree cell			0.210^{**}	0.305^{*}
			(0.105)	(0.168)
Affected by 2003-05 upsurge			0.056^{***}	0.045^{***}
× Any violent conflict elsewhere in 1 degree cell			(0.017)	(0.015)
Observations	400668	180999	400668	180999
Outcome mean post-2005, no upsurge	0.019	0.023	0.019	0.023
p: coefficients shown all =0	0.000	0.000	0.016	0.021
Country-Year FE	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Inverse propensity weights	Yes	Yes	Yes	Yes

Note: The dependent variable is a dummy for any violent conflict event observed. Cells are regarded as 'affected' by a 2003-2005 upsurge swarm for all years starting from the first year in which a swarm is recorded in the cell. Cells exposed in other years are not included. Inverse propensity weights calculated based on estimates of the propensities of cells to have been exposed to any swarm during the upsurge are included. Controls include annual total rainfall, maximum temperature, and population, and their interactions with the conflict activity variables. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

therefore be considered as illustrative of differences in upsurge impacts by the broader conflict environment rather than accurately estimating differences in the causal impacts. Being exposed to an upsurge swarm makes cells significantly more likely to engage in civil conflict when it emerges, even years after exposure. This variation in the returns to fighting over time explains the pattern of locust swarm exposure event study results.

8 Conclusion

Desert locust swarms can have devastating consequences for local agriculture, and this analysis shows that exposure to a locust swarm significantly increases long-term conflict risk. The results indicate the impact is driven by a wealth mechanism, where efforts to cope with the shock to agricultural production income lead to persistently lower wealth and productivity. This mechanism should receive additional attention in studies of economic shocks and conflict.

Importantly, the long-term decrease in the opportunity costs of fighting does not generally increase conflict incidence but rather makes areas affected by locust swarms more likely to become involved in periods of elevated civil conflict. A focus on impacts of income shocks on opportunity costs alone does not align with the way civil conflict occurs when fighting groups coalesce around certain objectives. Many factors have contributed to the increased onset and incidence of violent conflict in the sample countries in this period, including the Arab Spring, several civil wars, insurgencies, and the spread of terrorist organizations. The results illustrate how failing to support communities affected by disasters to fully recover can increase the incidence of future conflict and influence which areas become involved.

Impacts of swarms on the risk of conflict are concentrated in agricultural areas with effects on crop land particularly large. I use satellite-based measures of vegetation (NDVI) to show evidence of the immediate production shock, but the analysis is limited and likely underestimates the full effect of locust swarm exposure. I also find long-term decreases in cereal yields in areas exposed to locust swarms, consistent with persistent reductions in agricultural productivity. Further research on impacts of agricultural shocks on household measures of agricultural productivity (as in Marending and Tripodi (2022)), labor supply, food security, and wealth would help further illuminate the wealth mechanism and its effect on the opportunity cost of fighting. The results imply that short-term efforts to provide food aid and other relief to populations affected by locust swarms—and potentially other economic shocks—may be insufficient to prevent some households falling into productivity traps and more support is required to facilitate full recovery.

Swarms have no significant effect on violent conflict in the year of exposure and the following year, though they do increase the probability of protests or riots. This indicates that reduced returns to predatory attacks over agricultural output following locust may discourage violent conflict and offset the reduced opportunity costs of fighting for agricultural producers.

Other mechanisms may also help explain the null effect. I show that international agricultural aid increases in years countries are affected by locust swarms, but geographically-disaggregated data on relief could be useful to test whether such support can limit the extent of the wealth shock and long-term increase in conflict risk. This would imply that policies to increase the diversity and resilience of livelihood strategies in the sample countries could decrease the risk of violent conflict following an adverse agricultural shock, as shown by some recent studies (Fetzer 2020; Garg, McCord, and Montfort 2020). Psychological mechanisms may also play a role and are under-explored in the economics literature on conflict. Studies of the impacts of agricultural shocks on psychological factors such as aspirations, beliefs, and religiosity, as well as correlations between these factors and conflict risk could help test the potential importance of these mechanisms.

I show that the methods typically used in the climate-conflict literature, which treat agricultural shocks as only affecting conflict risk in the short-term, can result in downward-biased estimates of short-term impacts when agricultural shocks have long-term impacts. The increases in conflict risk immediately following deviations in rainfall and temperature documented in the literature might therefore be underestimates. Event study analyses of severe weather shocks, as in the example of droughts in this paper, could show the extent and patterns of long-term impacts on conflict risk and how this affects estimates of short-term effects.

The results also have implications for estimates of the economic and social costs of desert locust outbreaks. In addition to short-term impacts on agricultural production, incomes, and food security, previous studies have found that children exposed to locust swarms have worse education and health outcomes (Conte, Tapsoba, and Piemontese 2021; De Vreyer, Guilbert, and Mesple-Somps 2015; Le and Nguyen 2022; Linnros 2017). This study shows that swarm exposure also increases the long-term risk of conflict, which imposes further costs.

Past research on desert locusts has argued that limited impacts of outbreaks on aggregate national measures of agricultural production may mean expensive locust monitoring and control operations have limited net economic benefits (Joffe 2001; Krall and Herok 1997), though others have argued that local damages are extensive and motivate continued proactive locust control efforts (Showler 2019; Zhang et al. 2019). Decisions about proactive locust control versus potential alternative responses—for example, increasing adoption of agricultural insurance or relying entirely on disbursement of relief after locust damages (Hardeweg 2001)—should take the broader economic and social impacts of agricultural destruction by locusts into consideration. These costs should also motivate increased cross-country communication and collaboration in response to threats of locust swarms, particularly in light of the recent 2019-2021 outbreak..

Beyond contributing to our understanding of the relationship between agricultural productivity shocks and conflict risk, the findings are also relevant for considering multilateral policy around climate change mitigation and adaptation. Climate change is increasing the frequency and severity of agricultural shocks, including by creating conditions suitable for desert locust swarm formation. These shocks impose additional costs on society through their impacts on conflict risk which should be considered when weighing the costs and benefits of potential actions to reduce and respond to risks from agricultural shocks.

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Appendix A: Additional Figures and Tables

Table A1: Summary statistics

	Mean	SD	Min	25^{th}	50^{th}	75^{th}	Max	N
Any violent conflict event - ACLED	0.02	0.14	0.0	0.0	0.0	0.0	1.0	538086
Any violent conflict event in cell in any year	0.14	0.35	0.0	0.0	0.0	0.0	1.0	538086
Any swarm in cell	0.00	0.07	0.0	0.0	0.0	0.0	1.0	538086
Any swarm within 100km outside cell	0.04	0.21	0.0	0.0	0.0	0.0	1.0	538086
Any swarm within 100-250km of cell	0.11	0.31	0.0	0.0	0.0	0.0	1.0	538086
Any swarm in cell previous year	0.01	0.07	0.0	0.0	0.0	0.0	1.0	538086
Any swarms within cell in any year	0.10	0.30	0.0	0.0	0.0	0.0	1.0	538086
Any swarms within 100 km in any year	0.56	0.50	0.0	0.0	1.0	1.0	1.0	538086
Population (10,000s)	1.75	9.30	0.0	0.0	0.2	1.0	749.8	464708
Total annual rainfall (100 mm)	2.47	3.80	0.0	0.3	0.9	3.0	43.4	532498
Max annual temperature (deg C)	37.54	5.17	12.4	33.8	38.1	41.4	49.0	532498
Any cropland or pasture in cell	0.54	0.50	0.0	0.0	1.0	1.0	1.0	526272
Share of crop and pasture land in cell	0.24	0.32	0.0	0.0	0.0	0.5	1.0	526272
Any cropland in cell	0.29	0.45	0.0	0.0	0.0	1.0	1.0	526272
Share of cropland in cell	0.05	0.13	0.0	0.0	0.0	0.0	1.0	526272
Any pasture in cell	0.53	0.50	0.0	0.0	1.0	1.0	1.0	526272
Share of pasture in cell	0.19	0.27	0.0	0.0	0.0	0.3	1.0	526272

Note: Observations are grid cells approximately 28×28km by year.

Table A2: Balance by exposure to any locust swarm during full sample period and during 2003-2005 upsurge

	N	Never swarm Mean (SD)	Any swarm treatment diff (SE)	N	Never swarm Mean (SD)	2003-2005 swarm treatment diff (SE)
Population in 2000	23242	1.30	1.22**	22748	1.30	1.07
(10,000s)		(6.39)	(0.61)		(6.39)	(0.86)
Gross cell product	21931	0.25	0.13	21513	0.25	0.16
in 2005 (USD PPP)		(0.95)	(0.09)		(0.95)	(0.11)
Mean of cell	22982	0.05	0.01*	22490	0.05	0.01
nightlights 1996-2012 (0-1)		(0.04)	(0.00)		(0.04)	(0.01)
First month rainy	22982	6.29	0.40	22490	6.29	0.43
season		(3.33)	(0.26)		(3.33)	(0.35)
Percent of cell	22714	4.80	0.90	22225	4.80	1.41
covered by crop land in 2000		(13.33)	(0.79)		(13.33)	(0.99)
Percent of cell	22714	17.95	10.68***	22225	17.95	11.66***
covered by pasture land in 2000		(27.26)	(2.62)		(27.26)	(2.98)
Mean annual rainfall	22988	2.50	0.08	22494	2.50	0.06
1997-2018 (dm)		(3.83)	(0.29)		(3.83)	(0.36)
Mean annual max	22988	37.60	-1.41***	22494	37.60	-1.21**
temperature 1997-2018 (deg C)		(5.19)	(0.47)		(5.19)	(0.60)

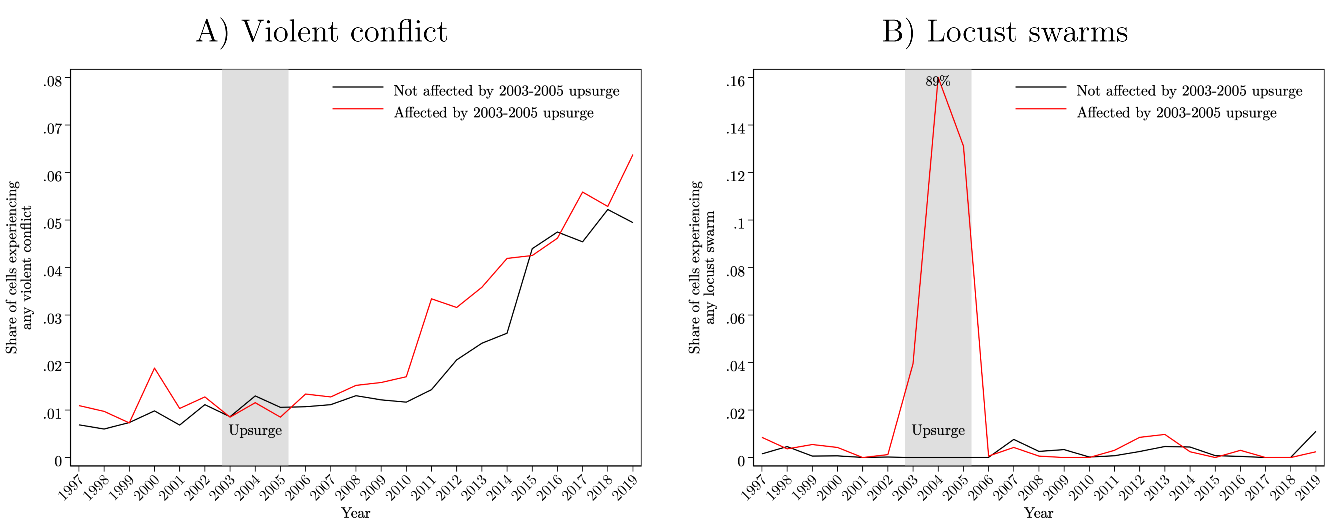
Note: The table shows results from separate bivariate regressions of baseline or mean cell outcomes on locust swarm exposure. The rows indicate which dependent variable is used. The first set of columns compares cells where a swarm was first observed between 1998-2018 ('Any swarm treatment') to cells where no swarm was observed from 1990-2018. The F-test for the joint significance of all variables gives $F = 8.01$, $p < 0.01$. The second set of columns compares cells where a swarm was first observed during the major 2003-2005 locust upsurge ('2003-2005 swarm treatment') to the same control cells. The F-test for the joint significance of all variables gives $F = 3.29$, $p < 0.01$. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A3: Average impacts of exposure to locust swarms on conflict risk by conflict type

	N	Never swarm Mean (SD)	Any swarm treat (SE)
Any violent conflict event - ACLED	505679	0.017	0.021***
		(0.131)	(0.006)
Any violent conflict event - UCDP	505679	0.009	0.010**
		(0.096)	(0.004)
Any violent non-state conflict - ACLED	505679	0.015	0.019***
		(0.123)	(0.005)
Any violent state conflict - ACLED	505679	0.005	0.012***
		(0.068)	(0.004)
Any violent one-sided conflict - ACLED	505679	0.010	0.015***
		(0.098)	(0.004)
Any protest or riot event - ACLED	505679	0.007	0.018***
		(0.086)	(0.004)
Total fatalities - ACLED	505679	0.542	1.097
		(51.676)	(0.708)
Total fatalities - UCDP	505679	0.451	-1.845
		(85.388)	(2.106)

Note: This table shows estimates of the impact of a locust swarm in the same year from Equation 1 using different measures of conflict as the outcome variable. All regressions include weather and population controls along with country by year and cell FE. I first show the mean probability of conflict in cells not affected by locust swarms and then the coefficient for the average impact of being 'affected' by a swarm across all years starting from the first year in which a swarm is recorded in the cell. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

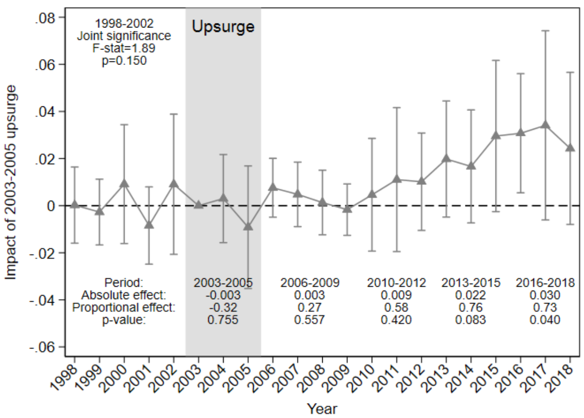
Figure A1: Trends in swarm and violent conflict events over time, by experience of 2003-2005 locust upsurge



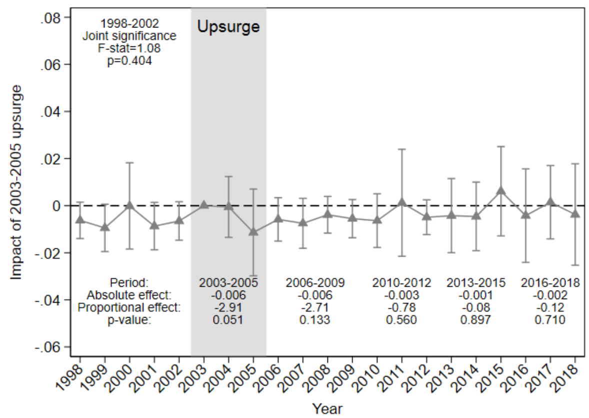
Note: The figures shows the share of cells experiencing any locust swarm or violent conflict event by year, separately for cells that did and did not experience any locust swarms during the 2003-2005 upsurge. Observations are grid cells approximately 28×28km by year.

Figure A2: Impacts of exposure to 2003-2005 locust upsurge swarms on conflict risk over time, by conflict type

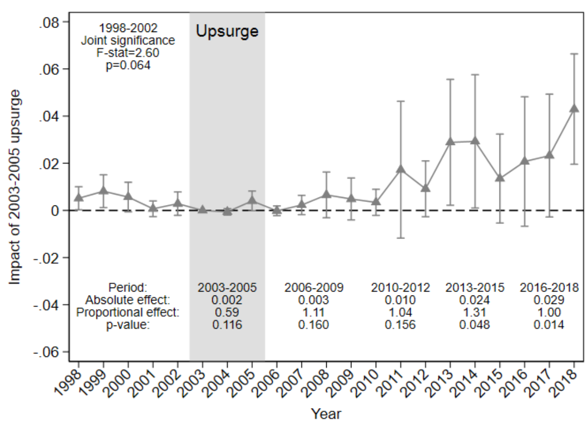
A) Violent conflict involving non-state actors



B) Violent conflict involving state actors

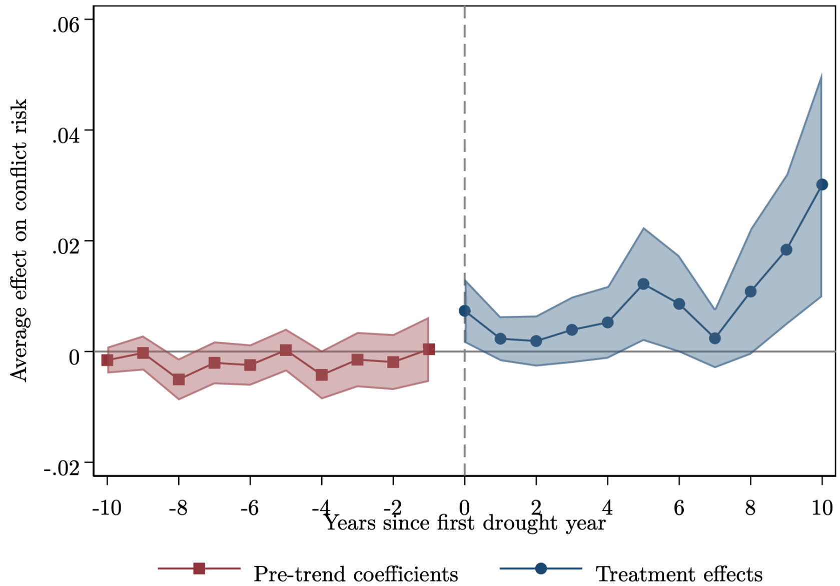


C) Protests and riots



Note: The dependent variables are dummies for any conflict event being observed in a cell in a year, with the conflict type specified in the panel title. Coefficients are for the interaction of a dummy for being exposed to a locust swarm between 2003-2005 with year. The reference year is 2003, the first year of the upsurge period which is shaded in gray. All regressions are weighted by the inverse of the propensity to have been exposed to a swarm during the 2003-2005 upsurge. Bars represent 95% confidence intervals using SEs clustered at the country level. The regressions include controls for rainfall, temperature, population, and cell and country-by-year FE. Observations are 0.25° grid cells (approximately 28×28km) by year. Estimates from the same specification with binned years are reported at the bottom of the figure. Proportional effects are relative to the probability of observing any of the particular type of conflict during the particular time period. *p*-values are for tests of the null of 0 impact of the upsurge in each period. In the top left are the results from a joint test of the hypothesis that all pre-upsurge coefficients equal 0.

Figure A3: Average impact of drought exposure on conflict risk over time



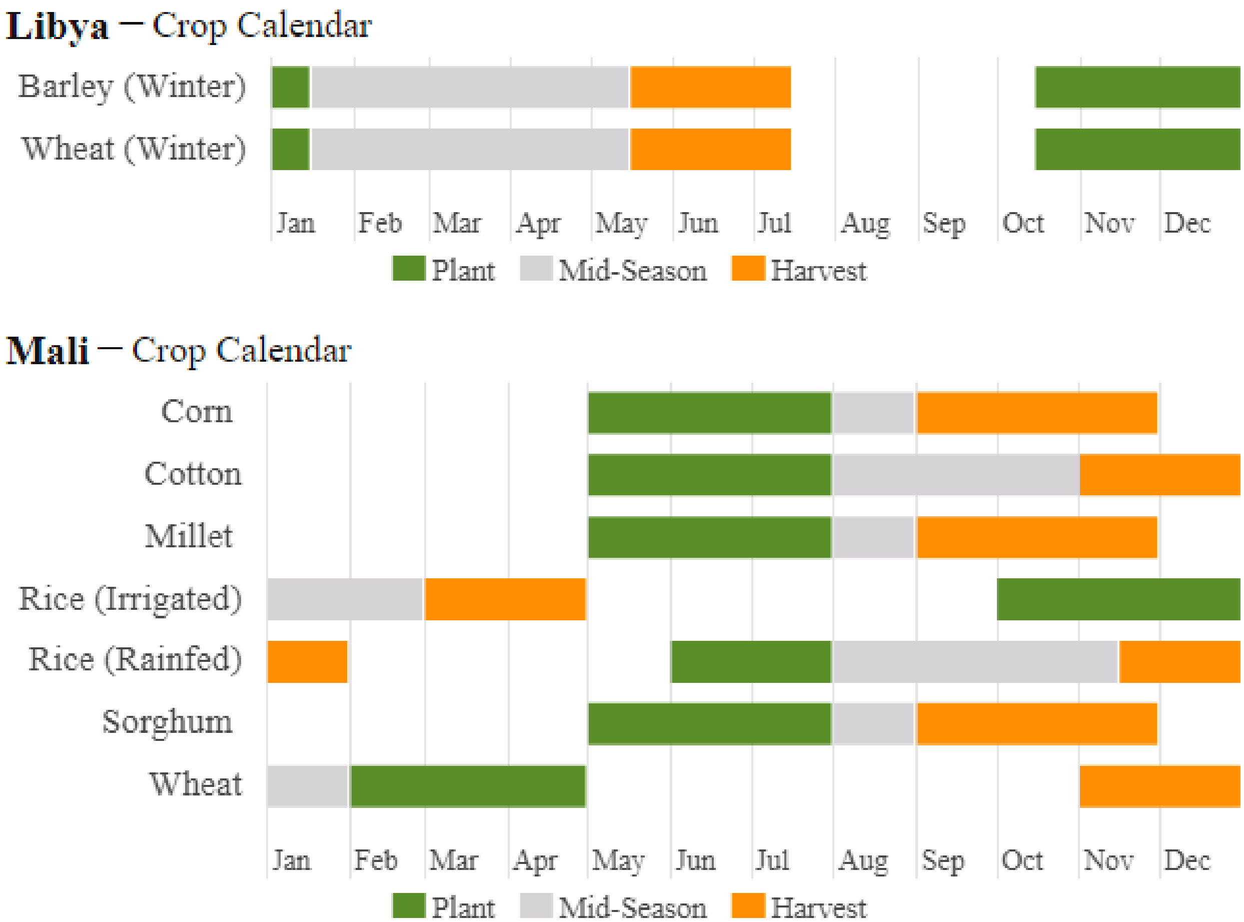
Note: Event study results for impacts of exposure to any drought on conflict risk over time using the approach in Borusyak, Jaravel, and Spiess (2021). All regressions include year and cell fixed effects. Drought exposure is based on the first year a drought (4 consecutive months with SPEI<-1.5) is observed in a cell. Estimated impacts in each time period are weighted averages across effects for drought exposure in particular years. The time period 0 is the year of drought exposure. The shaded areas represent 95% confidence intervals. The reference year for treatment effects is the year prior to exposure. Coefficients are based on comparisons against the pre-exposure period. Observations are grid cells approximately 28×28km by year. SEs are clustered at the region level.

Table A4: Correlations between locust swarm exposure and international development flows to agriculture

Outcome: Development flows to agriculture (2021 USD millions)	(1)	(2)	(3)	(4)
Any swarm in year	140.6			
	(156.2)			
Any swarm previous year		204.6*		
		(116.0)		
Any swarm in year during upsurge			267.1	
			(189.5)	
Any swarm previous year during upsurge				371.4**
				(168.5)
Observations	962	936	962	936
Outcome mean, no swarms	915.7	918.1	935.8	945.2
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Note: This table shows estimates of the correlation between any locust swarm being recorded in a country in a given year and total international development flows to agriculture received (FAOSTAT 2023). The first two rows consider locust swarms recorded at any point in the sample period (1997-2018). The second two rows consider only locust swarms recorded during the major 2003-2005 locust upsurge which received significant international attention. Regressions are at the country-year level and include country and year fixed effects. SEs clustered at the country level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

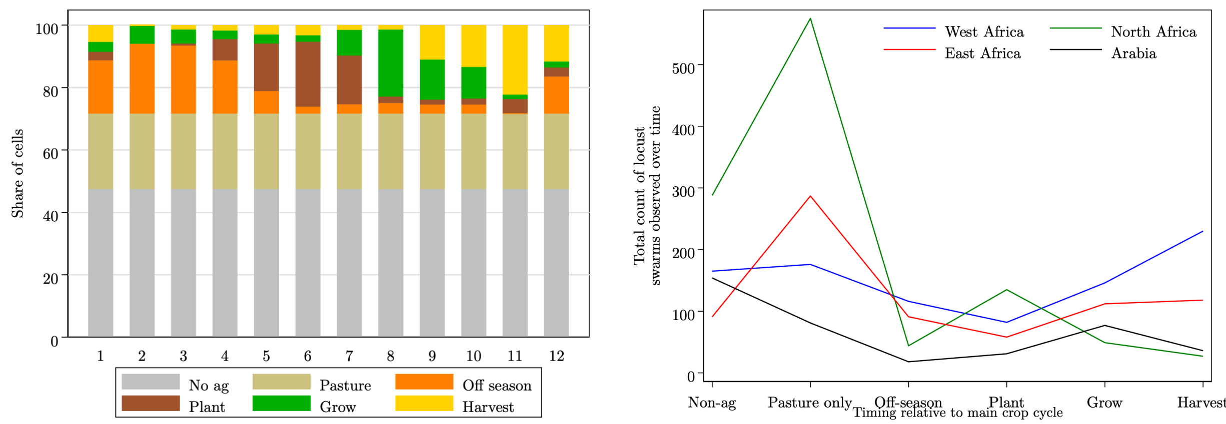
Figure A4: Example crop calendars



Source: U.S. Department of Agriculture Foreign Agricultural Service, International Produlsion Assessment Division (USDA 2022).
Note: The Libya crop calendar is fairly representative of other North African countries, and the Mali crop calendar is fairly representative of other West African countries.

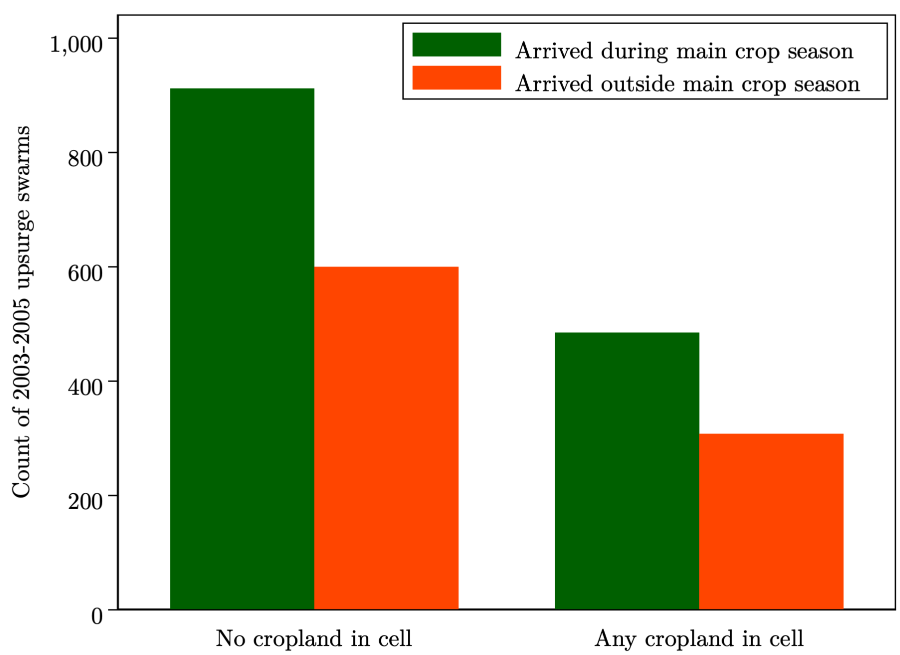
Figure A5: Timing of locust swarm arrival by phase of crop calendar and region

A) Agricultural activities by month of year   B) Timing of locust swarm arrival



Note: Agricultural activities by month are determined by assigning each cell with any crop land the primary activity for that month in the country in which it is located, using USDA 2022 crop calendars. Land cover in the year 2000 is from Ramankutty et al. (2010). Locust swarm observations are matched to agricultural activities based on the location and month of their arrival.

Figure A6: Count of locust swarms recorded during the 2003-2005 upsurge by swarm timing and land cover



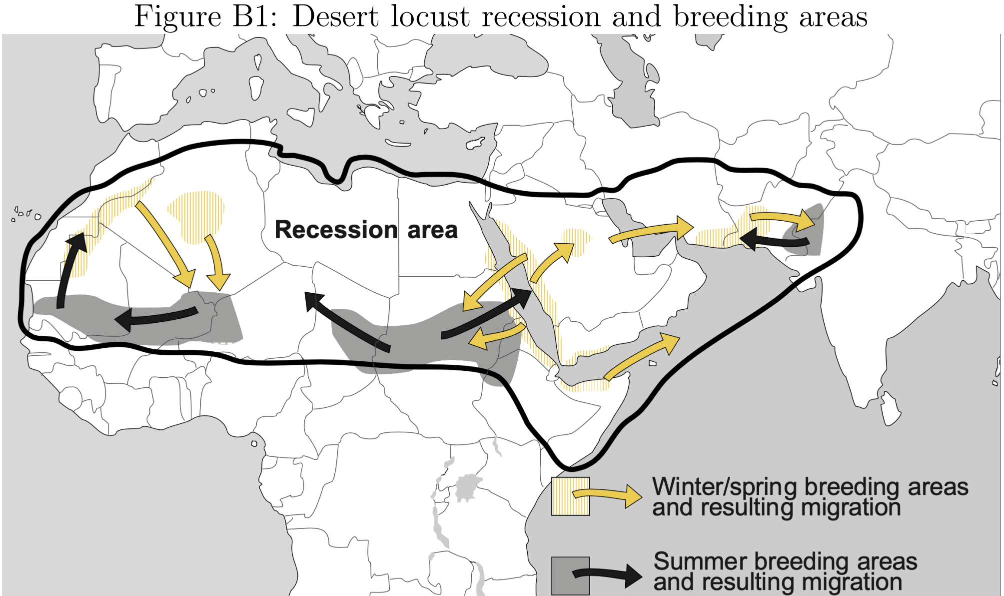
Appendix B: Desert locusts background

The desert locust is considered the world's most dangerous and destructive migratory pest (Cressman, Van der Elstraeten, and Pedrick 2016; Lazar et al. 2016). Locusts consume any available vegetation, and swarms frequently lead to the total destruction of local agricultural output (Showler 2019). Damages from locust shocks can be extreme, with a small swarm covering one square kilometer can consume as much food in one day as 35,000 people. During the last locust upsurge in 2003-2005 in North and West Africa, 100, 90, and 85% losses on cereals, legumes, and pastures respectively were recorded, affecting more than 8 million people (Renier et al. 2015; Brader et al. 2006). Damages to crops alone were estimated at \$2.5 billion USD and \$450 million USD was required to bring an end to the upsurge (ASU 2020).

In the most recent upsurge from 2019-2021 in East Africa and the Arabian Peninsula, over 40 million people in 10 countries faced severe food insecurity due to crop destruction. Locust control operations undertaken by the United Nations Food and Agriculture Organization (FAO) and its partners, primarily via ground and aerial spraying of pesticides, and global food aid efforts helped reduce the damages (Food and Agriculture Organization of the United Nations (FAO) 2022a). The FAO estimates that 3.5 million people were affected by locust destruction, but that control efforts saved agricultural production worth \$1.7 billion USD.

Small numbers of locusts are always present in desert 'recession' areas from Mauritania to India (Figure B1). The population can grow exponentially under favorable climate conditions: periods of repeated rainfall and vegetation growth overlapping with the breeding cycle. The 2019-2021 upsurge persisted in large part because of repeated heavy precipitation out of season due to cyclones, prompting explosive reproduction (Cressman and Ferrand 2021). The 2003-2005 upsurge was initiated by good rainfall over the summer of 2003 across four separate breeding areas. This was followed by two days of unusally heavy rains in October 2003 from Senegal to Morocco, after which environmental conditions were favorable for reproduction over the following 6 months (FAO and WMO 2016).

Figure B1: Desert locust recession and breeding areas

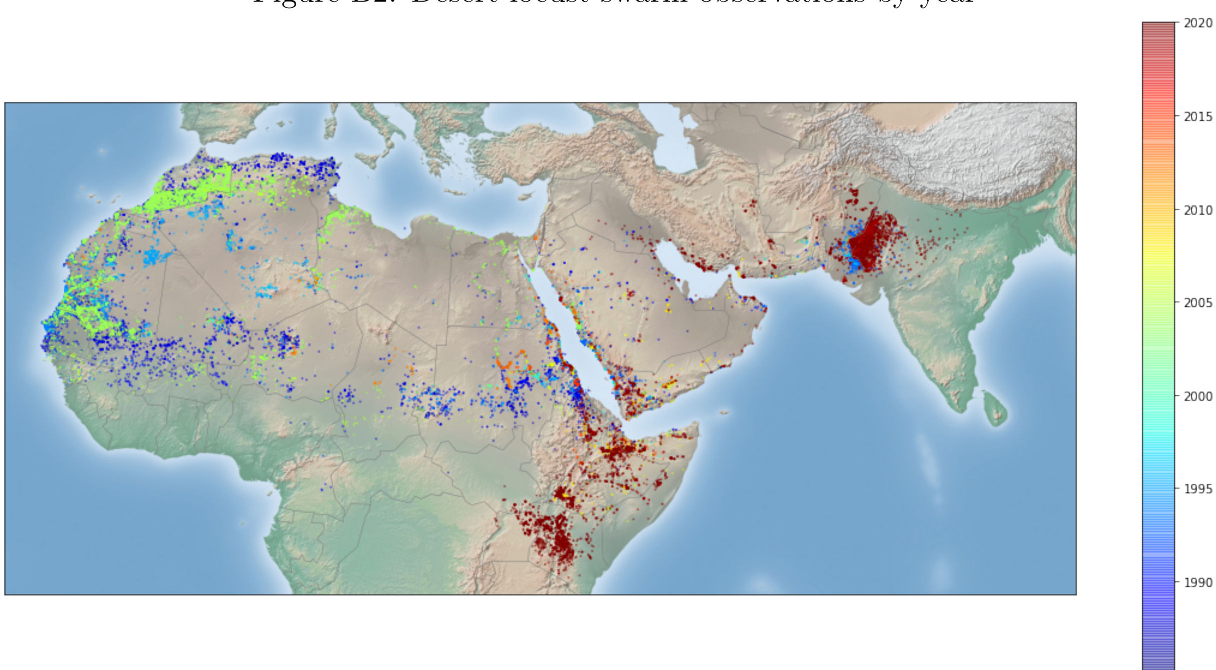


Source: Symmons and Cressman (2001).

Unique among grasshopper species, after reaching a particular population density desert locusts undergo a process of 'gregarization' wherein they mature physically and form large bands or swarms which move as a cohesive unit (Symmons and Cressman 2001). Locust bands may extend over several kilometers and alternate between roosting and marching, typically downwind (FAO and WMO 2016). Locust swarms form when bands of locusts remain highly concentrated when they reach the adult stage and become able to fly. This formation of swarms can lead to 'outbreaks,' where locusts spread out from their largely desert initial breeding areas. Locusts in swarms have increased appetites and accelerated reproductive cycles, and are thus particularly threatening to agriculture. The FAO distinguishes different levels of locust swarm activity (Symmons and Cressman 2001). I use the terms 'outbreak' and 'upsurge' interchangeably to refer to any locust swarm activity. By the FAO definition 'outbreaks' refer to localized increases in locust numbers while 'upsurges' refer to broader and more sustained locust activities. A third level, 'plagues,' is characterized by larger and more widespread locust infestations. Few locust swarms are observed outside of major outbreaks, as conditions favoring swarm formation tend to produce large swarms which reproduce and spread rapidly and are very difficult to control.

As illustrated by Figure B2, locust swarms are not observed with any regularity over time or space. Desert locusts are migratory, moving on after consuming all available vegetation, and outside of outbreak periods are ultimately restricted to desert 'recession' areas. Unlike many other insect species, therefore, the arrival of a desert locust swarm does not signal a permanent change in local agricultual pest risk. Instead, the arrival of a swarm can be considered a locally and temporally concentrated natural disaster where all crops and pastureland are at risk (Hardeweg 2001).

Figure B2: Desert locust swarm observations by year

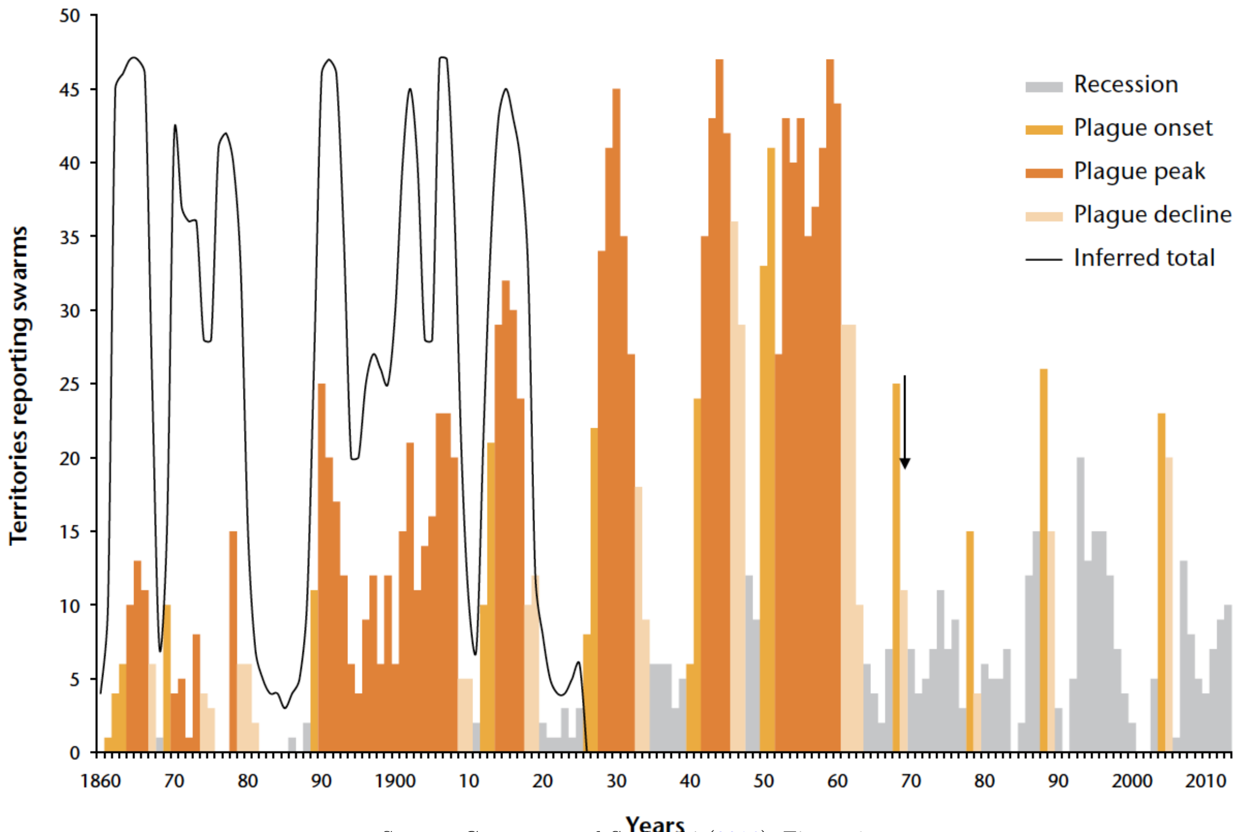


Map created by authors using swarm observations recorded in the FAO Locust Watch database.

The frequency of large-scale outbreaks has fallen since around the 1980s (Figure B3), in large part due to increases in coordinated preventive operations (Cressman and Stefanski

2016), as shown by the figure below. Given their tolerance for extreme heat and responsiveness to periods of heavy precipitation, however, climate change might create conditions conducive to more frequent desert locust outbreaks.

Figure B3: Desert locust observations by year



Source: Cressman and Stefanski (2016), Figure 6.

Farmers have no proven effective recourse when faced with the arrival of a locust swarm, though activities such as setting fires, placing nets on crops, and making noise are commonly attempted. While these may slow damage they have little effect on locust population or total damages (Dobson 2001; Hardeweg 2001; Thomson and Miers 2002). Locust outbreaks end due to a combination of migration to unfavorable habitats, failure of seasonal rains in breeding areas, and control operations (Symmons and Cressman 2001). The only current viable method of swarm control is direct air or ground spraying with pesticides (Cressman and Ferrand 2021). These control operations do not prevent immediate agricultural destruction as they take some time to kill the targeted locusts, but will limit their spread. The 2003-2005 locust upsurge ended due to lack of rain and colder temperatures which slowed down the breeding cycle, combined with intensive ground and aerial spraying operations which treated over 130,000km^2 at a cost of over US$400 million (FAO and WMO 2016).

Desert locust control is most effective before locust populations surge, and the FAO manages an international network of early monitoring, warning, and prevention systems in support of this goal (Zhang et al. 2019). While improvements in desert locust management have been largely effective in reducing the frequency of outbreaks (as seen in Figure B3), many challenges remain. Desert locust breeding areas are widespread and often in remote or insecure areas. Small breeding groups are easy to miss by monitors, and swarms can migrate quickly. In addition, control operations are slow and costly, resources for monitoring and control are limited outside of upsurges, and the cross-country nature of the thread creates coordination issues. Insecurity may also limit locust control activities (Showler and Lecoq 2021).

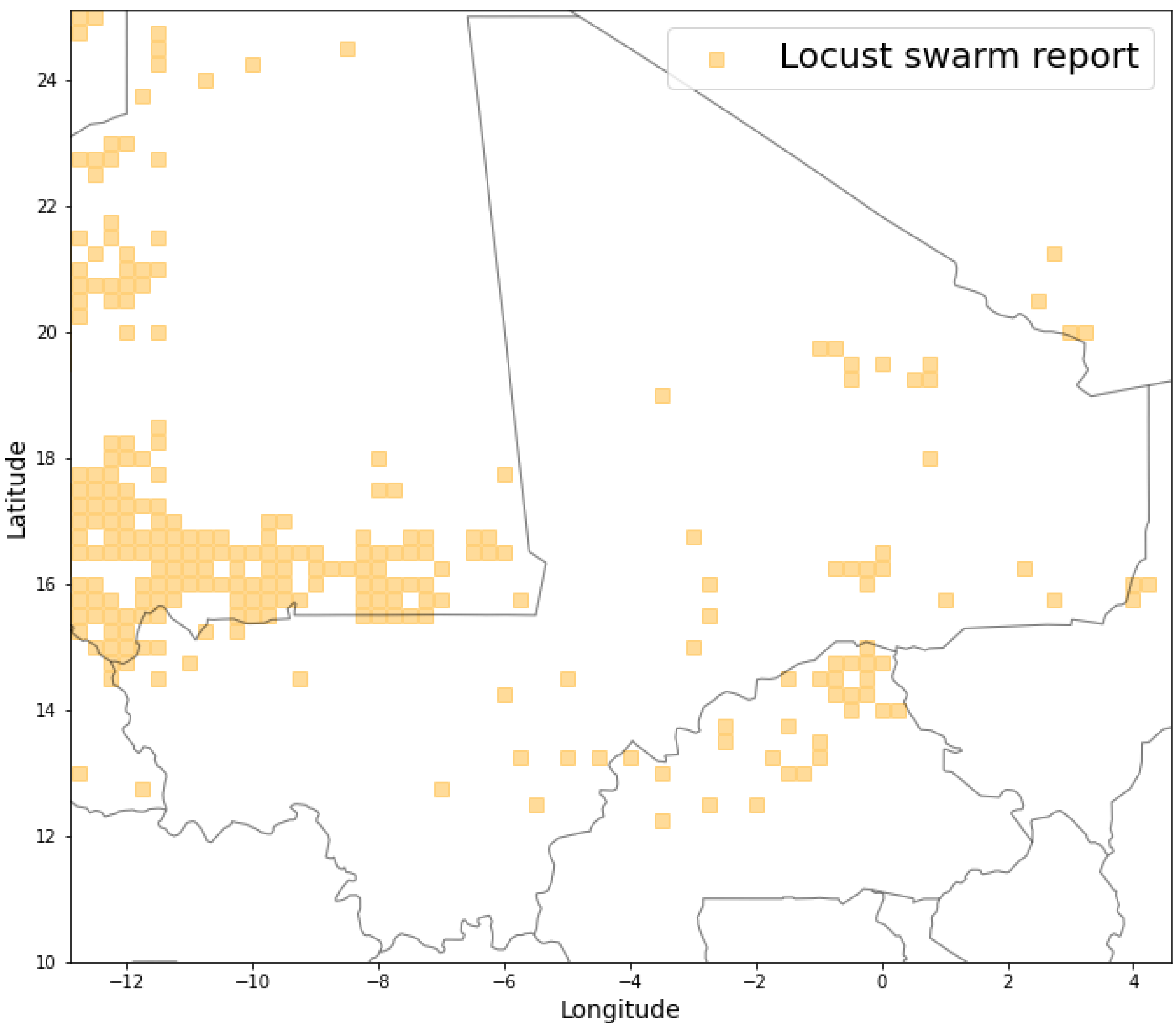
Locust swarms vary in their density and extent (Symmons and Cressman 2001). The average swarm includes around 50 locusts per m^2 with a range from 20-150, and can cover under 1 square kilometers to several hundred (Symmons and Cressman 2001). About half of swarms exceed 50km^2 in size (FAO and WMO 2016), meaning swarms typically include over a billion individuals. Swarms fly downwind from a few hours after sunrise to an hour or so before sunset when they land and feed. Swarms do not always fly with prevailing winds and may wait for warmer winds. Small deviations in the positions of individual locusts in the swarm can also lead to changes in swarm flight trajectory, making their movements difficult to predict. Seasonal changes in these winds tend to bring locusts to seasonal breeding areas at times when rain and the presence of vegetation is most likely, allowing them to continue breeding (FAO and WMO 2016).

These movement characteristics inform efforts to predict locust swarm movements, but these remain highly imprecise. The desert locust bulletins produced monthly by the FAO include forecasts of areas at risk of desert locust activity, but the areas described are quite large, often encompassing several countries in periods with increased swarms. While breeding regions and the broad areas at risk over different time periods can generally be predicted with some accuracy (Latchininsky 2013; Samil et al. 2020; Zhang et al. 2019), predicting specific local variation in swarm presence remains a challenge due to the multiple factors influencing specific flight patterns (FAO and WMO 2016).

Patterns in swarm movements lead to local variation in locust swarm exposure. After taking off, swarms fly for 9-10 hours rather than landing as soon as they encounter new vegetation. A swarm can easily move 100km or more in a day even with minimal wind (Symmons and Cressman 2001). Consequently, the flight path of a locust swarm will include both affected and unaffected areas, with the affected areas determined by largely by patterns of wind direction and speed over time from the initial swarm formation in breeding areas. An important result of the local variation in locust swarm damages during outbreaks is that macro level impacts may be muted, since outbreaks occur in periods of positive rainfall shocks which tend to increase agricultural production in unaffected areas. Several studies find that impacts of locust outbreaks on national agricultural output and on prices are minimal, despite devastating losses in affected areas (Joffe 2001; Krall and Herok 1997; Showler 2019; Thomson and Miers 2002; Zhang et al. 2019).

Figure B4 illustrates the variation in areas affected by locust swarms over space, showing reports of locust swarms in 2004—the peak of the 2003-2005 upsurge—around Mali. Swarm reports are densely clustered in the breeding areas in southern Mauritania where locust swarms reproduced in summer 2004. Outside of this area there is considerable variation in where swarms were reported, with distances between reported swarm over time consistent with typical flight distances. I leverage the quasi-random variation over both time and space in the areas affected by swarms to identify their impact on conflict.

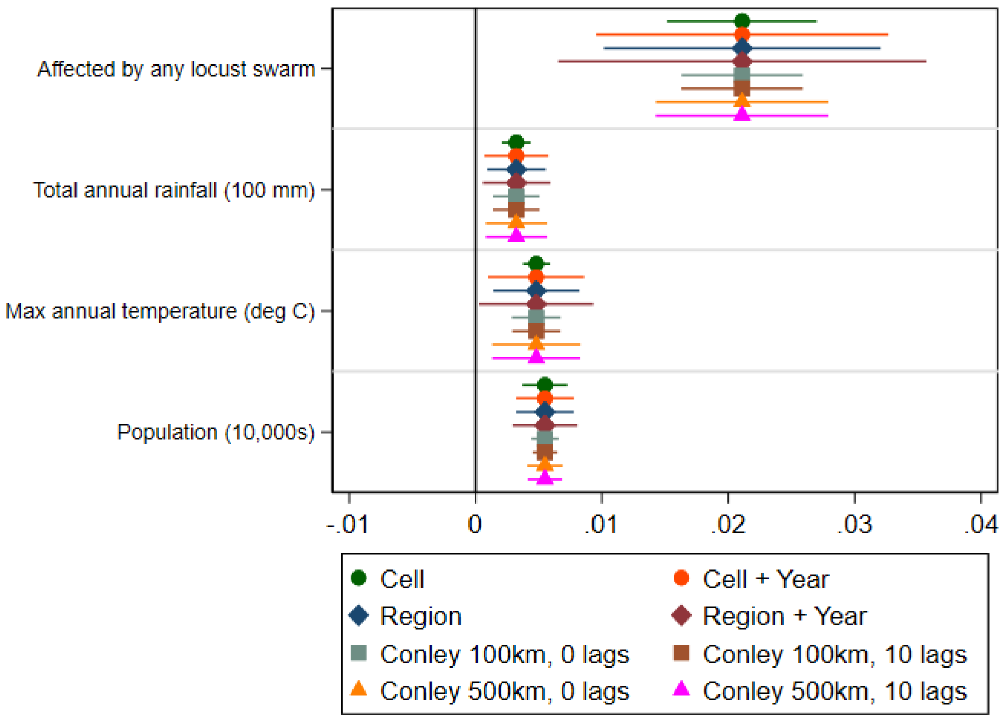
Figure B4: Reports of locust swarms and violent conflict around Mali, selected years



Note: The figure illustrates the grid cells in which locusts swarms were reported for the area around the country of Mali in 2004, the peak year of the 2003-2005 locust upsurge. Locust swarm reports are from the FAO Locust Watch database.

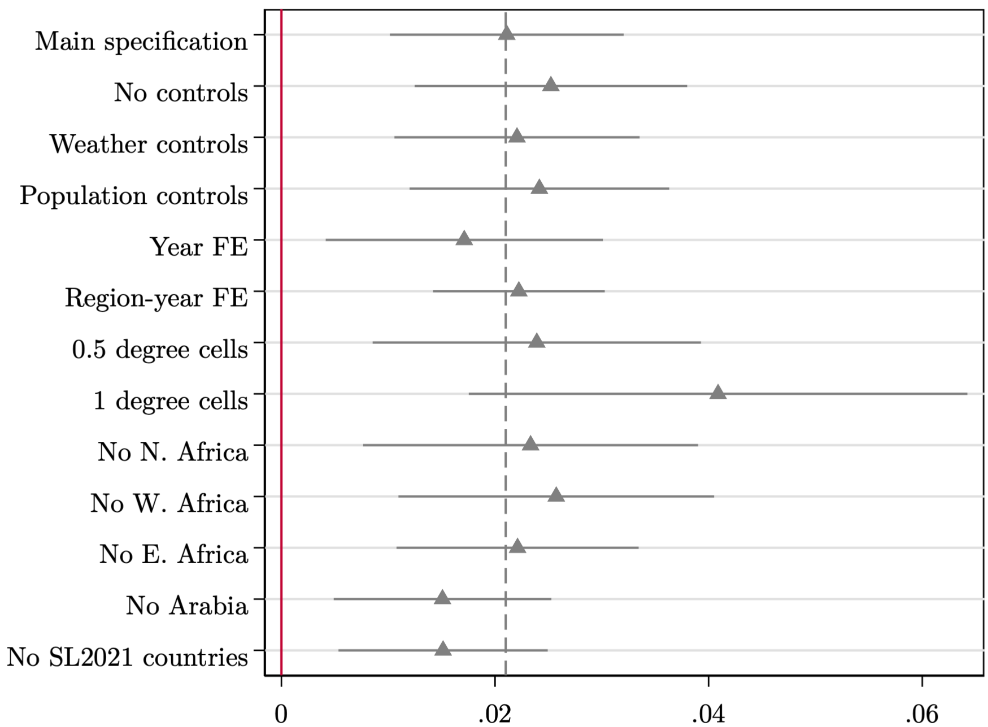
Appendix C: Robustness

Figure C1: Estimated coefficients from Equation 1 with different SEs



Note: The figure shows 95% confidence intervals for estimates from Table 1 column (1) applying different clustering for the SEs. The outcome variable is a dummy for any violent conflict observed. Observations are grid cells approximately 28×28km by year. Regressions also include year and cell FE.

Figure C2: Average impacts of locust swarm exposure on conflict risk, varying specifications and samples



Note: The figure shows 95% confidence intervals for estimates from Table 1 column (1) varying controls, fixed effects, cell size, and countries included in the sample. 'SL2021' countries are those listed in Showler and Lecoq (2021) as having areas where insecurity limited desert locust control operations during the sample period, and include Chad, Mali, Somalia, Sudan, Western Sahara, and Yemen. The outcome variable is a dummy for any violent conflict observed. Observations are grid cells approximately 28×28km by year. Regressions all include cell FE as well as year FE unless otherwise stated.

Table C1: Balance by exposure to a locust swarm, including inverse propensity weights

	N	Never swarm Mean (SD)	Any swarm treatment diff (SE)	N	Never swarm Mean (SD)	2003-2005 swarm treatment diff (SE)
Population in 2000	21536	1.26	0.27	21147	1.26	-0.36
(10,000s)		(6.16)	(0.35)		(6.15)	(0.35)
Gross cell product	21536	0.24	-0.00	21147	0.24	-0.07
in 2005 (USD PPP)		(0.92)	(0.07)		(0.92)	(0.07)
Mean of cell	21536	0.05	0.00	21147	0.05	-0.00
nightlights 1996-2012 (0-1)		(0.04)	(0.00)		(0.04)	(0.00)
First month rainy	21536	6.21	0.13	21147	6.22	0.16
season		(3.34)	(0.21)		(3.35)	(0.28)
Percent of cell	21536	4.97	-0.32	21147	4.97	-1.56
covered by crop land in 2000		(13.63)	(1.04)		(13.62)	(1.31)
Percent of cell	21536	16.42	-2.46	21147	16.40	-6.56*
covered by pasture land in 2000		(25.95)	(2.37)		(25.94)	(3.52)
Mean annual rainfall	21536	2.50	0.06	21147	2.50	-0.65
1997-2018 (dm)		(3.90)	(0.45)		(3.90)	(0.56)
Mean annual max	21536	37.88	-0.27	21147	37.89	0.52
temperature 1997-2018 (deg C)		(5.12)	(0.61)		(5.13)	(0.79)

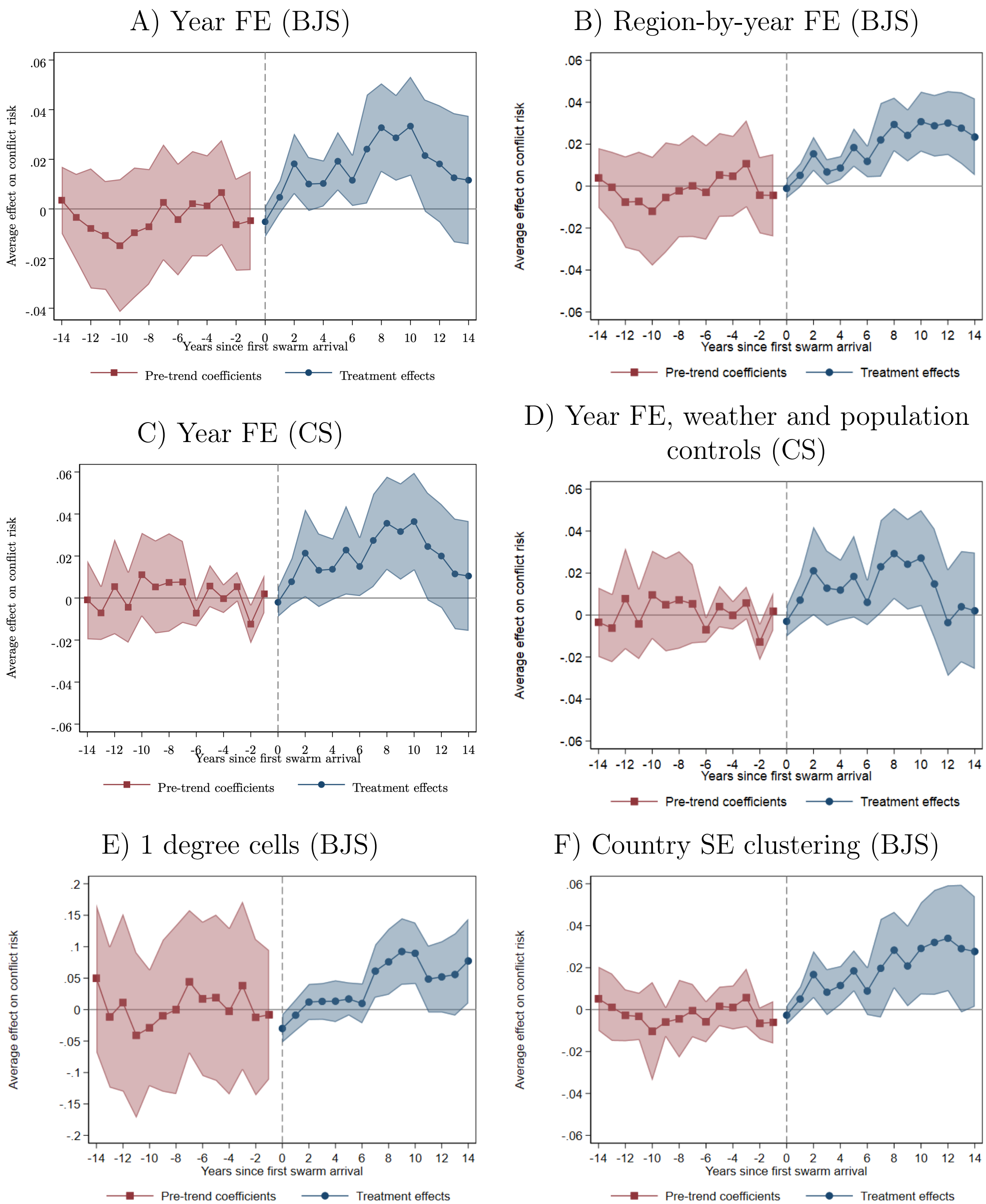
Note: The table shows results from separate bivariate regressions of baseline or mean cell outcomes on locust swarm exposure, including inverse propensity weights. The rows indicate which dependent variable is used. Inverse propensity weights are calculated based on estimates of the propensities of cells to have been exposed to any swarm during the study period and to have been exposed during the 2003-2005 upsurge. The first set of columns compares cells where a swarm was first observed between 1998-2018 ('Any swarm treatment') to cells where no swarm was observed from 1990-2018. The F-test for the joint significance of all variables gives $F = 0.99$, $p = 0.450$. The second set of columns compares cells where a swarm was first observed during the major 2003-2005 locust upsurge ('2003-2005 swarm treatment') to the same control cells. The F-test for the joint significance of all variables gives $F = 0.95$, $p = 0.477$. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C2: Average impacts of exposure to locust swarms on conflict risk, including inverse propensity weights

Outcome: Any violent conflict event	(1) All land	(2) Any crop or pasture land	(3) Any crop land
Affected by any locust swarm	0.008*	-0.002	-0.003
	(0.004)	(0.003)	(0.003)
Affected by any locust swarm × Land=1		0.017**	0.033**
		(0.007)	(0.014)
Observations	473754	473754	473754
Outcome mean, no swarms	0.013	0.013	0.013
Country-Year FE	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
Inverse propensity weights	Yes	Yes	Yes

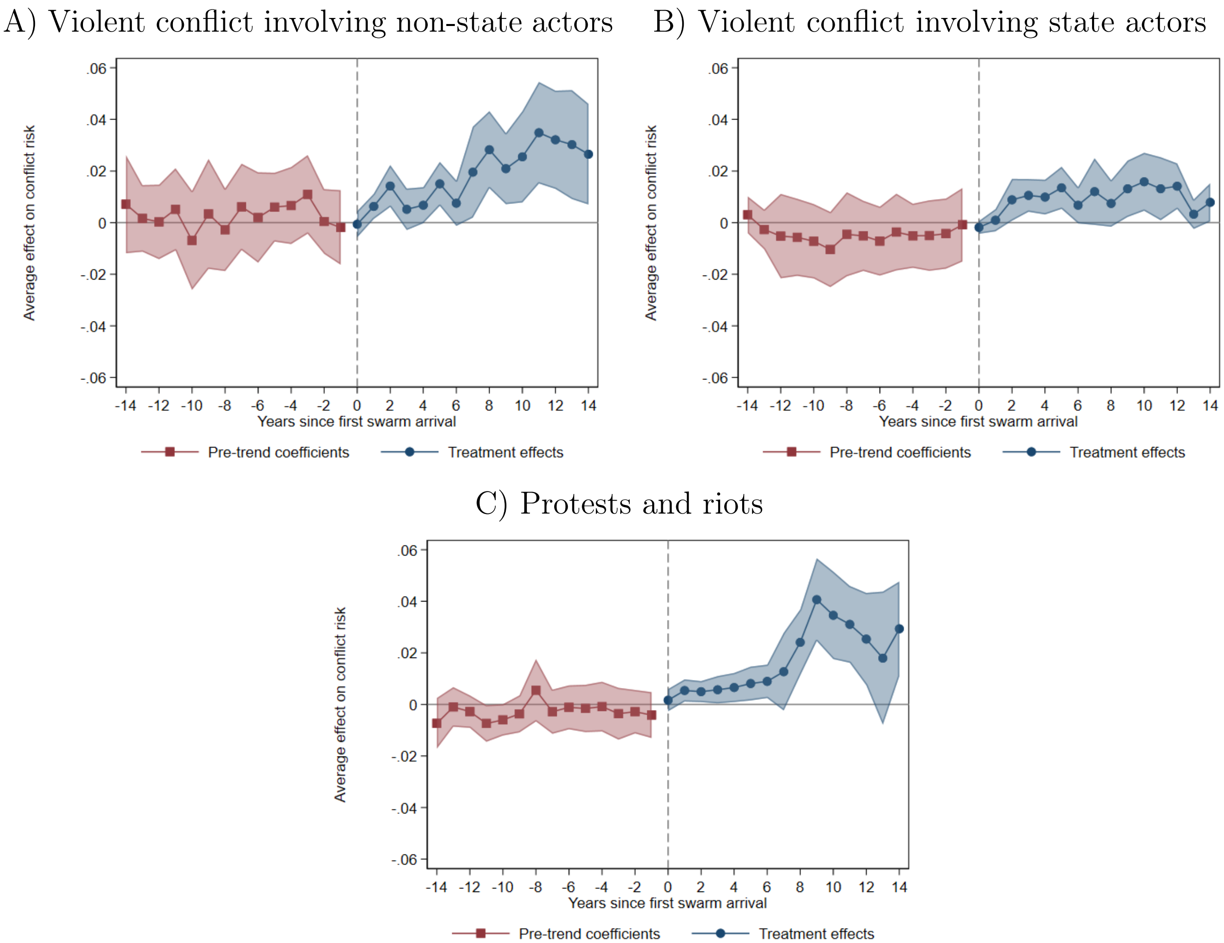
Note: The dependent variable is a dummy for any violent conflict event observed. Cells are regarded as 'affected' by locust swarms for all years starting from the first year in which a swarm is recorded in the cell. Inverse propensity weights calculated based on estimates of the propensities of cells to have been exposed to any swarm during the study period are included. Controls include annual total rainfall, maximum temperature, and population, and their interactions with the land variables. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure C3: Sensitivity of locust swarm exposure event study results



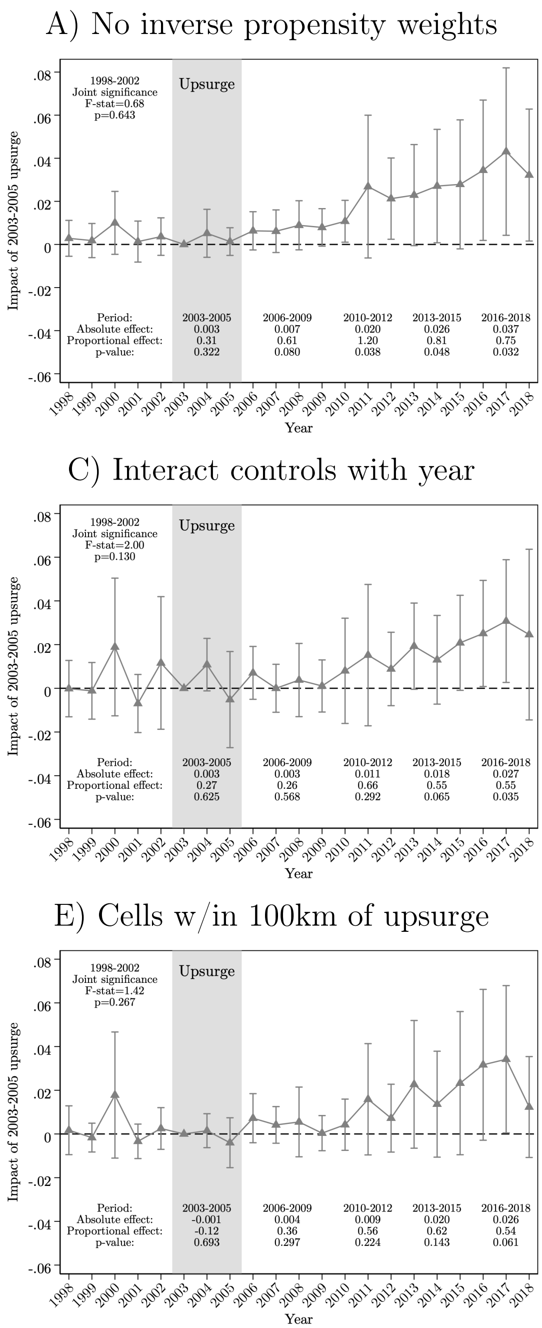
Note: Event study results for impacts of exposure to any locust swarm on conflict risk over time using the approaches in Borusyak, Jaravel, and Spiess (2021) and Callaway and Sant'Anna (2021). All regressions include country by year and cell FE unless otherwise specified. The CS *csdid* package did not converge with country by year FE and the BJS *did_impute* did not converge when including weather and population controls, so a more complete comparison of estimates was not possible. Locust swarm exposure is based on the first year a locust swarm is observed in a cell; cells with locust swarms observed before the start of the sample period are not included in the analysis. Estimated impacts in each time period are weighted averages across effects for swarm exposure in particular years. The time period 0 is the year of swarm exposure. The shaded areas represent 95% confidence intervals using SEs clustered at the region level unless otherwise specified. The reference year for treatment effects is the year prior to exposure. The BJS method calculates all effects relative to the full pre-exposure period. The CS method calculates pre-trend effects using adjacent years and treatment effects relative to the year prior to exposure. Observations are 0.25° grid cells (approximately 28×28km) by year unless otherwise specified. SEs are clustered at the region level.

Figure C4: Impact of locust swarm exposure over time on different conflict types



Note: Event study results for impacts of exposure to any locust swarm on risk of different types of conflict risk over time, using data on conflict events from ACLED. All effects are estimated using the approach in Borusyak, Jaravel, and Spiess (2021) including country by year and cell fixed effects. Locust swarm exposure is based on the first year a locust swarm is observed in a cell; cells with locust swarms observed before the start of the sample period are not included in the analysis. Estimated impacts in each time period are weighted averages across effects for swarm exposure in particular years. The time period 0 is the year of swarm exposure. All effects are estimated relative to the full pre-exposure period. The shaded areas represent 95% confidence intervals with SEs clustered at the sub-national region level. Observations are grid cells approximately 28×28km by year.

Figure C5: Sensitivity of upsurge swarm exposure event study results



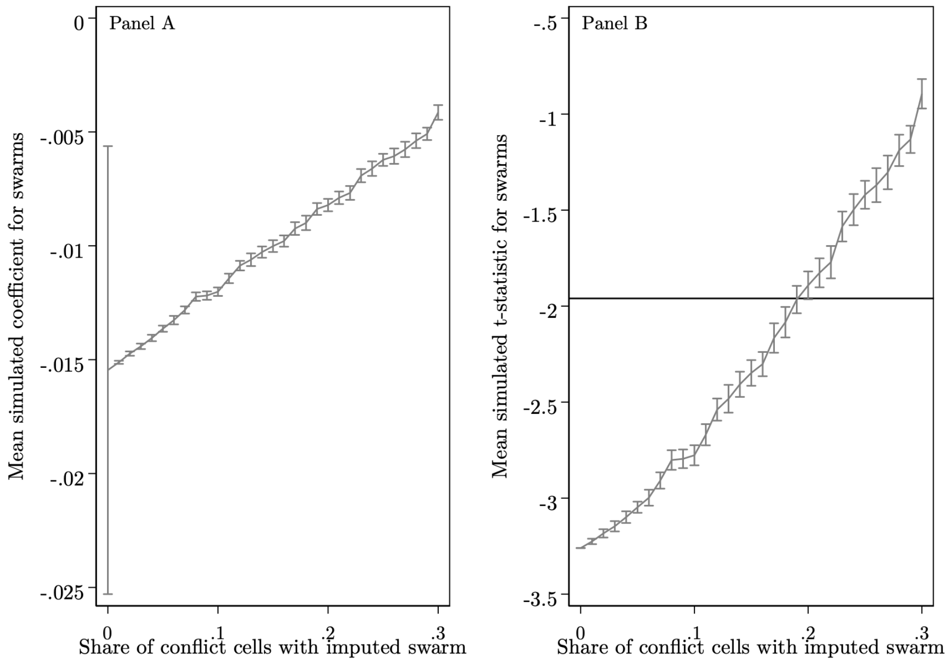
Note: The dependent variable is a dummy for any violent conflict event observed. Coefficients are for the interaction of a dummy for being exposed to a locust swarm between 2003-2005 with year. The reference year is 2003, the first year of the upsurge period which is shaded in gray. All regressions are weighted by the inverse of the propensity to have been exposed to a swarm during the 2003-2005 upsurge, except in Panel A. Bars represent 95% confidence intervals using SEs clustered at the country level, except in panel B. The regressions include controls for rainfall, temperature, population, and cell and country-by-year FE, except as specified in panels C and D. Observations are 0.25° grid cells (approximately 28×28km) by year, except in Panel F. Estimates from the same specification with binned years are reported at the bottom of the figure. Proportional effects are relative to the probability of observing any violent conflict during the particular time period. p-values are for tests of the null of 0 impact of the upsurge in each period. In the top left are the results from a joint test of the hypothesis that all pre-upsurge coefficients equal 0.

Table C3: Naive short-term impact of locust swarms on the risk of conflict, controlling for insecurity

	(1)	(2)	(3)	(4)	(5)
	Locust swarm	Violent conflict	Violent conflict	Violent conflict, no prior yr conflict	Drop countries from Showler & Lecoq (2021)
Any violent conflict in cell previous year	-0.004**		0.236***		
	(0.002)		(0.021)		
Any swarm in cell		-0.015***	-0.012***	-0.010***	-0.014***
		(0.004)	(0.003)	(0.003)	(0.005)
Any swarm in cell previous year	-0.020**	-0.006	-0.004	0.001	-0.010***
	(0.009)	(0.004)	(0.004)	(0.004)	(0.004)
Observations	508269	508269	508269	499306	341869
Outcome mean	0.005	0.020	0.020	0.011	0.013
Controls	Yes	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes

Note: Columns indicate which dummy dependent variable is used. The first column tests impacts of prior year conflict on the probability of observing a locust swarm. The remaining columns test the impact of locust swarms on the probability of observing violent conflict; column (2) replicates column (1) from Table 3. Column (5) drops Chad, Mali, Somalia, Sudan, Western Sahara, and Yemen from the analysis as countries discussed in Showler and Lecoq (2021) as having had insecurity issues potentially affecting desert locust control and monitoring operations during the study period. Observations are grid cells approximately 28×28km by year. All columns include cell and country by year FEs. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure C6: Results of simulating 'missing' swarms in cells experiencing conflict



Note: The figures show the results from simulations randomly assigning swarms to a certain share of cells that experienced conflict in a given year and are within 50km of a recorded locust swarm. I increase the share of imputed locust swarms by 1 percent for up to 30 percent of these conflict cells with no recorded swarms being assigned an imputed swarm. At each step I conduct 100 simulations of Equation 2, randomly assigning the imputed swarms in each simulation. Both panels plot the mean and 95% confidence interval for simulation results at each step. Panel A shows the estimated coefficients for the impact of swarms on conflict, and Panel B shows the associated *t*-statistics. The values when the share of imputed swarms is 0 are from Table 3. In all simulated regressions, the dependent variable is a dummy for any violent conflict and the independent variable is a dummy for any locust swarm, including the imputed swarms. Other controls are as in Equation 2. Observations are grid cells approximately 28×28km by year. SEs are clustered at the country level.