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

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Abstract

This paper tests the importance of changes in opportunity costs related to agriculture on the risk of violent conflict using data on locust swarms and conflict collapsed to annual 0.25° (approx. 28km^2) grid cell observations across Africa and the Arabian peninsula. The identification exploits exogenous local variation in locust swarm exposure driven by patterns in swarm movements together with weather controls and grid cell and country-by-year fixed effects to identify causal impacts of these agricultural shocks. Locust swarms decrease the likelihood of violent conflict event in a given year by around 20%. Effects are driven by areas with crop and pasture land, and there is no evidence of conflict spillovers to nearby areas. The impacts are largest for swarms that arrive in the off-season or planting season for major crops, based on national crop calendars, and the patterns are not consistent with effects on conflict driven by changes in conflict opportunity costs related to agriculture. This points to the availability of non-agricultural livelihood opportunities and to alternative factors such as psychological impacts and relief efforts less often discussed in this literature as crucial in determining whether an agricultural shock increases conflict risk. In contrast to short term negative effects on conflict, cells affected by the 2003-2005 major desert locust upsurge were 62% more likely to experience any conflict in a given year afterward.Absolute impacts are increasing over time alongside a general increase in conflict in the sample countries, suggesting affected areas are made vulnerable to future shocks which precipitate conflict.

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

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1 Introduction

A growing literature explores the role of agricultural shocks in increasing the risk of conflict (e.g., Dube and Vargas 2013; Harari and La Ferrara 2018; Maystadt and Ecker 2014; McGuirk and Nunn 2021; Miguel, Satyanath, and Sergenti 2004), with particular attention to Africa where the number of conflict events has been increasing rapidly since the late 2000s. Understanding this relationship is increasingly important in the context of climate change as the frequency and severity of weather-related shocks increases. This paper provides new evidence on the relationship between agricultural shocks and conflict in the short- and long-term by analyzing outbreaks of desert locusts, the world's most dangerous and destructive migratory pest (Cressman, Van der Elstraeten, and Pedrick 2016; Lazar et al. 2016).

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, I estimate a model of conflict at the annual level for 0.25° (around 28 km^2) grid cells between 1997-2018 across Africa and the Arabian peninsula. The identification exploits exogenous local variation in locust swarm exposure driven by swarm flight patterns to identify causal impacts of these shocks. The regressions control for current and lagged local weather realizations, country-by-year fixed effects, and cell fixed effects, generally following the approach in Burke, Hsiang, and Miguel (2015) and Harari and La Ferrara (2018) and other recent papers.

As in these papers and others in the climate and conflict literature, I find that deviations in rainfall and temperature from historical norms increase conflict risk in the short term. On the other hand, the presence of a locust swarm in a location decreases the likelihood of any violent conflict event occurring in the same year, by around 20% in the most conservative subsamples. This result contrasts with most of the literature on climate and conflict (Burke, Hsiang, and Miguel (2015)) but is robust to a variety of alternative specifications and subsamples. Negative impacts on conflict risk persist into the following year. Impacts of swarms on conflict are largely local with no significant spillovers into surrounding areas up to 500km away,indicating effects are not driven by displacement of conflict to nearby areas.

The negative average impact of swarms on conflict at the annual level is driven largely by swarms that arrive in the local off-season or planting season for major crops. Swarms arriving during the growing and harvest period have no statistically significant effect. The pattern of results is similar across regions with very different crop calendars. The literature on agricultural shocks and conflict typically interprets the relationship through the lens of a simple model of opportunity costs related to agriculture and returns to fighting over agricultural output, but the results for locust swarms are not consistent with such a model. This implies an important role for opportunity costs related to non-agricultural work, and for other factors less frequently discussed in this literature such as psychological impacts, social cohesion, and relief efforts.

I next explore long-term impacts of an agricultural shock on conflict using an event study of the 2003-2005 major desert locust upsurge. While contemporaneous effects of locust swarms on conflict are negative, cells that experienced a locust swarm during this outbreak are 62% more likely to experience any conflict in a given year afterward relative to cells that were not affected by the upsurge. The impact on conflict risk increases rather than decreases over time, suggesting affected areas do not recover from this agricultural disaster over time but rather remain vulnerable to future shocks which may precipitate conflict.

This paper makes three main contributions. First, I provide new evidence on the drivers of conflict, particularly in Africa (see e.g., Blattman and Miguel 2010; Collier and Hoeffler 1998; McGuirk and Burke 2020; Miguel, Satyanath, and Sergenti 2004), testing the most commonly discussed mechanisms linking agricultural shocks to conflict. Using local variation in desert locust swarms, a novel agricultural shock in this literature, I find that an extreme agricultural shock decreases the short-term risk of conflict, in contrast to much of the empirical evidence (see Burke, Hsiang, and Miguel (2015) for a review). Despite local variation in locust swarm destruction, I find no evidence of conflict displacement or spillovers.I build on recent papers analyzing the role of agricultural seasonaliy in conflict (Crost et al. 2018; Guardado and

Pennings 2021; Ubilava, Hastings, and Atalay 2022, and show that the impacts of locust swarms on conflict by swarm timing do not align with seasonal differences in effects of locust on agricultural productivity. How an agricultural shock affects conflict risk is therefore not necessarily a simple function of the impact on agricultural production.

Second, I add to our understanding of the economic and social effects of natural disasters (see Botzen, Deschenes, and Sanders (2019) and Klomp and Valckx (2014) for reviews) as one of the first to study long-term impacts on the risk of violent conflict. This is a broad literature but the evidence on long-term impacts of disasters such as hurricanes and droughts is limited, inconclusive, and focused on a small number of outcomes (Botzen, Deschenes, and Sanders 2019; Cavallo et al. 2013; Gignoux and Menéndez 2016; Heger and Neumayer 2019; Hsiang and Jina 2014; Kocornik-Mina et al. 2020). I show that desert locust swarms—a natural disaster that operates almost entirely through effects on the agricultural sector—increase conflict risk over the following 15 years.

Third, I expand the evidence base on the economic impacts of agricultural pest shocks (Bradshaw et al. 2016; Oerke 2006). A large literature reports on the short-term impacts of agricultural pests on agricultural production, household consumption, or coping mechanisms, but few studies consider broader or long-term impacts (some exceptions include Baker, Blanchette, and Eriksson (2020), Banerjee et al. (2010), Conte, Tapsoba, and Piemontese (2021), and De Vreyer, Guilbert, and Mesple-Somps (2015)). 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 desert locusts are ideally situated to benefit from climate change (ASU 2020). Policies to address this challenge should be informed by estimates of the costs outside of immediate agricultural losses. This paper analyzes how destruction caused by an important migratory pest affects local risk of conflict in the short and long term across Africa and the Arabian peninsula.

The remainder of the paper is organized as follows. Section 2 provides background on desert locusts and discusses how agricultural shocks may affect the risk of violent conflict.

Section 3 discusses the data used in the analyses and Section 4 outlines the empirical approaches. Section 5 shows and discusses the results on short-term impacts of swarms on conflict, spatial spillovers, agricultural destruction and seasonality, and long-term impacts. Section 6 concludes.

2 Background

2.1 Desert locusts

Damages from desert locust swarms—the world's most dangerous and destructive migratory pest (Cressman, Van der Elstraeten, and Pedrick 2016; Lazar et al. 2016)—can be extreme.During the 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). 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 (Food and Agriculture Organization of the United Nations (FAO) 2022a). The food insecurity motivates large numbers of individuals to move away from locust-affected areas: the World Bank estimates that 8 million people were internally displaced during this most recent upsurge (The World Bank 2020).

Small numbers of locusts are always present in desert 'recession' areas from Mauritania to India, posing little threat to livelihoods.[1] 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 form large bands or swarms (Symmons and Cressman 2001). This process can lead to 'outbreaks' or 'upsurges'where locust swarms spread from their

[1] 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.

desert breeding areas. Few locust swarms are observed outside of major outbreaks.

Figure 1 displays the locations of desert locust swarm observations 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 or space. The countries affected by the 2003-2005 upsurge are not the same as those that have experienced more recent outbreaks. Desert locusts are migratory, moving on after consuming all available vegetation, rather than becoming endemic. The arrival of a swarm is thus a locally and temporally concentrated natural disaster where all crops and pastureland are at risk (Hardeweg 2001) but does not signal a permanent change in local agricultual pest risk.

[Figure 1 here]

Locust outbreaks end due to a combination of migration to unfavorable habitats, failure of seasonal rains, 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). 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.

Locust swarms vary in 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 $1km^2$ to several hundred. Swarms fly for 9-10 hours each day, from a few hours after sunrise to an hour or so before sunset. They fly downwind and can easily move 100km or more in a day even with minimal wind. As a result of this flight pattern, some areas in the flight path of a locust swarm are spared any agricultural destruction. This can be seen in Figure 1 by many unaffected areas even in countries with large numbers of swarms during the 2003-2005 upsurge. Where swarms land during an outbreak is determined largely by patterns of wind direction and speed over time from the initial breeding areas. I leverage this quasi-random variation in the areas affected by swarms to identify their impact on conflict.

2.2 Agricultural shocks and conflict

While conflict between states has become less common in recent decades, civil conflicts are increasing in frequency in many parts of the world.These conflicts have a variety of proximate causes, but a growing literature explores the impacts of climate or weather on conflict (see Burke, Hsiang, and Miguel (2015) and Dell, Jones, and Olken (2012) for reviews), generally finding that deviations from historical norms increase conflict risk.

Though some studies have pointed to psychological or infrastructural effects of weather shocks in explaining impacts on conflict (Chemin, De Laat, and Haushofer 2013; Hsiang and Burke 2014; Sarsons 2015; Witsenburg and Adano 2009), the majority of papers focus on the role of changes in agricultural productivity and opportunity costs of conflict, in line with the Chassang, Miquel, et al. (2009) model. Many studies find support for the argument that impacts of agricultural shocks on the decision to engage in conflict are driven by changes in the opportunity cost of fighting (Crost et al. 2018; Fjelde 2015; Guardado and Pennings 2021; Harari and La Ferrara 2018). Others emphasize changes in the potential returns to conflict over outputs following an agricultural shock (McGuirk and Nunn 2021; Ubilava, Hastings, and Atalay 2022). Both mechanisms are common to the literature on the sources of conflict more generally (see e.g., Blattman and Miguel 2010; Chassang, Miquel, et al. 2009; Collier and Hoeffler 1998, 2004; Dal Bó and Powell 2009; Dal Bó and Dal Bó 2011; Dube and Vargas 2013; Fearon 1995; McGuirk and Burke 2020).

In the parts of the world in the migratory range of desert locusts, a large share of households rely on agriculture for their livelihoods, making agricultural productivity shocks particularly important for conflict. Consider a simple Roy model in which individuals choose their occupation from between agricultural production, non-agricultural work, and fighting to capture resources.[2] Adverse agricultural shocks reduce the opportunity cost of fighting by reducing the expected gains from engaging in agricultural production. At the same time, reduced agricultural productivity reduces the potential gains from fighting to the extent that

[2]This simple model is developed in more detail in Appendix C.

agricultural outputs are an important share of the resources that could be captures. Non-agricultural livelihood opportunities play an important role in setting a lower bound on how far the opportunity cost of fighting falls following a negative agricultural shock, assuming returns to non-agricultural work are less affected by such shocks.

Agricultural shocks may also have long-term impacts on conflict risk, but the evidence is limited. Crost et al. (2018) and Harari and La Ferrara (2018) find impacts of agricultural production shocks persist in the short-term but do not consider impacts beyond two years. 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. Adverse agricultural shocks may similarly affect long-term outcomes if they cause persistent decreases in agricultural productivity, such as through destruction of infrastructure, environmental degradation, or reduction of household productive assets. Lasting reductions in agricultural productivity could increase the risk of conflict due to reduced opportunity costs of fighting.

3 Data

The Locust Watch database (FAO 2022) includes data from 1985 to the present on observations of desert locust swarms, as well as smaller concentrations of locusts. These data include latitude, longitude, and date of observations.I consider only data on locust swarms, high density groups of gregarious locusts that can move in a coherent manner, and do not consider observations of locusts at lower density as these typically pose less of a threat.

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, and nature of conflict events globally starting from 1997. 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 violent conflicts from the Uppsala Conflict Data Program (UCDP) (Sundberg and Melander 2013), which uses a more restrictive definition of conflict.[3]

I collapse the data to raster grid with annual observations for cells with a 0.25° resolution (15 arcminutes, approximately 28km^2). In each cell and year I measure whether any locust swarm/conflict event was observed. To account for possible spatial spillovers, I also measure whether any swarms are observed in bands at different distances outside of the cell.I categorize swarms as arriving during particular stages of the crop production cycle by matching the specific date 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).[4] I define four main seasons: planting, growing, harvesting, and the off season between harvesting and planting. Figure A2 shows the share of sample cells at different stages of agricultural cycle by month and the counts of locust swarms observed by season and region.

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 arrival of a locust swarm. I measure annual precipitation (in mm) and maximum temperature (in °C) through 2018 using high-resolution monthly data from WorldClim.[5] I also incorporate raster population data for every 5 years from CIESIN 2018, linearly interpolating 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).

Although desert locust swarms are observed as far east as India, I restrict my analysis to countries in Africa and the Arabian Peninsula with at least 10 locust swarm observations from 1985-2018. These countries include all of North Africa, most of the Arabian Peninsula,

[3]UCDP 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.

[4]Figure A1 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.

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

and countries along the Sahel. I drop unpopulated (largely desert and water) cells from the analysis. Since ACLED records conflicts beginning in 1997 and the weather data are available until 2018, I retain only data from 1997 to 2018.

The resulting analysis sample covers 22 years across 24,459 cells, for a total of 538,086 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 experienced at least one locust swarm, and 56% 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. I conduct my main analyses using the full analysis sample, and test robustness and heterogeneity using subsamples based on these characteristics.

[Figure 2 here]

4 Empirical approach

I estimate the causal impacts of locust swarms on conflict in the short term using a linear probability model estimated via OLS, which takes the form:

$$Conflict_{cit} = \alpha + \beta Swarms_{cit} + \delta X_{ct} + \gamma_{it} + \mu_c + \epsilon_{cit} \quad (1)$$

where c indexes cells, i indexes countries, and t indexes years. $Conflict$ is a dummy variable for observing any conflict event and $Swarms$ is a dummy variable for observing any locust swarm. γ_{it} are country-year fixed effects, and μ_c are cell fixed effects. X_{ct} is a vector of controls at the cell level. My preferred specification includes as controls an indicator for any locust swarms in the area outside the cell within 100km from the cell centroid, total annual rainfall (in mm), the maximum annual temperature (in $^{\circ}C$), and 1 year lags of locust swarms, rainfall, and max temperature. Standard errors (SEs) are clustered at the country level to allow for correlation in the errors within countries.[6]

This fixed effects model is similar to Fjelde (2015), Harari and La Ferrara (2018), McGuirk and Nunn (2021), and Ubilava, Hastings, and Atalay (2022), and others in the use of a grid cell panel data to analyze the impact of weather on conflict in Africa and to Burke, Hsiang, and Miguel (2015) in structure and the use of lagged weather variables. The country-year fixed effects flexibly control for factors varying over time at the country level that might affect conflict and the impact of locust swarms, such as the policy environment and national economic and social conditions. The cell fixed effects control for time invariant cell characteristics, such as geography and typical wind patterns. Effects of locusts are therefore identified from variation in swarm presence within cells over time controlling for time-varying national conditions.

Controlling for swarms in the previous year and in the area outside the cell accounts for potential temporal and spatial spillovers. The rainfall and temperature controls and lags allow me to isolate the impact of the locust shock from concurrent environmental factors that may affect agricultural productio and the risk of conflict. Desert locust outbreaks follow periods of heavy rainfall and vegetation growth in breeding areas. Given spatial correlation in weather, this would tend to increase agricultural production in affected areas if not for the destruction of locust swarms. Indeed, while swarms cause major localized agricultural losses, at the national level production may increase in outbreak years (Krall and Herok 1997).

Conditional on swarm formation in breeding areas, variation in wind direction and typical locust flight duration create quasi-random variation in areas where swarms land. After including controls for weather and fixed effects, we can therefore consider swarm shocks to be exogenous to local conditions which might affect the risk of conflict and interpret the coefficient on $Swarms$ as a causal impact.

[6] This is likely more restrictive than necessary and will lead to a conservative interpretation of the results. Results are similar when using Conley (1999) Heteroskedasticity and Autocorrelation-Consistent (HAC) SEs allowing for both spatial and serial correlation following Hsiang (2010)'s approach.

I test robustness of the results to different controls and fixed effects, to different outcome definitions, to different restrictions of the analysis sample, and to different clustering of standard errors. Results of robustness tests are included in Appendix D. 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 for spatial spillovers by considering impacts of swarms in bands at a particular radius from the cell, and by estimating impacts at different levels of analysis, collapsing the data across cells. To test whether effects vary by swarm timing, I estimate Equation 1 separating out $Swarms$ into a series of dummy variables indicating the presence of locust swarms during particular periods of the crop calendar.

Finally, to test whether impacts of locust swarms persist beyond the short term I analyze long-term impacts of the 2003-2005 locust upsurge, the last major locust outbreak prior to the most recent upsurge in 2019-2021 and the only major upsurge in the sample period (1997-2018). This upsurge accounts for 59.5% of swarm observations in the sample. I estimate a two-way fixed effects difference-in-differences regression

$$Conflict_{cit} = \alpha + \beta Swarms_{cit} + \xi Upsurge_{ci} \times Post_t + \delta X_{ct} + \gamma_{it} + \mu_c + \epsilon_{cit} \tag{2}$$

where $Upsurge$ is an indicator for being in a cell with any locust swarm between 2003-2005 and $Post$ is an indicator for being in a year after 2005. The fixed effects absorb the individual $Upsurge$ and $Post$ terms. 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. I also conduct an event study analysis of the upsurge replacing $Post$ with individual year dummies.

Identification for the analysis of long-term impacts relies on the assumption of parallel trends between areas that did and did not experience locust swarms during the 2003-2005 upsurge. This assumption is supported by the quasi-random variation in where locusts land due to wind speed, direction, and flight duration. I also test for parallel pre-trends using the event study specification, and test the robustness of the results to different constraints on the areas included in the comparison sample.

5 Results

5.1 Short-term impacts

Table 1 presents estimates of Equation 1 for different subsamples, separately analyzing impacts on violent conflict events. The point estimates for contemporaneous and lagged weather are almost uniformly positive across subsamples: deviations from mean annual temperature and rainfall within cells are associated with a higher probability of conflict, consistent with the literature on climate and conflict. The magnitudes of the effects of rainfall and temperature fall in the upper middle of the range of estimates reported in Burke, Hsiang, and Miguel (2015)'s meta-analysis of the impacts of weather deviations on intergroup conflict.

Effects of rainfall and temperature are not always statistically significant when clustering SEs at the country level, but are significant when using Conley SEs allowing for more flexible spatial correlation. I find that SEs clustered at the country level are uniformly larger than SEs clustered at the country-year or cell level, and than Conley (1999) SEs allowing for spatial correlation within a radius of 500km (Figure A7). This is expected given that clustering at the country level implies a quite large level of spatial and serial correlation. SEs clustered at the country-year level are only slightly smaller on average than the SEs clustered at the country level,indicating spatial correlation in the errors is relatively more important than serial correlation in these analyses. I report only the country-clustered SEs in the main results as these are more conservative, though this approach might understate the significance of certain relationships.

[Table 1 here]

In contrast to rainfall and temperature, locust swarms significantly *decrease* the probability of conflict in the same year. In cells where a locust swarm is observed in a given year, the probability of observing any violent conflict event in that cell in that year falls by 1.5 percentage points holding all else constant in the full sample. This represents a reduction of 76% relative to the mean probability of observing violent conflicts in cells with no locust swarms. This result is robust to several restrictions of the set of analysis cells, shown in columns (2)-(6), and in particular to restricting the set of control cells to those that ever experienced a locust swarm during the sample period (column 5) and those that ever experienced violent conflict (column 6). The results from these subsamples indicate that locust swarms more conservatively decrease the risk of conflict by around 20% relative to cell-years with no swarms. While smaller than the estimate across all sample cells, which may be an upper bound, this remains a large and significant effect.

Experiencing a locust swarm the previous year also reduces the risk of violent conflict, by 0.9 percentage points (45%) in the full sample.This result loses statistical significance in the most restrictive samples, but the similar sign for both current and lagged swarms suggest a similar mechanism may be driving the impacts on the risk of conflict.[7]

The negative impact of locust swarms on conflict risk in the same year is robust to a variety of different specifications. Point estimates are consistently negative in specifications varying the set of control variables and fixed effects, but are only statistically significant when including weather controls (Table A3). Results are robust to varying the size of cells up to the level of 2 degree cells (Table 2), which I return to in the discussion of conflict spillovers. The proportional impact of locust swarms is similar in the samples of years before and after 2010, when conflict frequency began to markedly increase in the study area, though the post-2010 estimate is noisy as fewer swarms are observed in this period. Results are robust to dropping different regions of the study area from the analysis, indicating results are not driven by any one region (Table A4). Results are similar when considering alternative measures

[7]Both Crost et al. (2018) and Harari and La Ferrara (2018) find that a negative agricultural shock increases the risk of conflict in the current and following year, so similarly find persistent effects in the short-term but with the opposite sign.

of conflict, including ACLED protest/riot events, the more restrictive UCDP definition of violent conflict events, whether a state or government actor is involved in the conflict, and the intensive margin using counts of fatalities from conflict events in a year (Table A5).[8] Finally, I find no significant difference in the effect of experiencing a single swarm in a given year as opposed to multiple swarms on the risk of conflict across a variety of specifications, validating the focus of the analysis on the extensive margin of locust presence rather than the intensive margin (Figure A8).

A concern might be that violent conflict reduces the probability that locust swarms are observed, but the results are robust to controlling for this possibility, as shown in Table A2. I find no effect of violent conflict in the first half of a year on the probability of observing a locust swarm in the second half of the year (column 2), though conflict the previous year is associated with a lower probability of observing a swarm the current year (column 1). The effect of a locust swarm remains significant and large when controlling for lagged conflict, causing a 60% decrease in the risk of conflict in the full sample of cells (column 4) and is similar when restricting the sample to observations with no conflict the prior year (column 5). Further, a locust swarm in the first half of the year decreases the risk of violent conflict in the second half of the year by 42% (column 6.Reverse causality therefore does not apper to drive the negative effect of locust swarms on conflict.

5.2 Spatial spillovers

One possible explanation for the decrease in conflict risk in cells affected by locust swarms is spatial conflict spillovers. The returns to conflict will be lower in areas affected by swarms, making nearby unaffected areas relatively more attractive to groups aiming to capture resources.This could be particularly true since years with locust swarm outbreaks are typically more productive agriculturally, as the rainfall shocks in locust breeding areas leading to

[8] The impact of locust swarms on conflict when using UCDP data is only significant when considering impacts on any conflict event. Estimated impacts on specific types of conflict are negative but imprecise given the limited number of UCDP conflict events in the sample.

swarm formation are often correlated with positive rainfall shocks in agricultural areas. If conflict risk increases in areas surrounding locust-affected cells, the net effect of locusts on conflict at a broader spatial level might be null or positive.

As an example of this, McGuirk and Nunn (2021) find that droughts in pastoral areas of Africa lead to conflict in neighboring agricultural areas as pastoral groups are displaced in search of grazing opportunities. These spillovers lead to a negative estimated relationship between precipitation shocks and conflict in the sample overall, since the conflict takes place outside affected areas.Showler (2019) report instances of similar resource-based conflicts between farmers and pastoralists as a consequence of population movements caused by the 2003-2005 locust upsurge in West Africa, indicating potential for such conflict spillovers.

The main regression specification includes as a control an indicator for any locust swarm observed within 100km outside the cell (approximately 28km^2). Table 1 shows that locust swarms in the 100km outside a cell do not have any effect on the risk of conflict within the cell: the point estimate is a fairly precise 0. Figure 3 shows that this result is not sensitive to the choice of distances outside the cell to consider. Coefficients are close to zero and generally non-significant for swarms in bands at increasing distances from a cell in both the current and previous year. An exception is that locust swarms within 50km outside a cell and 100-150km outside a cell are marginally significantly associated with 0.4 and 0.2 percentage point *decreases* in the likelihood of violent conflict, respectively. If anything, this suggets that spillovers of swarm presence further suppress the risk of conflict in nearby areas, rather than displacing conflict to those areas.[9]

[Figure 3 here]

Another approach to testing whether spillovers may affect the resultsis to consider whether estimates vary with the granularity of the analysis, as in McGuirk and Nunn (2021). Table 2

[9] A possible reason for the negative effect of swarms immediately outside the cell is that those swarms may also have caused damages inside the cell. Swarms are assigned to cells based on the coordinates at which they are reported, but locust swarms can cover from under 1km^2 to several hundred at their largest extent, so some may cross into adjacent cells.

presents results from estimating the main specification at different scales. I collapse the data to higher levels of aggregation by taking the maximum of swarm and conflict event dummies and means of weather variables across 0.25° cells within the aggregated area.For example, in Column (2) both the violent conflict and swarm event variables measure whether such an event was recorded in any of the four 0.25° cells within a 0.5° cell.

[Table 2 here]

Estimated impacts of locust swarms on conflict are negative and statistically significant when aggregating cells up to 1° (around 110km^2), remain negative but no longer significant for 2° cells, and are positive and non-significant at the 5° cell or country level. Absolute effect magnitudes are increasing in the level of analysis up to 1° cells, though impacts relative to the mean conflict risk in areas with no swarms are decreasing as the likelihood that areas experience any conflict increases with the size of the area. For example, any locust swarm reported in a 1° cell decreases the probability of experiencing violent conflict in that year by 3.1 percentage points, or 24% relative to the mean in areas with no swarms.

These results are consistent with negative effects concentrated within cells and no significant spillovers in areas up to 250km away; conflict is not simply being displaced from the area affected by locusts to another nearby area. Decreases in relative impact magnitude at higher aggregations likely result from reduced treatment intensity, as the share of total area affected by locusts within treated areas falls at higher levels of aggregation. Figure 3 suggests it is not driven by positive conflict spillovers which offset the local decreases in conflict risk.

Positive non-significant effects of locusts on conflict at the 5° and country level likely reflect further reductions in locust treatment intensity as well as lower variation in the probability of conflict at these levels. When taking the mean instead of the maximum for conflict and swarm events across 0.25° cells within the aggregated areas to preserve treatment intensity, point estimates are negative and non-significant at the 5° cell and country level, and the negative effect at the 2° level becomes statistically significant (Table A6). The signs for the estimated impacts of temperature deviations on conflict risk also change at higher levels of aggregation, from positive to negative, suggesting aggregating variables across such large geographic areas loses too much of the spatial variation and makes it challenging to estimate causal relationships.

5.3 Agricultural destruction and seasonality

The impacts of locust swarms on conflict should operate primarily through first order effects on agricultural output. Locusts do not cause direct damages outside of consuming vegetation, though secondary impact channels could include psychological impacts or potential negative externalities from efforts to prevent crop destruction such as poisoning from pesticides or exposure to smoke from fires aiming to deter locusts.

Table 3 shows that impacts of locust swarms are indeed concentrated in agricultural areas, based on measures of land cover in 2000 from Ramankutty et al. (2010).[10] Point estimates for cells with no crop land or pasture land are negative but not significant.

[Table 3 here]

The impacts are largest in areas with crop land which are relatively more conflict-prone. Swarms decrease the risk of conflict by 2.4 percentage points more in cells with crop land compared to cells without, a 4.8 times larger effect, leading to a 62% decrease in conflict risk. The impact of swarms is 2 times larger in cells with pasture land than in cells with none, decreasing the risk of conflict by 53%. The effect of swarms the previous year remains negative and is larger in magnitude for agricultural areas, but not significantly so. There is no significant impact on conflict of swarms in the area surrounding a cell either in the current or previous year, regardless of whether the cell has agricultural land.

These results indicate that impacts of swarms on agricultural land and cropland in particular are the primary driver of the overall negative effect of swarms on conflict. I next

[10] 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 of the study period (Davis 2022; Liu and Xue 2020; Rahimi et al. 2021). If agriculture expanded to some areas with no pasture or crop land after 2000 (relatively early in our 1997-2018 sample period), this might reduce the estimated difference in impact by cell land cover.

estimate differences by swarm timing relative to the crop cycle, building on previous research on crop seasonality and conflict. Crost et al. (2018) find that the impact of increased rainfall on conflict in the Philippines depends on the season because of different effects on agriculture: a positive rainfall shock decreases conflict risk by increasing the opportunity cost of fighting. Guardado and Pennings (2021) show that the onset of harvest in Afghanistan, Iraq, and Pakistan similarly reduces conflict risk by changing the opportunity cost. If the negative impact of swarms on the risk of conflict is due to the returns to conflict falling by more than the opportunity costs, we should expect to find larger negative impacts of swarms arriving in parts of the year when crop destruction will be largest: the growing and early harvest months. Off-season swarms should have limited effects.

Table 4 presents the estimated impacts of swarms arriving in different seasons for subsets of cells by land cover. Cells with any crop land (nearly all of which also include pasture land) account for 28.3% of the sample and 36.2% of swarm observations. The count of swarms observed across different points in the agricultural cycle is similar, though somewhat higher in the growing and harvest seasons than in the off or planting seasons (Figure A2). Seasonality may also be relevant in cells with pasture land; agricultural cells together account for a further 75.1% of swarm events.

As in Table 1, prior year swarms consistently reduce the risk of conflict while effects of swarms in the 100km area outside the cell are not statistically significant. Consistent with a negative overall impact of swarms on the risk of conflict, point estimates for the impacts of swarms arriving in different seasons are negative, with the exception of swarms arriving during the harvest period where point estimates are positive but close to 0.

[Table 4 here]

Swarms arriving the off-season between harvest and planting of major crops significantly decrease the risk of conflict in cells with crop area, by 83%. This drives a large average effect across all cells. The difference in impacts in crop cells and agricultural cells in general indicates off-season swarms have a negligible impact in pastoral areas. This is surprising:

there should be no or very limited crop destruction during the off season, while destruction of existing vegetation might have been expected to adversely affect pastoralists.

Although the estimated impact magnitude in crop cells is largest for off-season swarms in crop cells, in all cells on average the largest magnitude is for planting season swarms: a 1.8 percentage point decrease in conflict risk. The magnitude is similar to those for crop cells and all agricultural cells, where estimates are close to marginally significant ($p = 0.102$ and $p = 0.124$, respectively). Similar estimated magnitudes for swarm impacts on conflict risk across types of land cover suggest this effect may not relate to agricultural damages, particularly since damage is likely to be limited during the parts of the planting season before seeds sprout. Growing season swarms do not significantly affect the risk of conflict, and the magnitudes of the point estimates are much smaller than for off-season or planting season swarms across all types of land cover.

The pattern of results is similar when analyzing impacts at the level of 0.5° cells rather than 0.25° (Figure A9), though at this level the impacts of planting season swarms on conflict are slightly smaller and no longer statistically significant while the impacts of growing season swarms are larger and significant in all samples. Estimated effects by season are also similar across regions, despite differences in crop calendars (Figure A10). This indicates that impacts by season are due to real differences in locust effects along the crop cycle rather than potentially mechanical differences by month of year.

Table 4 thus illustrates significant heterogeneity in swarm impacts by timing relative to the agricultural calendar, but in unexpected ways that do not align with predictions based on changes in returns to agriculture and to fighting.[11] Controlling for whether swarms arrive in other seasons of the year,[12] swarms arriving in the off season should have a limited effect

[11] Variation in the effects of prior year swarms by season also differ from the pattern that would be expected if lagged swarm impacts on current conflict risk were due to decreased returns to fighting (Figure A10). Negative overall effects are driven by swarms that arrived during the previous year's planting season. Point estimates for impacts of growing season swarms the prior year, when crop destruction should be most severe, are positive and close to significant at the 10% level. Point estimates for prior year harvest season swarms are close to 0.

[12] This is an important consideration, as there is some serial correlation in risk from locust swarms, particularly during major outbreaks or upsurges. Table A2 shows that locations with a swarm the prior year

on crop production, yet estimated impacts of swarms in cells with any crop land are largest for off-season swarms. This could reflect destruction of tree crops and other perennials, but annual crops (such as staple grains) take up the large majority of crop land in the sample countries overall so swarm damages to perennial crops should be small relative to damages to annual crops. Most cells with crop land also include some pasture land, so off-season impacts may also be due to loss of fodder for livestock—potentially very important as the off season in most countries is drier making sources of animal feed more scarce. But the coefficient for off-season swarms is smaller in agricultural cells overall than in crop cells in particular, suggesting that effects on pasture do not drive off-season swarm impacts.

Agricultural destruction should be largest for growing season swarms, as crops have sprouted but not yet been harvested. This implies that impact magnitudes should be largest for swarms arriving in this season, if agricultural destruction is the main mechanism. Results using 0.5° cells are more consistent with this, as the negative magnitudes are larger for growing season swarms than for planting or harvest season swarms (Figure A9). But with the main analysis sample of 0.25° cells, the estimated impacts are larger for planting season swarms than for growing season swarms.

Depending on whether harvest is completed by the time locusts arrive, swarms in the harvest season could either lead to very large agricultural destruction or have no effect. Assuming that harvest season swarms do reduce agricultural output on average, if this is the mechanism driving impacts of swarms on conflict we should expect a negative effect as seen for swarms in other seasons, but the point estimates for harvest season swarms are *positive*—though not distinguishable from 0.

These results highlight the importance of seasonality in the impacts of locust swarms on conflict risk, but a simple model of conflict based on changes in the returns and opportunity costs of fighting struggles to explain the patterns of impacts. This indicates that the mechanisms driving conflict responses to agricultural shocks are more complex than is presented

are less likely to have a locust swarm the current year, but locations with a swarm in the first half of the year are more likely to have a locust swarm in the second half of the year.

in much of the economics literature.

5.4 Long-term impacts

The analyses thus far have focused on the short-term: swarms in both the prior year and the same year reduce the likelihood of violent conflict events. But Table 1 shows that the probability of any violent conflict in years with no swarm is greater among cells that ever had a swarm than in cells that did not. Could this difference be due to positive long-term impacts of swarms on conflict risk?

I test long-term effects of locust swarms by considering impacts of the major locust upsurge in 2003-2005, the main outbreak in the sample period which affected 6.6% of cells. Table 5 presents the results from estimating Equation 2. Controlling for the 2003-2005 locust upsurge, locust swarms in the current and previous year still significantly reduce the risk of any violent conflict event, though the estimated effects of a prior year swarm are now larger than those of a swarm in the current year. In contrast, the 2003-2005 locust upsurge *increases* the risk of conflict in the following years. Cells where swarms were reported during this upsurge are 1.6 percentage points (62%) more likely to experience violent conflict in in a given after year 2005 relative to cells that were not affected by this upsurge. The results are nearly identical in the full sample and in the subsamples of cells within 250km and 100km from any swarm during the upsurge, indicating the effect is not driven by comparing upsurge-affected areas to dissimilar areas.

[Table 5 here]

This result suggests that locust swarms decrease the opportunity cost of fighting in the long term.[13] Adoption of agricultural insurance is low in the sample countries, and local risk sharing networks offer less support for a broad common shock such as a locust swarm. Recovery from locust shocks in this setting may therefore be limited. Households use a

[13]It is possible but highly unlikely that they increase the long-term returns to conflict.

variety of measures to cope with short-term food security and livelihood effects of locust outbreaks. Selling assets, sending household members away, and consuming seed stocks are commonly reported coping strategies that would adversely impact agricultural production in following years, decreasing the opportunity cost of fighting.

One puzzle is that this mechanism would predict increases in the risk of conflict to be greatest the year after a locust swarm arrives, as this is when household coping mechanisms would be expected to most adversely affect agricultural production. But the results consistently show negative effects of swarms in the previous year on the probability of conflict of a similar magnitude as effects of swarms in the current year. This indicates that either the effect of the upsurge on opportunity costs of fighting is delayed in some way, or that there are other mechanisms involved, or both.

Figure 4 shows the results of an event study analysis of the 2003-2005 upsurge. There are no significant differences in the risk of conflict between areas affected by locust swarms during this upsurge and areas that were not in the years preceding the upsurge ($p = 0.755$), and point estimates are close to 0. This supports the assumption of parallel trends between these areas if not for the upsurge. The analysis controls for whether any swarms were observed in the current and prior year. Consequently, there are no significant impacts of the upsurge in 2004 and 2005, the main years of the upsurge.[14]

[Figure 4 here]

Estimated impacts of the 2003-2005 upsurge on conflict become larger in magnitude over time, increasing in a nearly linear fashion from 2005 on except for a dip in 2018 at the end of the sample period. As would be expected, the standard errors increase over time with greater separation from the event, but the estimates are significant at the 90% level or greater for all years after 2008, including at the 95% confidence level for 2010, 2012, 2014, 2016, 2017, and 2018. Being affected by locust swarms during the 2003-2005 upsurge increases the risk

[14]The coefficient for 2004, for example, would therefore be interpreted as the impact on conflict of having been affected by a swarm in 2005.

of conflict in each year from 2011-2018 by between 2.2 and 4.4 percentage points, controlling for current and prior year locust swarms, weather, and cell and country-by-year fixed effects.

Though the magnitude of the impact of the upsurge increases over time, the size of the effect relative to the probability of violent conflict in unaffected areas generally decreases because that probability has been increasing over time, due to a variety of factors (Figure A3). The 2.8 percentage point increase in conflict risk in 2011 is a 171% increase relative to the risk in non-affected areas, while the 4.4 percentage point increase in 2017 is a 75% relative increase and the 3.3 percentge point increase in 2018 is a 59% relative increase.

The results are nearly unchanged when considering only the cells within 250km of a swarm during the upsurge and when restricting the sample to only cells with any agricultural land in 2000 (Figure A11). The pattern of increasing conflict risk over time also holds when using different definitions of conflict (Figure A12). There is a clear long-term increase in conflict risk in areas affected by the upsurge, particularly after 2010.

6 Conclusion

While desert locusts can have devastating consequences for local agriculture, this analysis shows that the arrival of a locust swarm does not increase the risk conflict. Instead, locust swarms *decrease* the likelihood of experiencing any violent conflict event in a given year by around 20% after controlling for the effects of rainfall, temperature, time-invariant local characteristics, and country-by-year fixed effects. Impacts of swarms on conflict are largely local with no significant spillovers into surrounding areas.

Swarms decrease the risk of conflict much more in agricultural areas with effects on crop land particularly large. A limitation of this analysis is the use of land cover data from 2000. Data on land cover over time would help to clarify the importance of crop versus pasture damages as mechanisms for the impacts of locust swarms. Incorporating measures of agricultural destruction following swarm events, potentially using satellite data on changes in vegetation, could be used to estimate direct impacts of agricultural damage on conflict.

Differences in the impact of swarms on conflict by their timing relative to the crop growing calendar indicate that effects are not driven solely by changes in agricultural productivity. Changes in opportunity costs related to non-agricultural activities by time of year could explain the patterns in effects of locusts on conflict risk. Farmers may see off and planting season locust swarms as indicating an increased risk of swarms later in the agricultural cycle and be better situated to switch into non-farm employment, whether that be a household enterprise, local wage work, or migrating in search of work. The availability of non-agricultural work sets a lower bound on how much the opportunity cost of fighting can fall following an agricultural shock, and may explain the negative effects of locusts on conflict risk as agricultural destruction also decreases the returns to conflict.

One potential implication of this result is that households would prefer to respond to an agricultural shock by engaging in a productive activity to earn their livelihood rather than to engage in conflict. 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 has been shown by some recent studies (Fetzer 2020; Garg, McCord, and Montfort 2020).

The contemporaneous reduction in conflict is contrary to what we might expect from a food insecurity shock, but major locust outbreaks are the object of significant international attention and aid which may attenuate food insecurity effects in the short term. Individuals in locust-affected areas may also attempt to avoid violent conflict in the short term in order not to deter potential aid from arriving. Geographically disaggregated data on locust relief efforts (or more general aid flows) could be useful to explore whether these play a role in reducing risk of fighting by increasing its opportunity cost in both the short and long term. Data on food insecurity could help identify whether impacts on conflict differ when locust swarms have more adverse effects on food security. Migration is also a common response to locust shocks: over 8 million people were displaced across East Africa as a result of the

2019-2021 locust outbreak (The World Bank 2020). Data on population movements could help test this as a mechanism for negative local impacts of locust swarms.

Although short-term impacts of swarms on the risk of violent conflict are negative, the long-term impact is positive indicating that locust damages have permanent effects despite the transient nature of swarms. Areas affected by the 2003-2005 locust upsurge are 62% more likely than unaffected areas to experience violent conflict in a given year after 2005. Many factors have contributed to a general increase in violent conflict in the sample countries in this period, including several civil wars, insurgencies, and the spread of terrorist organizations. Locust swarms appear to make communities particularly vulnerable to engaging in these conflicts, potentially due to a permanent decrease in agricultural productivity.

Long-term negative impacts of locust swarms on children's education (De Vreyer, Guilbert, and Mesple-Somps 2015) and health (Conte, Tapsoba, and Piemontese 2021) could explain part of the positive long-term effect on conflict, but analyzing long-term changes in agricultural productivity, labor supply, household wealth, migration, and psychological factors such as aspirations and beliefs would help elucidate the key mechanisms. Future work could also incorporate data on other types of agricultural shocks and explicitly compare impacts on conflict with those of locust swarms to highlight what makes locust shocks different, as well as test whether a past locust shock makes households more vulnerable to another agricultural shock. In general, these results highlight how failing to support communities affected by disasters to fully recover can create conditions for future conflict.

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 desert locusts. Locusts do not respect country boundaries and require international coordinate for adequate monitoring and control. This paper highlights another important consequence of desert locust outbreaks which should be considered in weighting the costs and benefits of locust monitoring and control operations.

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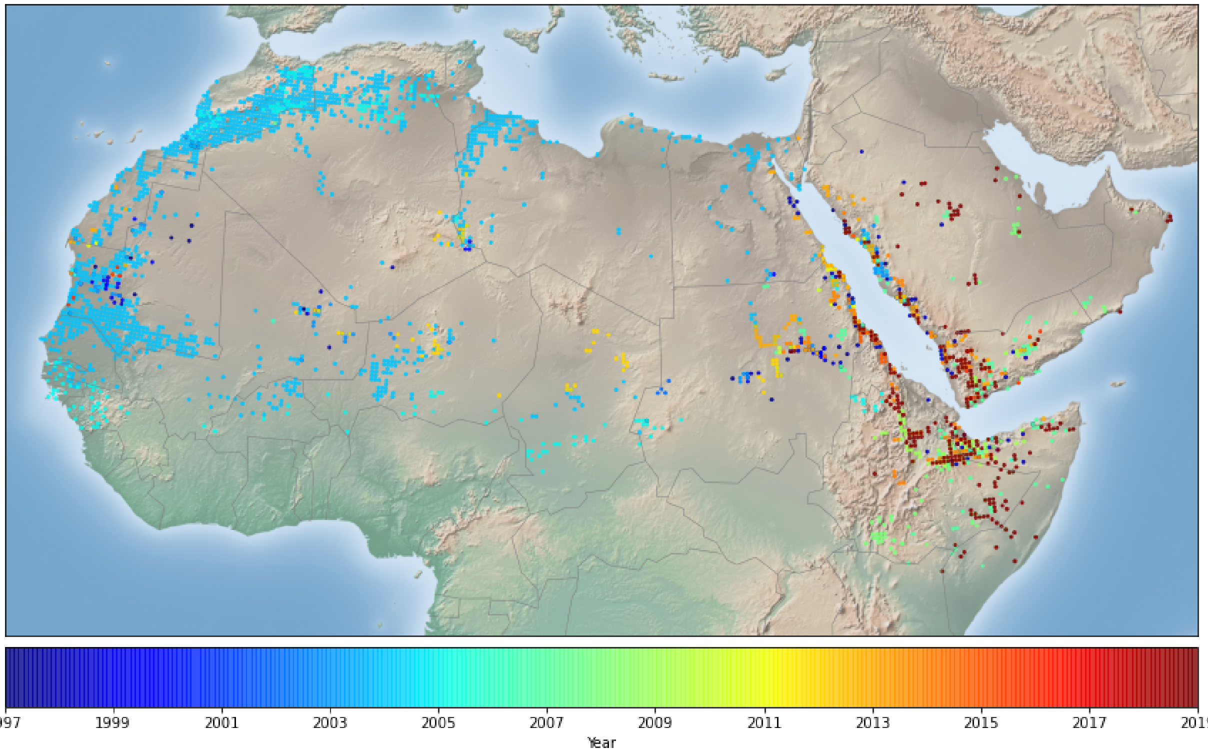
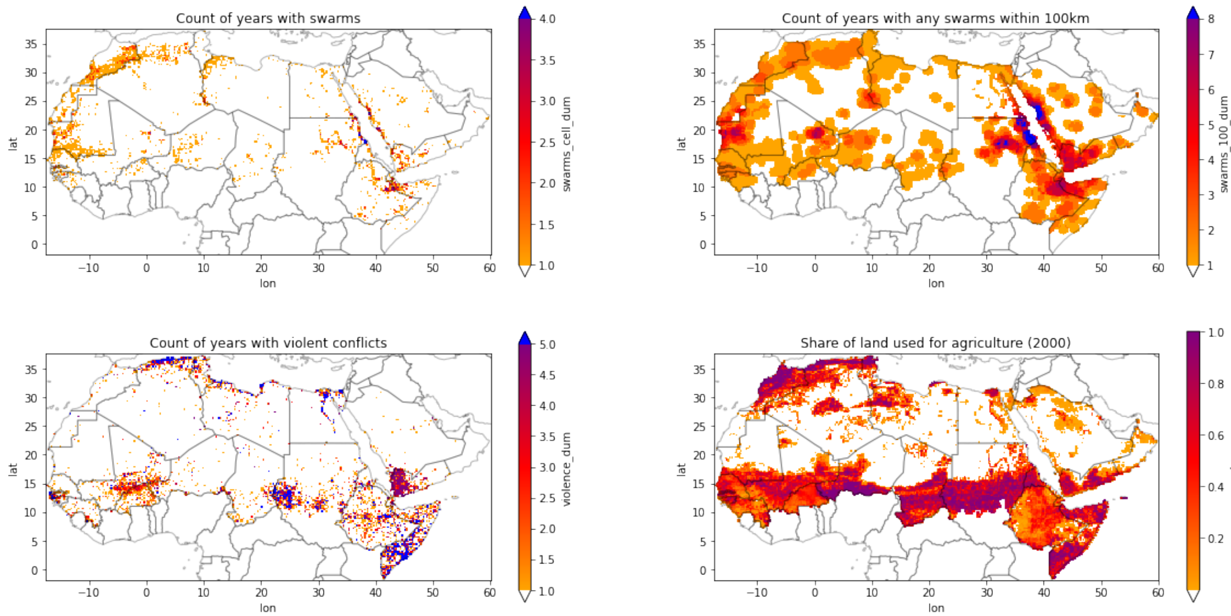
Figures

Figure 1: Desert locust observations by year, study period



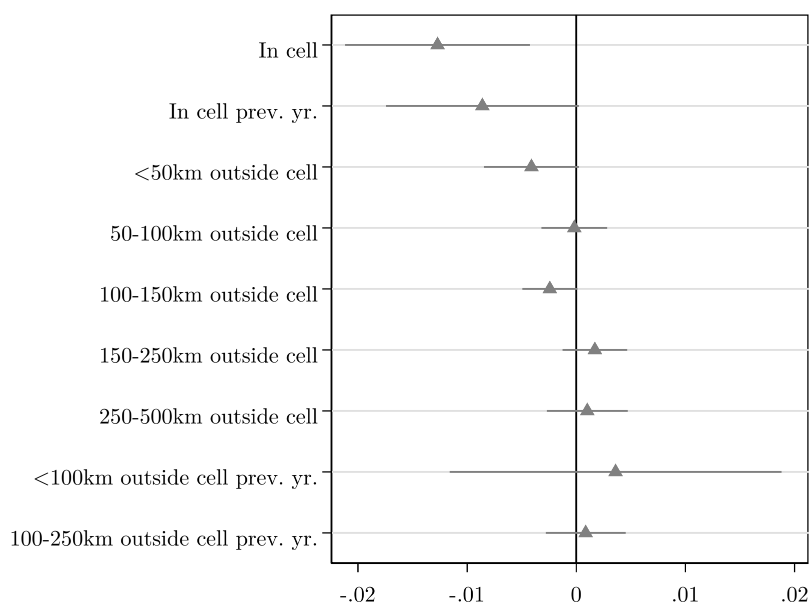
Map created by authors using swarms observations retrieved from the FAO Locust Watch database.

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



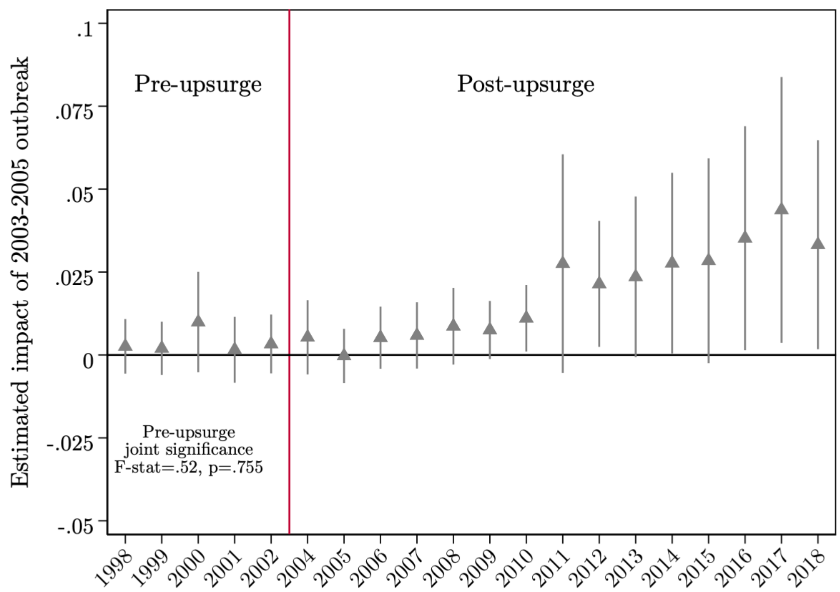
Land used for agriculture includes crop land and pasture land. This panel shows most clearly which countries in West, Central, and East Africa are excluded from the study sample.

Figure 3: Effect of locust swarms at varying distances from the cell



The figure shows point estimates and 95% confidence intervals for estimates of the impact of locust swarms by location relative to the cell on the probability of violent conflict in the cell. Observations are grid cells approximately 28km^2 by year. All regressions include weather controls as well as country-year and cell FE.

Figure 4: Effects of 2003-2005 locust upsurge on the risk of conflict by year



The dependent variable is a dummy for any violent conflict event observed. Coefficients are for the interaction of a dummy for being in a cell that had any swarm between 2003-2005 with year. The reference year is 2003, indicated by the red line. Bars represent 95% confidence intervals. The regression includes controls for current swarms, weather, and cell and country-by-year FE. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.

Tables

Table 1: Effect of locust swarms on the risk of conflict, by subsample

	(1) All cells	(2) >=10,000 population	(3) Any crop or pasture land	(4) Ever had a swarm w/in 100km	(5) Ever had a swarm in cell	(6) Ever had a violent conflict in cell
Any swarm in cell	-0.015***	-0.021***	-0.019***	-0.015***	-0.008**	-0.024***
	(0.005)	(0.006)	(0.005)	(0.005)	(0.004)	(0.007)
Any swarm in cell previous year	-0.009*	-0.005	-0.009*	-0.008*	-0.002	-0.008
	(0.004)	(0.008)	(0.004)	(0.004)	(0.005)	(0.009)
Any swarm within 100km outside cell	-0.001	0.003	-0.000	0.001	-0.001	0.003
	(0.002)	(0.004)	(0.003)	(0.002)	(0.004)	(0.009)
Any swarm within 100km outside cell previous year	0.004	0.001	0.007	0.006	0.001	0.002
	(0.008)	(0.006)	(0.010)	(0.009)	(0.008)	(0.009)
Total annual rainfall (100 mm)	0.003*	0.002	0.003	0.003	0.005	0.008*
	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)	(0.005)
Total annual rainfall previous year (100 mm)	0.003	0.003	0.003	0.003*	0.004	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)
Max annual temperature (deg C)	0.006*	0.003	0.008	0.007	0.008	0.019*
	(0.003)	(0.005)	(0.006)	(0.006)	(0.006)	(0.011)
Max annual temperature previous year (deg C)	0.005	0.002	0.007	0.008	0.006	-0.006
	(0.004)	(0.008)	(0.008)	(0.007)	(0.007)	(0.013)
Observations	508284	148522	269850	283214	50404	71234
Outcome mean, no swarms	0.020	0.048	0.034	0.025	0.040	0.142
Proportional effect of swarms	-0.755	-0.446	-0.545	-0.577	-0.210	-0.169
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes

The dependent variable is a dummy for any violent conflict event observed. Observations are grid cells approximately 28km^2 by year. SEs clustered at the country level are in parentheses. SEs for estimates in column (1) using different clustering approaches are reported in Figure A7.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Effect of locust swarms on the risk of conflict at different scales

	(1) 0.25 deg	(2) 0.5 deg	(3) 1 deg	(4) 2 deg	(5) 5 deg	(6) Country
Any swarm in cell	-0.015***	-0.024***	-0.033***	-0.019	0.056	0.015
	(0.005)	(0.006)	(0.009)	(0.020)	(0.036)	(0.027)
Any swarm in cell previous year	-0.009*	-0.011*	-0.008	-0.013	0.059*	-0.062
	(0.004)	(0.006)	(0.010)	(0.022)	(0.032)	(0.044)
Any swarm within 100km outside cell previous year	0.004	0.008	0.012	0.031	-0.005	0.026
	(0.008)	(0.009)	(0.009)	(0.021)	(0.027)	(0.049)
Total annual rainfall (100 mm)	0.003*	0.005**	0.003	0.009	0.005	0.027*
	(0.002)	(0.002)	(0.004)	(0.005)	(0.013)	(0.015)
Total annual rainfall previous year (100 mm)	0.003	0.005	0.004	0.009	-0.006	0.005
	(0.002)	(0.003)	(0.006)	(0.009)	(0.012)	(0.017)
Max annual temperature (deg C)	0.006*	0.009*	0.015**	0.008	-0.014	-0.013
	(0.003)	(0.005)	(0.006)	(0.007)	(0.010)	(0.030)
Max annual temperature previous year (deg C)	0.005	0.007	0.003	-0.021***	-0.039***	-0.016
	(0.004)	(0.007)	(0.006)	(0.006)	(0.012)	(0.023)
Observations	508284	139342	40823	13312	3673	483
Outcome mean, no swarms	0.020	0.053	0.117	0.214	0.358	0.809
Country-Year FE	Yes	Yes	Yes	Yes	Separate	Separate
Cell FE	Yes	Yes	Yes	Yes	Yes	No

The dependent variable is a dummy for any violent conflict event observed in the aggregated area in a year. Swarm presence variables are also dummies at the level of the aggregated area in a year. Results using the share of 0.25° cells in the aggregated area with any conflict or swarm event in a year are shown in Table A6. Weather controls are means for total annual rainfall and max annual temperature across cell-years within the aggregated area. Column (1) replicates Column (1) from Table 1. Subsequent columns incrementally increase the size of the spatial units in the analysis. Observations are grid cells of particular size (in terms of degrees) in Columns (1) to (5) and countries in Column (6), in a particular year. SEs are clustered at the country level.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Effect of locust swarms on the risk of conflict, by land cover

	(1) Any crop land	(2) Any pasture land
Any swarm in cell	-0.005	-0.006
	(0.004)	(0.004)
Any swarm in cell × Land	-0.024**	-0.012*
	(0.010)	(0.006)
Any swarm in cell previous year	-0.005	-0.008
	(0.004)	(0.005)
Any swarm in cell previous year × Land	-0.010	-0.002
	(0.006)	(0.006)
Any swarm within 100km outside cell	0.000	0.000
	(0.001)	(0.002)
Any swarm within 100km outside cell × Land	-0.004	-0.003
	(0.004)	(0.003)
Any swarm within 100km outside cell previous year	0.003	0.002
	(0.005)	(0.003)
Any swarm within 100km outside cell previous year × Land	0.003	0.004
	(0.010)	(0.008)
Observations	508284	508284
Outcome mean, no swarms and Land=0	0.009	0.004
Outcome mean, no swarms and Land=1	0.047	0.034
Country-Year FE	Yes	Yes
Cell FE	Yes	Yes

The dependent variable is a dummy for any violent conflict event observed. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Effect of locust swarms on the risk of conflict, by swarm timing and land cover

	(1) All cells	(2) Ag cells	(3) Crop cells
Any off season swarm in cell	-0.015*	-0.018	-0.039**
	(0.009)	(0.012)	(0.016)
Any planting season swarm in cell	-0.018*	-0.017	-0.022
	(0.009)	(0.010)	(0.013)
Any growing season swarm in cell	-0.005	-0.007	-0.008
	(0.004)	(0.005)	(0.007)
Any harvest season swarm in cell	0.000	0.002	0.002
	(0.005)	(0.006)	(0.009)
Any swarm in cell previous year	-0.009*	-0.009*	-0.011
	(0.004)	(0.004)	(0.006)
Any swarm within 100km outside cell	-0.002	-0.001	0.000
	(0.002)	(0.003)	(0.004)
Any swarm within 100km outside cell previous year	0.004	0.006	0.001
	(0.008)	(0.010)	(0.007)
Observations	508284	269850	145448
Outcome mean, no swarms	0.020	0.034	0.047
Weather controls	Yes	Yes	Yes
Country-year FE	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes

The dependent variable is a dummy for any violent conflict event observed. Locust swarm observations are matched to agricultural activities based on the month of their arrival and country-level crop calendars. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

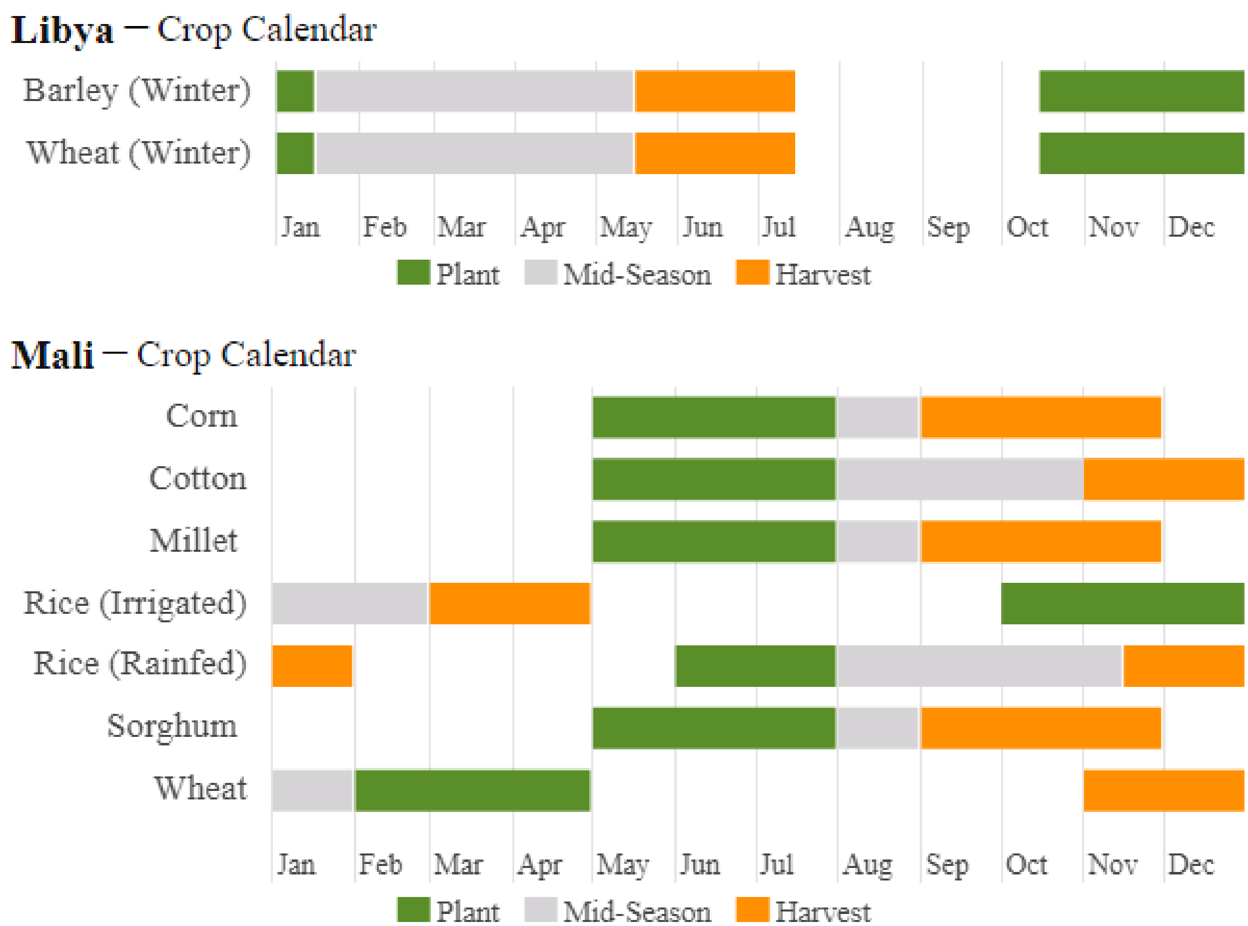
Table 5: Long-term effects of 2003-2005 locust upsurge on the risk of conflict

	(1) All cells	(2) Within 250km of swarm during upsurge	(3) Within 100km of swarm during upsurge
Any swarm in cell	-0.009**	-0.005*	-0.003
	(0.004)	(0.002)	(0.003)
Any swarm in cell previous year	-0.012**	-0.011*	-0.012
	(0.005)	(0.007)	(0.007)
Any 2003-05 swarm × Post	0.016*	0.017**	0.016**
	(0.008)	(0.008)	(0.007)
Observations	508284	320463	187953
Outcome mean, no 2003-2005 swarms	0.020	0.015	0.017
Outcome mean post-2005, no 2003-2005 swarms	0.026	0.019	0.023
Country-Year FE	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes
Swarm band and weather controls	Yes	Yes	Yes

The dependent variable is a dummy for any violent conflict event observed. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

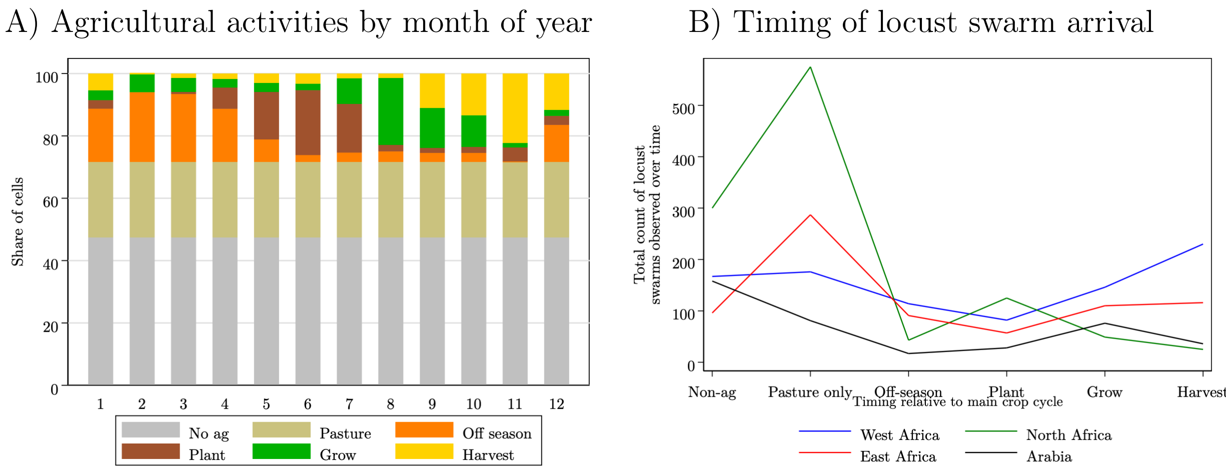
Appendix A: Additional Figures and Tables

Figure A1: Example crop calendars



Source: U.S. Department of Agriculture Foreign Agricultural Service, International Produlsion Assessment Division (USDA 2022).
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 A2: Timing of locust swarm arrival by phase of crop calendar and region



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.

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	513626
Any violent conflict event in cell in any year	0.14	0.35	0.0	0.0	0.0	0.0	1.0	513626
Any swarm in cell	0.01	0.07	0.0	0.0	0.0	0.0	1.0	513626
Any swarm within 100km outside cell	0.04	0.21	0.0	0.0	0.0	0.0	1.0	513626
Any swarm within 100-250km of cell	0.11	0.31	0.0	0.0	0.0	0.0	1.0	513626
Any swarm in cell previous year	0.01	0.07	0.0	0.0	0.0	0.0	1.0	513626
Any swarms within cell in any year	0.10	0.30	0.0	0.0	0.0	0.0	1.0	513626
Any swarms within 100 km in any year	0.56	0.50	0.0	0.0	1.0	1.0	1.0	513626
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	3.81	0.0	0.3	0.9	3.0	43.4	508292
Max annual temperature (deg C)	37.55	5.18	12.4	33.8	38.1	41.4	49.0	508292
Any cropland or pasture in cell	0.53	0.50	0.0	0.0	1.0	1.0	1.0	513626
Share of crop and pasture land in cell	0.24	0.32	0.0	0.0	0.0	0.5	1.0	502349
Any cropland in cell	0.28	0.45	0.0	0.0	0.0	1.0	1.0	513626
Share of cropland in cell	0.05	0.13	0.0	0.0	0.0	0.0	1.0	502349
Any pasture in cell	0.52	0.50	0.0	0.0	1.0	1.0	1.0	513626
Share of pasture in cell	0.19	0.27	0.0	0.0	0.0	0.3	1.0	502349

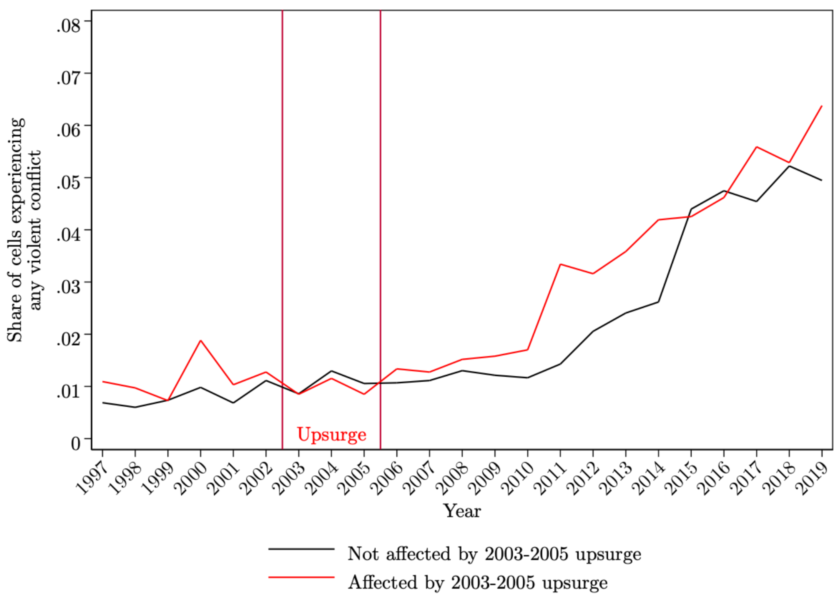
Observations are grid cells approximately $28km^2$ by year.

Table A2: Effect of locust swarms on the risk of conflict, controlling for lagged conflict

	(1) Locust swarm	(2) Locust swarm Aug.-Dec.	(3) Violent conflict	(4) Violent conflict	(5) Violent conflict, no prior yr conflict	(6) Violent conflict Aug.-Dec.	(7) Violent conflict Aug.-Dec.
Any violent conflict in cell previous year	-0.005*			0.237***			
	(0.002)			(0.046)			
Any swarm in cell previous year	-0.026***	-0.028***	-0.009*	-0.006*	-0.005	-0.006*	-0.005
	(0.009)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
Any swarm within 100km outside cell	0.076***	0.028***	-0.001	-0.002**	-0.002**	-0.002	-0.002
	(0.008)	(0.007)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Any swarm within 100km outside cell previous year	0.004**	0.000	0.004	0.004	0.005	0.005	0.004
	(0.001)	(0.001)	(0.008)	(0.007)	(0.006)	(0.006)	(0.004)
Total annual rainfall (100 mm)	0.000	-0.001	0.003*	0.003*	0.002**	0.003**	0.002***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Total annual rainfall previous year (100 mm)	-0.000	-0.000	0.003	0.002	0.002	0.001	0.001
	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Max annual temperature (deg C)	-0.001	-0.000	0.006*	0.005*	0.003**	0.004	0.002
	(0.001)	(0.001)	(0.003)	(0.003)	(0.001)	(0.003)	(0.002)
Max annual temperature previous year (deg C)	0.002	-0.001	0.005	0.004	0.002	0.005	0.004
	(0.001)	(0.001)	(0.004)	(0.003)	(0.002)	(0.003)	(0.002)
Any swarm in Aug-Dec in cell		0.107*				-0.005*	-0.002
		(0.056)				(0.003)	(0.002)
Any violent conflict event in Jan-Jul in cell		-0.002					0.277***
		(0.001)					(0.050)
Any swarm in cell			-0.015***	-0.012***	-0.008***		
			(0.005)	(0.004)	(0.002)		
Observations	508284	508284	508284	508284	499306	508284	508284
Outcome mean	0.005	0.003	0.020	0.020	0.011	0.012	0.012

Columns indicate which dummy dependent variable is used. The first two columns test impacts of prior 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 (3) replicates column (1) from Table 1. Observations are grid cells approximately 28km^2 by year. All columns include cell and country-year FEs. SEs clustered at the country level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure A3: Trend in risk of violent conflict over time, by experience of 2003-2005 locust upsurge



The figure shows the share of cells experiencing any violent conflict by year, separately for cells that did and did not experience any locust swarms during the 2003-2005 upsurge. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.

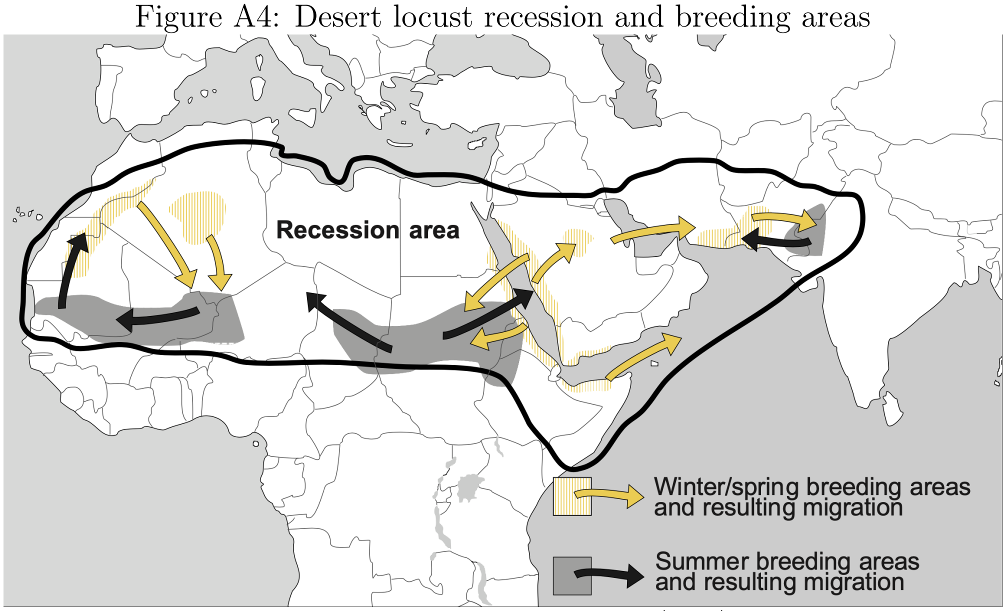
Appendix B: Desert locusts background

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). 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 A4). 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, prompting explosive reproduction (Cressman and Ferrand 2021).

Figure A4: Desert locust recession and breeding areas

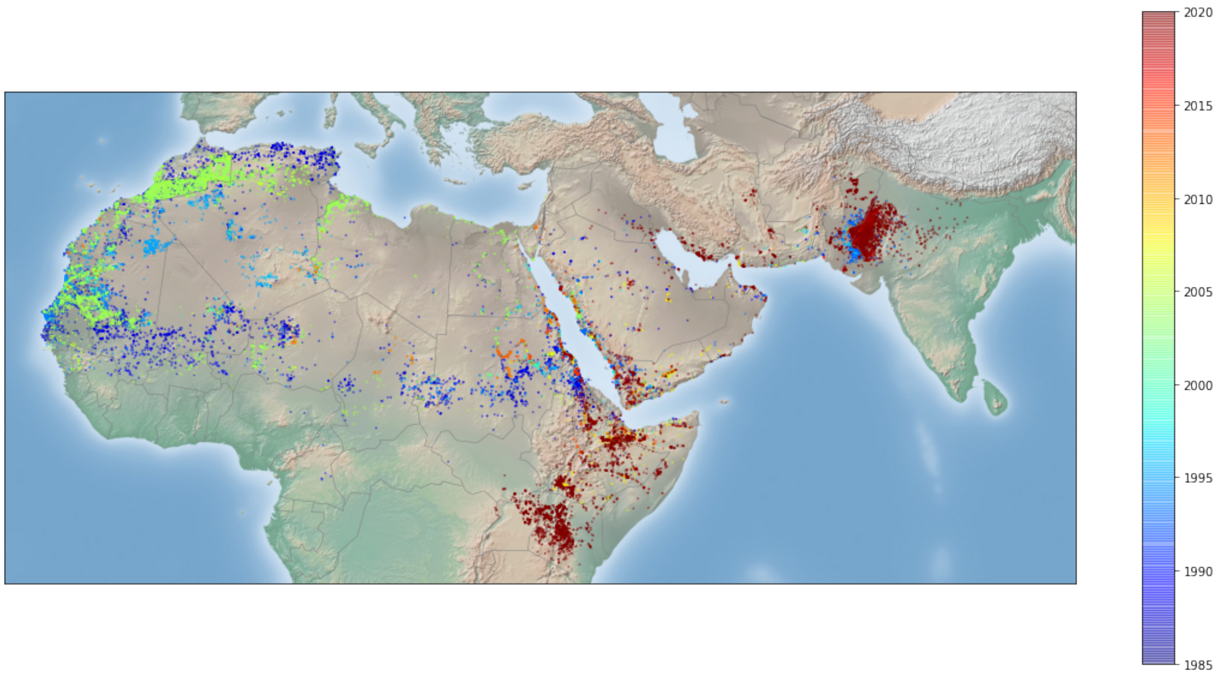


Source: Symmons and Cressman (2001)

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 (Symmons and Cressman 2001). This process typically leads 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 particularly threatening to agriculture because they fly in search of ideal feeding and reproduction location. The FAO distinguishes different levels of locust activity (Symmons and Cressman 2001). We 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.

As illustrated by Figure A5, 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 A5: Desert locust observations by year

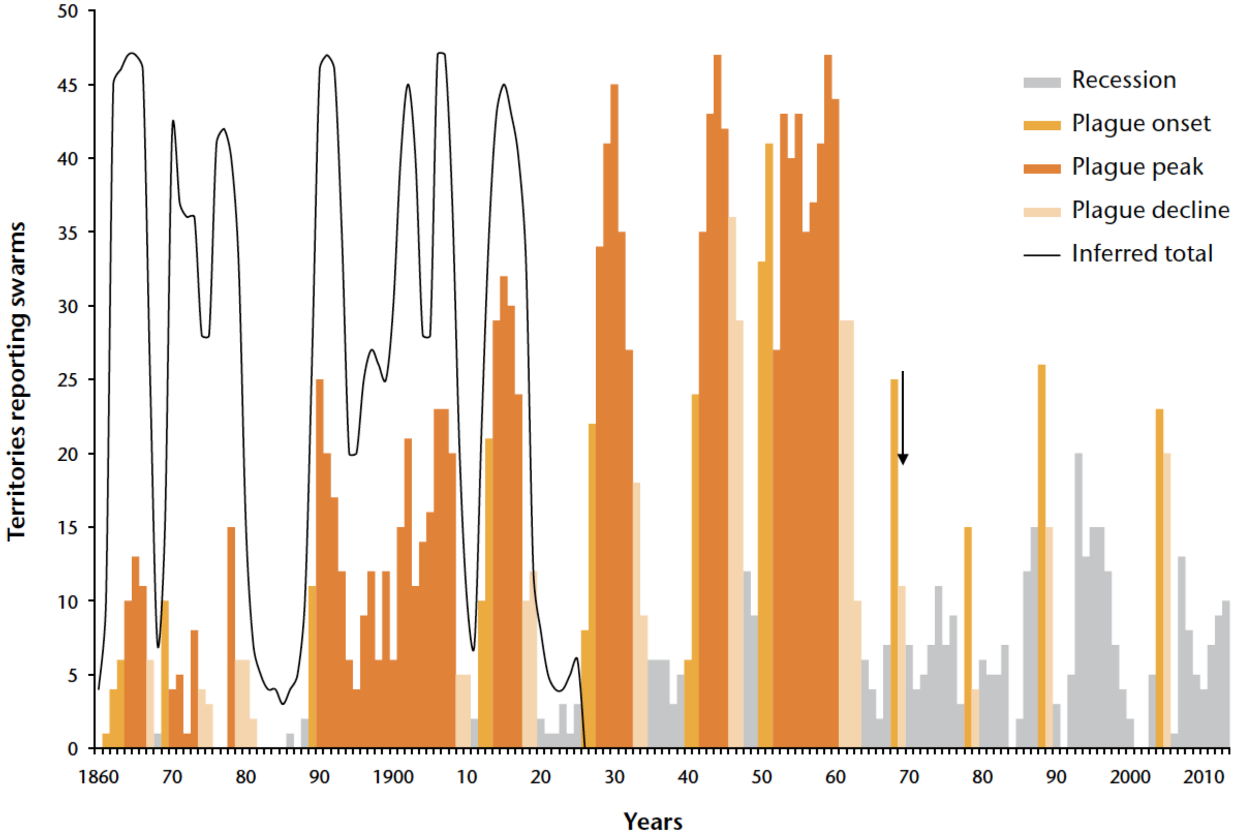


Map created by authors using swarms observations retrieved from the FAO Locust Watch database.

The frequency of large-scale outbreaks has fallen since around the 1980s, 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.

Locust outbreaks end due to a combination of migration to unfavorable habitats, failure of seasonal rains, 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. Farmers have no proven effective recourse when faced with the arrival of a locust swarm; some activities

Figure A6: Desert locust observations by year



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

such as setting fires or placing nets on crops may slow damage but have little effect on locust population (Dobson 2001; Hardeweg 2001).

Desert locust control is therefore 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, 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 creats coordination issues.

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 $1km^2$ to several hundred. It is therefore not uncommon for swarms to include over a billion locusts. Swarms fly downwind from a few hours after sunrise to an hour or so before sunset. Seasonal changes in winds tend to bring locusts to an area when rain is most likely, allowing them to continue breeding. The localized nature of locust swarm shocks stems from these patterns of swarm movements. After taking off in the morning, swarms fly downwind 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.

Appendix C: Simple model

A simple stylized model formalizing how changes to returns and opportunity costs of fighting affect conflict risk can be used to generate hypotheses about the effect of agricultural shocks on conflict. The conflict modeled here should be thought of as conflict initiated by non-state actors, as in much of the literature on agriculture shocks and conflict (Crost et al. 2018; Guardado and Pennings 2021; McGuirk and Nunn 2021; Ubilava, Hastings, and Atalay 2022). For simplicity, I focus on a static, partial equilibrium decision about time allocation with two parties.[15]

Consider a version of a simple Roy model (Roy 1951; French and Taber 2011) where two individuals[16] i and j choose their occupations to maximize net returns in a given time period. In this case, individual i decides between household agricultural work with net returns $F(S_i, X_i)$, work outside the household farm with net returns (wages) $w(X_i)$, and fighting to capture output or factors of production with net returns $R(X_i, S_j, X_j)$, where j indexes the other party. Net returns are a function of individual and location factors X[17]. Returns to agricultural production and fighting also depend on the realization of agricultural production shocks S, modeled as continuous between 0 and 1 with $S = 0$ indicating no shock and $S = 1$ indicating a shock that results in 0 agricultural production.[18] Non-farm returns do not depend on S.[19]

The returns to fighting $R(X_i, S_j, X_j)$ are the difference between expected benefits and expected costs. Benefits to i—who initiates the fighting—depend on the value of production outputs $F(S_j, X_j)$ and $w(X_j)$ and of factors of production in the held by the counterparty j, included in X_j. Factors of production, are valued based on the expected future stream of benefits from their use, bringing a long-term perspective into the static decision. The impact of agricultural shock S_j is through a reduction in the value of agricultural output that may be captured. Benefits of initiating fighting are received with some probability π of success which depends on X_i and X_j. For example, an increase in i's ability and resources relative to j increase π. Costs of fighting are incurred with certainty, and include both resource costs as well as potential social and emotional costs. If i decides to fight j, j also incurs some costs regardless of their own occupation decision. I abstract away from the possibility that j might capture resources from i following i's decision to initiate fighting.

[15] The model sets aside dynamic considerations in the decision to fight (which Chassang, Miquel, et al. (2009) show to be important) for simplicity, but we can think of the present returns to fighting in the model as incorporating long-term costs and benefits of fighting. We can also extrapolate to multiple parties, but I focus on the case of two for simplicity.

[16] We could also conceptualize the unit as representing households, communities, or other groups at which decisions to engage in conflict are made.

[17] For example, among many potential factors included in X wages will depend on education and urban setting, agricultural production will depend on farm assets (e.g., land, tools), soil characteristics, and weather, and returns to fighting will depend on individual ability, counterparty ability, and value of counterparty output.

[18] As I focus on the impact of locust swarms, I abstract away from the possibility of positive agricultural production shocks.

[19] Unlike shocks such as droughts and floods which affect agricultural production but may also affect economies and society more broadly, the literature on desert locusts indicates they have limited economic impacts outside of agriculture. The model could easily be generalized to allow non-farm wages to depend on agricultural shock with different effects for different types of agricultural shocks.

The individual's problem is to maximize returns over the choice of work sector Ag and decision to fight D

$$\max_{D,Ag} \left([F(S_i, X_i)(Ag_i) + w(X_i)(1 - Ag_i)] \cdot (1 - D_i) + R(X_i, S_j, X_j) \cdot D_i \right)$$
$$\text{subject to}$$
$$\frac{\partial F(X_i)}{\partial S_i} < 0; \quad \frac{\partial R(X_i, X_j)}{\partial S_j} < 0$$

For simplicitly and intuition I ignore uncertainty in returns. Suppose that decisions are made (or, equivalently, that they may be changed) after the agricultural shocks S_i, S_j are realized. In this scenario, the individual will choose the sector with the highest returns and will choose to fight only if the returns to fighting exceed the returns to working, or

$$Ag = 1 \text{ iff } F(S_i, X_i) > w(X_i)$$
$$D = 1 \text{ iff } R(X_i, S_j, X_j) > \max(F(S_i, X_i), w(X_i))$$

Since most individuals do not choose to fight in most time periods, even when the returns to working may be low as in the off season for poor smallholder farm households, I assume that $R(X_i, 0, X_j)$ is less than $F(0,_i)$ or $w(X_i)$ for most of the support of X_i, for example due to factors such as a low probability of success and high economic and social costs to fighting relative to the benefits.

Shock to agricultural production S_i and S_j will affect the decision to fight D only if they lead to a change in the inequality. In the case where fighting was not optimal with no agricultural shock, the opportunity cost of fighting—the returns to working in either sector—must fall below the returns to fighting. Even if $\frac{\partial F(X_i)}{\partial S_i}$ is large, returns to non-agricultural work $w(X_i)$ set a floor on how low the opportunity cost of fighting can fall following a shock S_i.

This model is ambiguous on the sign of how an agricultural shock will affect the risk of conflict in a particular area. A decrease in the returns to fighting in an area with a negative agricultural shock may deter parties from outside the area from attacking if agricutural output is a large share of the benefit from fighting. But decreased agricultural production in the area may push individuals to fight other parties nearby, even if those parties are also affected by the shock.

Opportunity costs of fighting will be lower on average following an agricultural shock, even if the shock induces some individuals to switch out of agriculture. I assume that $\frac{\partial w(X_i)}{\partial S_i} = 0$, but in the case this does not hold it is most likely that $\frac{\partial w(X_i)}{\partial S_i} < 0$, which would further decrease the opportunity costs of fighting. The returns from conflict $R(X_i, S_j, X_j)$ may also fall when S_i is larger if S_i and S_j are spatially correlated, as is the case for most weather shocks, by the decrease in agricultural output available to capture. This decrease will be limited by returns that can be obtained from the capture of factors of production and of non-agricultural output. If the fall in returns to fighting is not be as large as the fall in opportunity cost, this would imply that for some X_i—and more likely in agricultural areas when $w(X_i)$ is lower—we will have $\frac{\partial D}{\partial S} > 0$. **Hypothesis 1** is thus that agricultural shocks have a positive effect on the likelihood of conflict, on average. Rejecting this hypothesis would imply either that opportunity costs of fighting do not fall as much as expected following a shock, or that the returns to fighting fall by more than expected.

This hypothesis may be more likely to hold with locust shocks since all local vegetation is at risk of being consumed by a locust swarm, meaning $F(S_i, X_i)$ is close to 0 dramatically decreasing opportunity costs related to agriculture when S_i is a locust swarm. Locusts swarms also have limited other impacts which could reduce the returns to conflict, such as destruction of property as with floods.

An important characteristics of locust swarms is that the effect on agricultural production will depend on the timing of the swarm, with the largest effects between planting and harvest when crops are growing. Swarms should have limited effects once crops have been harvested and before they are planted, and smaller effects when crops have been planted but have not yet sprouted or could potentially be re-planted.[20] An exception might be if swarms arriving in these seasons are taken as signaling increased risk of additional swarms, which might reduce expected returns to agriculture. The destruction of agricultural output will be most catastrophic if a swarm arrives during the growing season or the start of harvest. At that point, inputs have been committed and after crops have been destroyed the returns to continuing work in agriculture for the year are nearly zero, reducing the opportunity cost of fighting. This is also the lean season when farmers have less food and cash, reducing the resources available to seek non-farm work.

We can formalize these differences by writing $0 = S_{offseason} < S_{planting} < S_{growing} < S_{earlyharvest} \approx 1$ for locust shocks, where the subscript indicates the timing of the swarm's arrival. Since $\frac{\partial F(X)}{\partial S} < 0$, this has implications for the magnitude of the production shock by swarm timing relative to the agricultural cycle. Based on these differences, if Hypothesis 1 holds then the impact of locusts on conflict should be greatest for swarms arriving during the growing season or the start of harvest when they reduce the opportunity cost related to agricultural work the most. A corrolary is that swarms should have little effect if they arrive in the off season. Rejecting this hypothesis would imply that changes in agricultural productivity alone do not explain the impacts of locust swarms on conflict.

While Hypothesis 1 is that the risk of conflict will increase with an agricultural shock, another consideration is *where* conflicts will take place. If i and j are not located in the same location, the model indicates that i's decision to fight leads to conflict in j's location, rather than i's own location. Indeed, Harari and La Ferrara (2018) show that a cell experiencing an agriculture-relevant weather shock increases the risk of conflict in neighboring cells in the same year. **Hypothesis 2** is that agricultural shocks in a particular area, having lowered the opportunity cost of fighting for individuals from that area, will increase the risk of conflict in surrounding areas as neighbors are attacked. Moreover, other parties deciding to fight would be more likely to attack a nearby unaffected area rather than a similar shock-affected area due to the different in agricultural output to capture. These conflict spillovers could lead to decreases in conflict observed in shock-affected areas, even if parties from those areas decide to engage in conflict.

Spillovers could be particularly important for desert locust swarms. Though there is spa-

[20]This assumes that annual crops such as staple grains make up the large majority of the value of agricultural production relative to perennial or tree crops and livestock. This is true for much of the sample area, but to the extent it is not that would attenuate any seasonality in the impact of swarms.

tial correlation in locust swarm events, $S_i > 0$ does not necessarily imply $S_j > 0$ for locations j near the individual at location i when S represents locust shock due to swarm movement patterns. Locusts often fly large distances between landings, creating more local variation in effects than other agricultural production shocks that typically are highly spatially correlated. This characteristic increases the likelihood that a decrease in $F(S_i, X_i)$ following a locust shock S_i reduces the opportunity cost of fighting sufficiently relative to $R(X_i, S_j, X_j)$ to make fighting optimal for i, creating an ideal setting for evaluating conflict spillovers.

An alternative possibility not captured in the model is that if S_i is large but $S_j = 0$ or is small, j could make a transfer to i conditional on i not attacking, in the same way that aid and relief often arrives in communities following agricultural shocks. Such a transfer could prevent conflict if it is larger than the returns to fighting for i and could be rational for j if it is below the cost it would incur if i attacked.

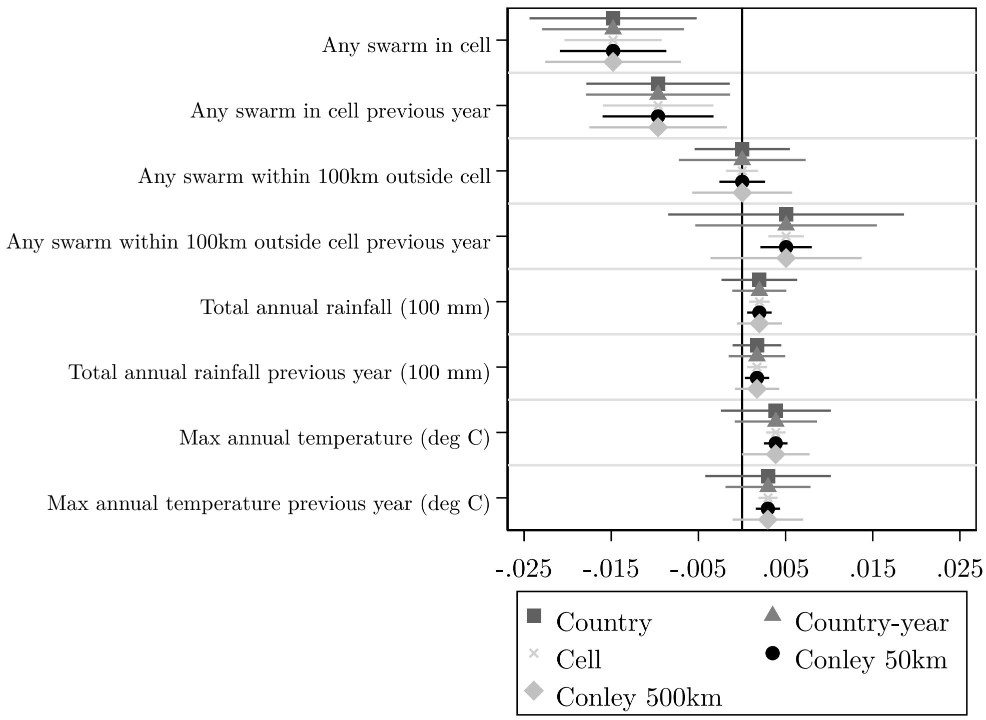
Finally, agricultural shocks may also have long-term impacts on the risk of conflict, though evidence of persistence more than one year after a shock is limited (Crost et al. 2018; Harari and La Ferrara 2018).Short-term impacts operate through the immediate agricultural productivity shock, but agricultural shocks might also affect long-term productivity. The model allows for long-term effects if we think of agricultural assets A for example as one of the X variables affecting agricultural production $F(S, X)$, and make current assets a function of past agricultural shocks. In the simplest sense, we would thus have $F(S_t, A_t(S_{t-s}), X_t)$, with $\frac{\partial F(S_t, X_t)}{\partial A_t} > 0$ and $\frac{\partial A_t}{\partial S_{t-s}} < 0$. Following this argument, **Hypothesis 3** is that impacts of agricultural shocks on conflict in an area persist in the long term but decrease over time as affected areas recover. Rejecting this hypothesis would imply that agricultural shocks do not have a persistent effect on agricultural productivity large enough to make fighting optimal. Another possibility is simply that affected individuals do not stay in the same area, breaking the connection between the shock and local conflict.

The arrival of a locust swarm does not increase the likelihood of locust damages in future years or otherwise change local agricultural fundamentals. In addition, locust damages are concentrated on vegetation, unlike shocks such as floods which might affect future productivity by damaging production infrastructure. On the other hand, the damages to agricultural production from locust swarms are severe, and individual efforts to cope with and recover from the locust shock might permanently affect their agricultural productivity. In particular, households that sell assets or send members away to cope with short-term livelihood and food security issues—common coping strategies—could end up with a persistently lower stock of productive assets, reducing productivity and lowering the opportunity cost to fighting. Given the catastrophic nature of locust destruction, the impact on the individual's assets $|\frac{\partial A_t}{\partial S_{t-s}}|$ might be particularly large, thus resulting in meaningful reductions in the opportunity cost of fighting related to agricultural production in time periods following a locust swarm's arrival. Since this is paired with no (or limited[21]) reduction in the current returns to fighting from past locust swarms, this would make affected areas more likely to decide to engage in conflict and more vulnerable to conflict following future agricultural shocks.

[21] Future returns to fighting would fall to the extent agricultural production is also persistently lower following a past swarm.

Appendix D: Robustness

Figure A7: Estimated coefficients from Equation 1 with different SEs



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 28km^2 by year. Regressions also include country-year and cell FE.

Table A3: Effect of swarms on the risk of conflict, varying controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Any swarm in cell	-0.009	-0.010	-0.009	-0.015***	-0.015***	-0.013***	-0.013**
	(0.008)	(0.006)	(0.008)	(0.005)	(0.005)	(0.004)	(0.006)
Any swarm within 100km outside cell		0.001			-0.001	-0.001	-0.003
		(0.004)			(0.002)	(0.001)	(0.002)
Any swarm in cell previous year			-0.008		-0.009*	-0.007*	-0.008
			(0.005)		(0.004)	(0.004)	(0.006)
Any swarm within 100km outside cell previous year					0.004	-0.000	0.008
					(0.008)	(0.002)	(0.009)
Observations	562539	562539	562539	508284	508284	507922	508284
Adj-R^2	0.316	0.316	0.316	0.320	0.320	0.385	0.275
Outcome mean, no swarms	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Proportional effect of swarms	-0.449	-0.485	-0.455	-0.773	-0.755	-0.685	-0.659
Swarm Bands	No	Yes	No	No	Yes	Yes	Yes
Swarm Lags	No	No	Yes	No	Yes	Yes	Yes
Weather	No	No	No	Yes	Yes	Yes	Yes
Time FE	Cntry-year	Cntry-year	Cntry-year	Cntry-year	Cntry-year	Region-year	Year
Location FE	Cell	Cell	Cell	Cell	Cell	Cell	Cell

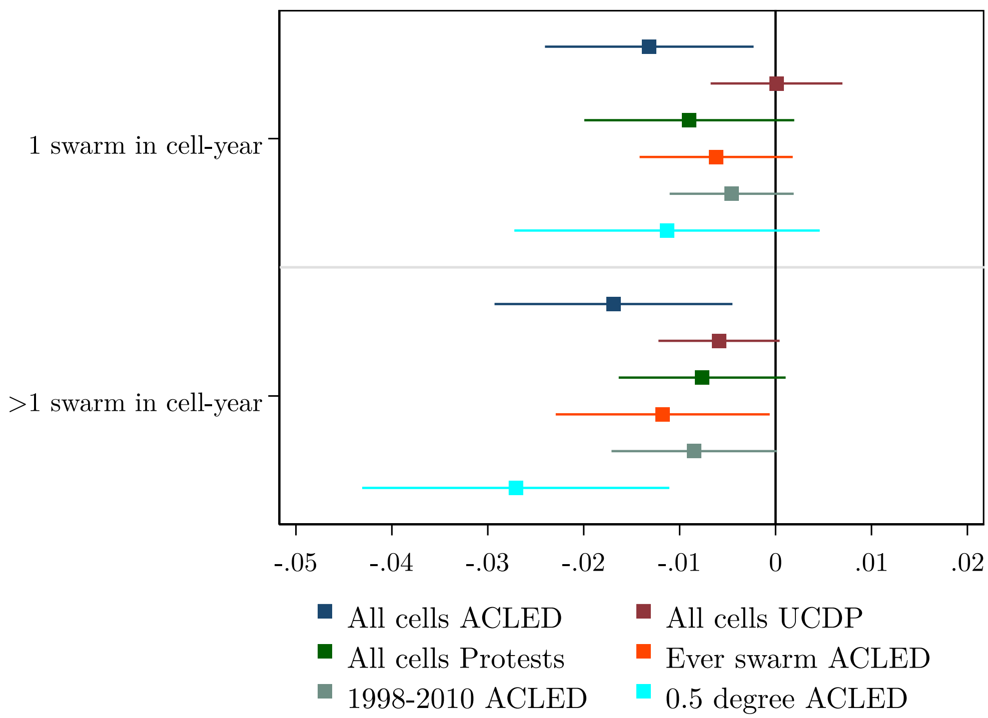
The outcome variable is a dummy for any violent conflict observed. The main independent variable is a dummy for any locust swarms observed. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A4: Effect of swarms on the risk of conflict, omitting particular years and regions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Any swarm in cell	-0.015***	-0.010***	-0.007**	-0.023	-0.013**	-0.016**	-0.018**	-0.013***
	(0.005)	(0.003)	(0.003)	(0.026)	(0.006)	(0.006)	(0.006)	(0.004)
Any swarm in cell previous year	-0.009*	-0.004	0.000	-0.011	-0.006	-0.012**	-0.009	-0.007
	(0.004)	(0.003)	(0.002)	(0.011)	(0.004)	(0.005)	(0.006)	(0.005)
Any swarm within 100km outside cell	-0.001	-0.003**	0.001	-0.017	-0.001	-0.002	-0.000	-0.002
	(0.002)	(0.001)	(0.002)	(0.012)	(0.002)	(0.002)	(0.002)	(0.002)
Any swarm within 100km outside cell previous year	0.004	0.003	-0.000	0.009	0.006	0.009	0.006	-0.004*
	(0.008)	(0.007)	(0.001)	(0.013)	(0.010)	(0.010)	(0.011)	(0.002)
Total annual rainfall (100 mm)	0.003*	0.002*	0.000	0.002	0.004	0.001	0.004	0.004*
	(0.002)	(0.001)	(0.001)	(0.003)	(0.002)	(0.001)	(0.003)	(0.002)
Total annual rainfall previous year (100 mm)	0.003	0.002	0.002	0.002	0.004**	0.000	0.002	0.003
	(0.002)	(0.002)	(0.001)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Max annual temperature (deg C)	0.006*	0.005**	0.004	0.003	0.009	0.005	0.008	0.004*
	(0.003)	(0.002)	(0.003)	(0.006)	(0.006)	(0.004)	(0.005)	(0.002)
Max annual temperature previous year (deg C)	0.005	0.004	0.002	0.004	0.009	0.005	0.006	0.002
	(0.004)	(0.003)	(0.002)	(0.008)	(0.007)	(0.005)	(0.006)	(0.003)
Observations	508284	435679	314663	217842	348010	399918	350581	426342
Outcome mean, no swarms	0.020	0.015	0.010	0.011	0.022	0.012	0.024	0.021
Proportional effect of swarms	-0.755	-0.637	-0.627	-0.613	-0.598	-1.295	-0.736	-0.613
Regions	All	All	All	All	No N. Africa	No E. Africa	No W. Africa	No Arabia
Years	All	1998-2015	1998-2010	2010-2018	All	All	All	All

The dependent variable is a dummy for any violent conflict event observed. Column (1) replicates column (1) from Table 1. Columns 2-5 restrict the sample of to different time periods. Columns 6-8 restrict the sample of geographies by dropping selected regions from the analysis. Observations are grid cells approximately 28km^2 by year. All columns include cell and country-year FEs. SEs clustered at the country level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure A8: Impacts of one vs. multiple swarms in a year on violent conflict risk



The figure shows 95% confidence intervals for estimates of the main regressions specification replacing the swarms dummy with dummy variables for either 1 swarm observed in a year or more than 1 swarm, across different outcomes and specifications. The outcome variables are all dummy variables for either ACLED or UCDP violent conflict or for ACLED protests/riots. The legend also indicates what subset of cells is considered for the analysis. Observations are 0.25° grid cells—approximately 28km^2—by year except where 0.5° cells are specified. Regressions also include controls for swarm lags and bands, for weather, and country-year and cell FE.

Table A5: Effect of swarms on different conflict outcomes

	N	Control Mean (SD)	Any swarm (SE)
Any violent conflict event - ACLED	508284	0.020	-0.015***
		(0.139)	(0.005)
Any violent conflict event - UCDP	508284	0.010	-0.003*
		(0.100)	(0.002)
Any violent state conflict - ACLED	508284	0.013	-0.011***
		(0.114)	(0.004)
Any violent state conflict - UCDP	508284	0.007	-0.001
		(0.086)	(0.002)
Any violent non-state conflict - ACLED	508284	0.013	-0.010***
		(0.112)	(0.004)
Any violent state conflict - UCDP	508284	0.002	0.000
		(0.042)	(0.001)
Any violent one-sided conflict - ACLED	508284	0.011	-0.010***
		(0.106)	(0.004)
Any violent one-sided conflict - UCDP	508284	0.002	-0.001
		(0.049)	(0.001)
Any protest or riot event - ACLED	508284	0.010	-0.008**
		(0.098)	(0.004)
Total fatalities - ACLED	508284	0.695	-1.000*
		(52.139)	(0.511)
Total fatalities - UCDP	508284	0.475	-1.772
		(83.310)	(1.807)

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 nearby swarm and weather controls along with country-year and cell FE. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A6: Effect of swarms on the risk of conflict at different scales, taking means over swarm and conflict events

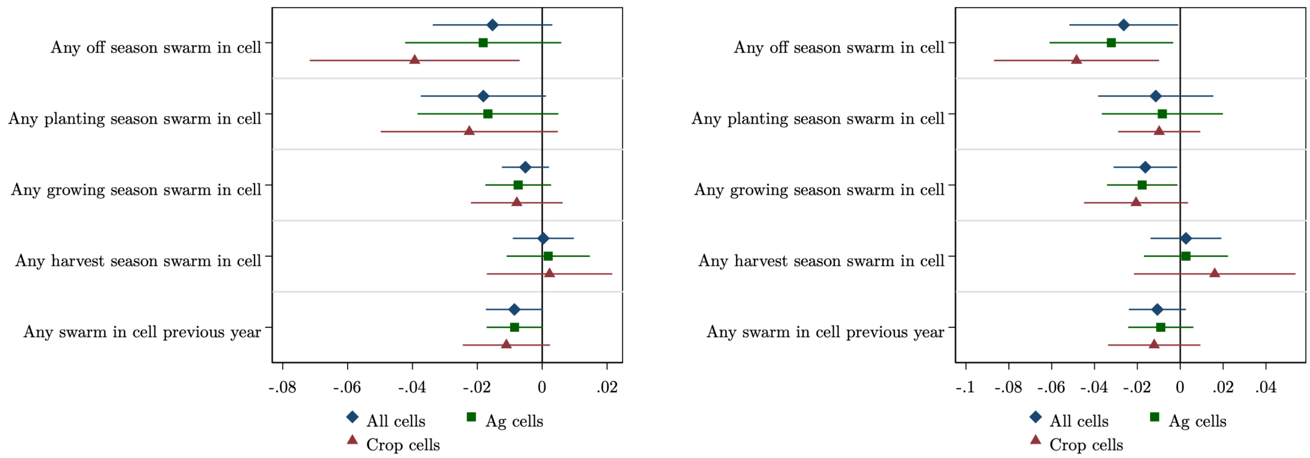
	(1) 0.25 deg	(2) 0.5 deg	(3) 1 deg	(4) 2 deg	(5) 5 deg	(6) Country
Any swarm in cell	-0.015***	-0.017**	-0.018*	-0.029*	-0.013	-0.002
	(0.005)	(0.007)	(0.010)	(0.015)	(0.018)	(0.037)
Any swarm in cell previous year	-0.009*	-0.010	-0.016	-0.048*	-0.074	-0.020
	(0.004)	(0.008)	(0.019)	(0.028)	(0.046)	(0.044)
Any swarm within 100km outside cell	-0.001					
	(0.002)					
Any swarm within 100km outside cell previous year	0.004	0.007	0.009	0.015	0.025	0.016
	(0.008)	(0.009)	(0.010)	(0.012)	(0.016)	(0.016)
Total annual rainfall (100 mm)	0.003*	0.003	0.003	0.002	0.004*	0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)
Total annual rainfall previous year (100 mm)	0.003	0.002	0.002	0.003	0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)
Max annual temperature (deg C)	0.006*	0.005*	0.003**	-0.001	-0.000	-0.006
	(0.003)	(0.003)	(0.002)	(0.001)	(0.001)	(0.004)
Max annual temperature previous year (deg C)	0.005	0.004	0.002	-0.001	-0.002*	-0.006
	(0.004)	(0.004)	(0.002)	(0.001)	(0.001)	(0.003)
Observations	508284	139342	40823	13312	3673	483
Outcome mean, no swarms	0.020	0.020	0.022	0.023	0.023	0.032
Country-Year FE	Yes	Yes	Yes	Yes	Separate	Separate
Cell FE	Yes	Yes	Yes	Yes	Yes	No

The dependent variable is the share of 0.25 degree cells in the aggregated area with any violent conflict event in a year. Similarly, swarm presence variables are the share of 0.25 degree cells in the aggregated area with any swarm in a year. Weather controls are means for total annual rainfall and max annual temperature across cell-years within the aggregated area. Column (1) replicates Column (1) from Table 1. Subsequent columns incrementally increase the size of the spatial units in the analysis. Observations are grid cells of particular size (in terms of degrees) in Columns (1) to (5) and countries in Column (6), in a particular year. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure A9: Effect of swarms on the risk of conflict by season and land cover, by cell size

A) 0.25° cells

B) 0.5° cells

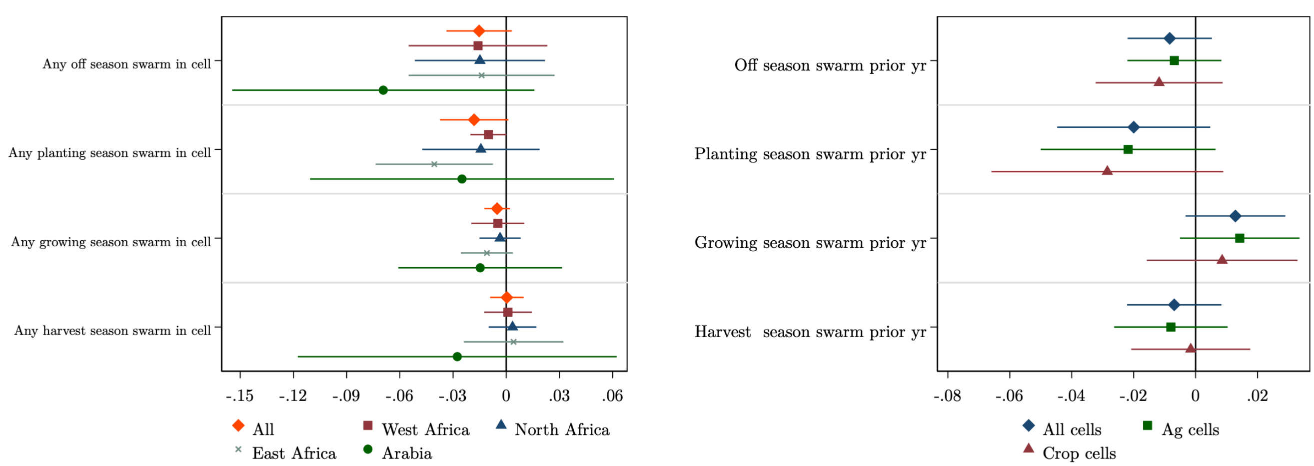


The figure shows 95% confidence intervals for estimates from Table 4 by land cover in 2000. The outcome variable is a dummy for any violent conflict observed. Observations are grid cells by year, where in panel A we consider the baseline sample of 0.25° cells—approximately 28km^2—and in panel B we consider 0.5° cells—approximately 56km^2. Regressions also include controls for locusts in surrounding areas and weather as well as country-year and cell FE.

Figure A10: Seasonal effect of swarms on the risk of conflict, by region and prior year

A) Impacts by region

B) Impacts of prior year swarms

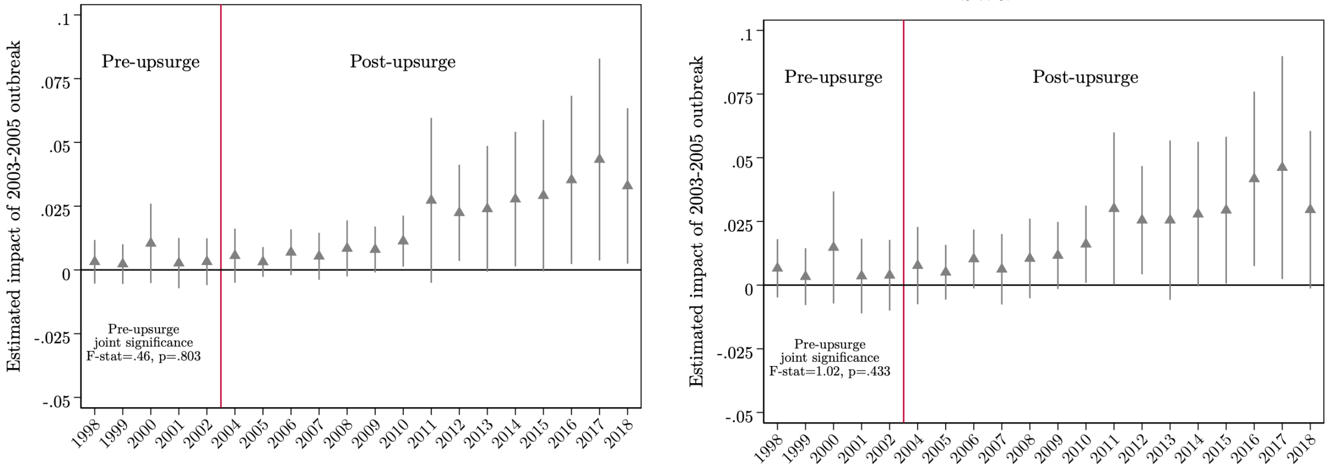


The figure shows 95% confidence intervals for estimates from Table 4 by region (Panel A) and for swarms the prior year by land cover in 2000 (Panel B). The outcome variable is a dummy for any violent conflict observed. Observations are grid cells approximately 28km^2 by year. Regressions also include controls for locusts in surrounding areas and weather as well as country-year and cell FE.

Figure A11: Effect of 2003-2005 upsurge on the risk of conflict by year in subsamples of cells

A) Cells within 250km of an upsurge swarm

B) Agricultural cells within 250km of an upsurge swarm

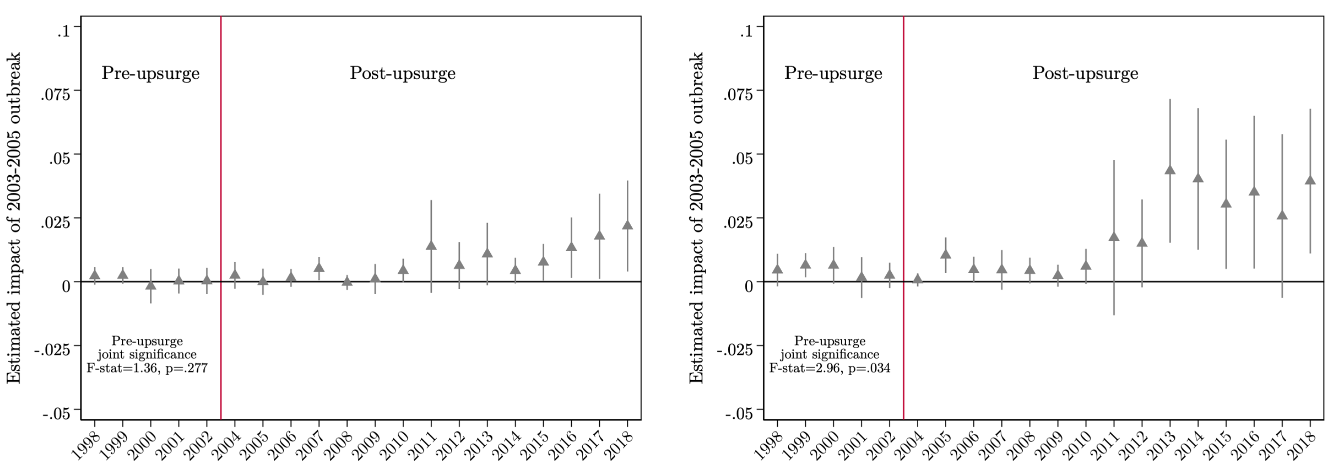


The dependent variable is a dummy for any violent conflict event observed. Coefficients are for the interaction of a dummy for being in a cell that had any swarm between 2003-2005 with year. The reference year is 2003, indicated by the red line. Bars represent 95% confidence intervals. The regression includes controls for current swarms, weather, and cell and country-by-year FE. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.

Figure A12: Effect of 2003-2005 upsurge on different definitions of conflict by year

A) UCDP violent conflict (>25 fatalities in year)

B) ACLED protests and riots



The dependent variable is a dummy for any conflict event observed, where the definition of conflict in indicated in the panel. Coefficients are for the interaction of a dummy for being in a cell that had any swarm between 2003-2005 with year. The reference year is 2003, indicated by the red line. Bars represent 95% confidence intervals. The regression includes controls for current swarms, weather, and cell and country-by-year FE. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.