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

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Abstract

This paper tests whether income-related mechanisms commonly cited in the literature are sufficient to explain impacts of severe agricultural shocks on the risk of violent conflict. I identify causal impacts of agricultural shocks using exogenous local variation in exposure to desert locust swarms driven by swarm flight patterns together with weather controls and location and country-by-year fixed effects for annual grid cell observations across Africa and the Arabian peninsula from 1997-2018. Locust swarms decrease the likelihood of violent conflict events in a given year by around 20%, with larger effects in areas that had been experiencing conflict. Effects are driven by agricultural areas, and there is no evidence of conflict spillovers to nearby areas. These impacts suggest that a reduced incentive for predatory conflict outweighs reduced opportunity costs of fighting in the short term on average. Despite the short-term conflict suppression, cells affected by the 2003-2005 major desert locust upsurge are 62% more likely to experience violent conflict in a given year afterward. The increased conflict risk is not realized until after 2008 when the frequency of conflicts increases in the sample countries. This pattern suggests persistent decreases in agricultural productivity leading to reduced opportunity costs of fighting, and highlights the importance of the broader conflict environment to determine the impact of agricultural shocks on conflict.

JEL codes: Q54; D7; Q10; O13; N57
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1 Introduction

A growing literature explores the effects of agricultural shocks on the risk of conflict[1], with particular attention to Africa where the number of conflict events has been increasing rapidly since the late 2000s. Violent conflicts negatively affect societies in a wide variety of ways, including health and mortality, displacement and forced migration, destruction of productive resources, psychological trauma, increased uncertainty and risk, and more. Understanding the relationship between agricultural shocks and conflict 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, a particularly destructive transitory agricultural shock.

Using data on the location and timing of desert locust swarm observations from the Food and Agricultural Organization of the United Nations and of conflict events from the Armed Conflict Location & Event Data Project, 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 together with variation in swarm presence within locations over time 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.[2]

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.

[1]Burke, Hsiang, and Miguel (2015) and Koubi (2019) offer reviews of the literature on climate and conflict. Dube and Vargas (2013), Harari and La Ferrara (2018), Maystadt and Ecker (2014), McGuirk and Burke (2020), and Miguel, Satyanath, and Sergenti (2004) are prominent examples of papers focusing on the impacts of agricultural shocks in particular. I discuss additional recent papers in Section 2.

[2]Torngren Wartin (2018) uses similar methods to estimate impacts of desert locusts on conflict in Africa, focusing on potential measurement issues.

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%. This result contrasts with much 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. Estimated effects of swarms are largest in agricultural areas, and in cells with some cropland in particular as expected if swarms affect conflict risk through destruction of agricultural production.

The negative effects of swarms are not driven by displacement of conflict to nearby areas: effects on conflict are largely local with no significant spillovers into surrounding areas up to 500km away. Torngren Wartin (2018) also explores the impacts of desert locusts on conflict risk, and argues that negative impacts are due to measurement error in locust observations that is correlated with conflict risk, as insecurity may reduce the probability that swarms are reported in an area. I argue that locust swarms are less likely to suffer from such reporting error than smaller groups of locusts and show that the negative impacts of swarms are robust to controlling for recent and surrounding conflict, indicating the results are not driven by measurement error or reverse causality.

I also 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. This pattern is robust to various restrictions on the set of unaffected cells included in the analysis, and suggests persistent adverse effects of this agricultural disaster over time. The impact of the upsurge on conflict risk does not become significant until after 2008 after which it increases in magnitude over time, concurrent with a general increase in conflict risk in the sample countries over this period.

I interpret these results through the lens of a simple model of occupation choice which formalizes the mechanisms most commonly discussed in the economic literature on agricultural shocks and conflict: changes in opportunity costs related to agriculture and returns to fighting over agricultural output (or 'predation'). Negative short-term impacts of swarms on local conflict risk suggest the predation effect outweighs the opportunity cost effect, which may be the case for locust swarms and not for other agricultural shocks explored in the literature because of the extreme destruction caused by locusts. Swarms particularly decrease the probability of violent conflict in areas that experienced such confiict the previous year and in areas with conflict in neighboring cells, consistent with destruction of agricultural output reducing incentives for predatory conflict to extend over time and space. The pattern of long-term impacts similarly emphasizes the importance of the broader conflict environment in determining impacts of an agricultural shock on conflict risk. Effects of the 2003-2005 locust upsurge suggest persistent decreases in agricultural productivity leading to reduced opportunity costs of fighting, but this only translates into increased conflict risk locally once conflicts have been initiated by other proximate causes. Long-term increases in conflict risk are driven by increases in years and areas with increased local conflict.

Seasonal patterns in the impacts of locust swarms also help shed light on how the opportunity cost and predation effects interact. The negative average impact of swarms on conflict at the annual level in the short term is driven largely by swarms that arrive in the local off-season or planting season for major crops. Reduction in opportunity cost are therefore limited in comparison with reductions in perceived returns to fighting in the locust-affected area, so the predation mechanism drives reduced conflict risk. This combination can similarly explain the negative impacts of locust swarms the previous year on current conflict. In contrast, swarms arriving during the growing and harvest period have no statistically significant effect. Agricultural destruction is greatest in these periods so reduces both the opportunity cost of and the returns to fighting, which cancel each other out to have no significant effect on conflict risk on average. The pattern of results is similar across regions with very different crop calendars. Differences in long-term impacts by seasonal timing of swarms during the 2003-2005 upsurge are noisier but suggestive of larger effects for swarms that arrived in cells with cropland during the crop growing season. This is consistent with effects operating through persistent decreases in productivity following an initial agricultural production shock, though the results also indicate locusts may affect conflict risk through other mechanisms.

These results emphasize that changes in agricultural opportunity costs alone do not determine how adverse agricultural shocks affect the risk of conflict. In particular, the broader conflict environment matters, but other factors may also influence the opportunity costs of and net returns to fighting following an agricultural shock. Opportunity costs related to non-agricultural work, including the possibility of migration, should receive more attention. Other factors less frequently discussed in the economic literature on agricultural shocks and conflict such as psychological impacts, social cohesion, relief efforts, and the broader social and policy environment also likely play important roles.

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, I find that an extreme agricultural shock decreases the short-term risk of conflict locally, 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 seasonality in conflict (Crost et al. 2018; Guardado and Pennings 2021; Hastings and Ubilava 2023; 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, but may be explained by less variable impacts on perceived returns to fighting. How an agricultural shock affects conflict risk is therefore not necessarily a simple function of the impact on opportunity costs related to agriculture; the broader conflict environment influences the predation mechanism and plays an important role.

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. Importantly, impacts are not realized until the frequency of conflict begins rising more generally in the sample countries, indicating that natural disasters may have long-term consequences that depend on future economic and social conditions.

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), De Vreyer, Guilbert, and Mesple-Somps (2015), and Torngren Wartin (2018)). 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. Although short-term conflict risk is suppressed, long-term increases in conflict risk indicate persistent vulnerablity of areas affected by locust swarms.

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 presents a simple model of how occupational choice, including the decision to fight, depends on agricultural shocks through income-related mechanisms. Section 4 discusses the data used in the analyses and Section 5 outlines the empirical approaches. Section 6 shows and discusses the results on short-term impacts of swarms on conflict, spatial spillovers, agricultural destruction and seasonality, and long-term impacts. Section 7 discusses the results through the frame of the simple model, and Section 8 concludes.

2 Background

2.1 Desert locusts

Damages from desert locust (*Schistocerca gregaria*) swarms—the world's most dangerous and destructive migratory pest (Cressman, Van der Elstraeten, and Pedrick 2016; Lazar et al. 2016)—can be extreme.Locusts consume any available vegetation, and swarms frequently lead to the total destruction of local agricultural output (Showler 2019). 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). These impacts on agricultural production, food security, and population movements may directly push affected populations to engage in violent behavior or make them more open to joining armed groups engaged in fighting.

Small numbers of locusts are always present in desert 'recession' areas from Mauritania to India, posing little threat to livelihoods.[3] 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 which move as a cohesive unit (Symmons and Cressman 2001). In this paper I focus exclusively on locust swarms, which form when bands of locusts remain highly concentrated when they reach the adult stage and become able to fly. This formation of swarms can lead to 'outbreaks' or 'upsurges'where locusts spread from their desert breeding areas. Few locust swarms are observed outside of major outbreaks, as conditions favoring swarm formation tend to produce large swarms which reproduce and spread rapidly and are very difficult to control.

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; Thomson and Miers 2002). The only current viable method of swarm control is direct spraying with pesticides (Cressman and Ferrand 2021, which can take days to have

[3] 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.

effects as well as being slow and costly to organize and requiring robust locust monitoring infrastructure.Control operations are most effective before locust bands reach the adult stage and form swarms, but this requires extensive monitoring activities.

Locust swarms vary in density and extent. The average swarm includes around 50 locusts per m^2 and can cover tens of square kilometers, including billions of locusts (Symmons and Cressman 2001). About half of swarms exceed 50km^2 in size (FAO and WMO 2016). Swarms fly for 9-10 hours each day, from a few hours after sunrise to an hour or so before sunset when they land and feed. They fly downwind and can easily move 100km or more in a day even with minimal wind (FAO and WMO 2016).[4] These movement characteristics inform efforts to predict locust swarm movements, but these remain highly imprecise (Latchininsky 2013).

Swarm flight patterns result some areas in the swarm's flight path being spared any agricultural destruction. This can be seen in Figure 1 by many areas with no reported swarms even in countries with large numbers reported 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.

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

[4] Swarms do not always fly with prevailing winds and may wait for warmer winds which lead to seasonal breeding areas (FAO and WMO 2016).

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), Dell, Jones, and Olken (2012), and Koubi (2019) for reviews), generally finding that deviations from historical norms increase conflict risk.

Though some studies have pointed to physiological, 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 income mechanisms from changes in agricultural productivity and opportunity costs of conflict, in line with the Chassang and Padró i Miquel (2009) and Dal Bó and Dal Bó (2011) models. Many studies find support for the argument that impacts of agricultural shocks on 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), generally referred to the predation or rapacity mechanism.

Both mechanisms are common to the literature on the sources of conflict more generally (see e.g., Blattman and Miguel 2010; Chassang and Padró i Miquel 2009; Collier and Hoeffler 1998, 2004; Dal Bó and Powell 2009; Dal Bó and Dal Bó 2011; Fearon 1995; McGuirk and Burke 2020), with a small number of studies finding evidence for both. Dube and Vargas (2013) study the impacts of changes in prices of export goods in Colombia on conflict. They find that a fall in (labor-intensive) coffee prices reduced wages and increased conflict in coffee-producing municipalities in Colombia, consistent with an opportunity cost effect, while an increase in (not labor-intensive) oil prices increased municipal revenue and conflict in oil-producing areas, consistent with a rapacity effect. Hastings and Ubilava (2023) analyze how conflict in Southeast Asia changes during the rice harvest months. They find that protests and riots decrease, consistent with increased opportunity costs for rice producers, while violence against civilians increases, consistent with predation against rice producers. Importantly, the opportunity cost effect holds across all years, but the predation effect is only observed in periods with increased conflict more generally. McGuirk and Nunn (2021) show how agricultural shocks in pastoral regions of Africa can lead to conflict spillovers. They report that droughts in the territory of transhumant pastoralists (reducing the returns to pastoralism in these areas) increase conflict risk in neighboring agricultural areas where the returns to predation are greater. These papers largely focus on conflict initiated by non-state actors, as the opportunity cost effect matters for individuals generally engaged in agricultural production while the predation effect is most relevant for militants or insurgents.

The majority of studies of the impact of agricultural shocks on conflict focus on impacts within the same time period. 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 Conceptual framework

A stylized model of occupational choice can generate hypotheses about the effect of agricultural shocks on conflict through the two most commonly discussed channels: opportunity cost and predation. 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. For simplicity, I focus on a static, partial equilibrium decision with two parties.[5]

Consider a simple Roy model (Roy 1951; French and Taber 2011) where two individuals[6] i and j choose their occupations to maximize net returns in a given time period. Individual i decides between agricultural production with net returns $F(S_i, X_i)$, non-agricultural work with net returns (wages) $w(S_i, S_j, X_i)$, 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. This follows the general structure of the Dal Bó and Dal Bó (2011) model and is similar to the Becker (1968) framework where individuals choose between a productive sector and a criminal sector.

Net returns to all activities depend on individual and location factors X.Agricultural shocks S affect the returns to agricultural production—the opportunity cost mechanism—as well as the returns to fighting to the extent that agricultural output is an important share of the resources that could be captured—the rapacity or predation mechanism. Non-agricultural returns may also depend on S if the shock has more general economic effects beyond reducing agricultural production.[7]If we assume returns to non-agricultural work are less affected by agricultural shocks, this sets a lower bound on how far the opportunity cost of fighting may fall following a negative agricultural shock. I allow $w()$ to vary with the neighbor's agricultural shock to reflect that some non-agricultural opportunities may involve migrating to work. In what follows I suppress the dependence of w on S for illustration.

The benefits to i of deciding to fight j depend on the value of j's production outputs $F(S_j, X_j)$ and $w(X_j)$ and factors of production included in X_j. Benefits of initiating fighting

[5]The model sets aside dynamic considerations in the decision to fight (which Chassang and Padró i Miquel (2009) show to be important), 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.

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

[7]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.

are received with some probability π of success which depends on X_i and X_j. 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 also incurs costs regardless of their own occupation decision.

Let S fall between -1 and 1 with $S = 0$ indicating no shock, $S = -1$ indicating a strongly positive shock to agricultural production, and $S = 1$ indicating a strongly negative shock. The individual's problem is to maximize returns over the choice of work sector Ag and decision to fight D given some shock realizations S_i, S_j[8]

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

The individual will choose the sector with the highest returns and will 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 $F(0, X_i)$ 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.

Shocks to agricultural production S will affect the decision to fight D only if they lead to a change in the inequality. If fighting is not optimal with no agricultural shock, a negative shock must push the opportunity cost of fighting—the returns to working in either sector—

[8] For simplicitly and intuition I ignore uncertainty in returns and suppose that decisions are made after the agricultural shocks are realized.

below the returns to fighting to make conflict optimal. But 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 a negative agricultural shock will affect the risk of conflict in a particular area. An individual experiencing a negative agricultural shock is less likely to be attacked by a neighbor due to decreased returns to predation, but is more likely to attack their neighbor due to decreased opportunity costs related to agriculture. The different mechanisms would be magnified if the two parties' shocks are negatively correlated. Which effect dominates depends on many factors.

With desert locust shocks all local vegetation is at risk of being consumed by the swarm, meaning $F(S_i, X_i)$ is close to 0—dramatically decreasing opportunity costs related to agriculture. The decreased in opportunity cost may be especially important in this context given the labor intensive nature of agriculture (Dal Bó and Dal Bó 2011). Locusts swarms also have limited other impacts which could reduce the returns to conflict beyond decreased returns from agricultural output, such as destruction of property as with floods. In addition, locust swarms create local variation in damages due to their flight patterns, meaning neighboring areas may have different locust shock realizations. This could make unaffected locations near locust-affected areas more of a target for conflict through the predation effect.

Based on the literature, these characteristics suggest two hypotheses: first, that the opportunity cost effect will dominate and locust shocks will increase conflict risk in general, and second, that conflict will increase more in areas neighboring those affected by locusts. Rejecting these hypotheses would imply that the opportunity costs of fighting do not fall by more than the returns following a locust shock, or that other mechanisms not captured in the model are more important for the decision to fight..

Another important characteristic 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. An exception might be if swarms arriving in the off or planting seasons are taken as signaling increased risk of additional swarms, which might reduce expected returns to agriculture. If the opportunity cost effect dominates, this suggests that effects on conflict should be greatest for swarms arriving during the growing season or the start of harvest when they most affect the opportunity cost related to agriculture. A corollary is that swarms should have little effect if they arrive in the off season. Rejecting these hypotheses would imply that changes in agricultural productivity alone do not explain the impacts of locust swarms on conflict.

While the simple model focuses on short-term impacts of agricultural shocks through immediate changes in agricultural productivity, agricultural shocks might also affect long-term productivity. The model can allow for long-term effects if we consider some of the X variables affecting agricultural production $F(S, X)$ a function of past agricultural shocks. For example, we could have agricultural assets A depend on prior S and write $F(S_t, A_t(S_{t-s}), X_t)$, with $\frac{\partial F(S_t, X_t)}{\partial A_t} > 0$ and $\frac{\partial A_t}{\partial S_{t-s}} < 0$.

The arrival of a locust swarm does not change the likelihood of locust damages in future years or otherwise affect local agricultural fundamentals. On the other hand, individual efforts to cope with and recover from a locust shock might reduce their future 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 might be particularly large, thus resulting in persistent reductions in the opportunity cost of fighting related to agricultural production. If reduced opportunity costs dominate the reduced returns from capturing agricultural output, we would expect increases in conflict risk following locust shocks to persist in the long term. Rejecting this hypothesis would imply that locust shocks do not have a persistent effect on agricultural productivity large enough to make fighting optimal.

4 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.[9]

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.Analyzing impacts at this spatial level allows me to leverage local variation in swarm presence created by their flight patterns. As about half of locust swarms exceed 50km^2 in extent, I test for robustness to analyzing data at the level of 0.5° cells (approximately 56km^2). I determine the country and highest subnational administrative level in which each cell lies using country boundaries from the Global Administrative Areas (2021) database v3.6.

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)

[9]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.

(2022).[10] 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.[11] 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, 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

[10] 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.

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

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]

5 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 $°C$), and 1 year lags of locust swarms, rainfall, and max temperature.[12] Standard errors (SEs) are clustered at the country level to allow for correlation in the errors within countries.[13]

This fixed effects model is similar to Fjelde (2015), Harari and La Ferrara (2018), McGuirk and Nunn (2021), 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 inclusion of lagged weather variables. The country-year fixed effects flexibly control for factors varying over time at the country level that might

[12] Results are robust to including squared current and prior year temperature and rainfall terms.

[13] 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.

affect conflict and the impact of locust swarms, such as the policy environment and national economic and social conditions. These fixed effects importantly control for trends in conflict risk, which increases over the sample period for most sample countries. The cell fixed effects control for time invariant cell characteristics, such as topography, agricultural suitability, 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 production, the likelihood of experiencing a swarm, 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.

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 C. 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

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

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.

6 Results

6.1 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 C1). 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.[14]

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 C1). Results are robust to varying the size of cells up to the level of 2 degree cells (Table 3), 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 C2). Results are similar when considering alternative measures 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 C3).[15]

[14]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.

[15]The impact of locust swarms on conflict when using UCDP data is only significant when considering

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 C2).

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).These results suggest that measurement error in locust observations correlated with conflict (resulting in reverse causality) does not drive the negative effect of locust swarms on conflict.

The negative impacts of locust swarms on violent conflict risk results suggest the predation mechanism outweighs the opportunity cost mechanism in this setting, though it may also suggest displacement of conflict which I explore further in the following section. Hastings and Ubilava (2023) observe that the predation mechanism following an agricultural shock may be most relevant in settings with some ongoing conflict: they find that the onset of rice harvest in Southeast Asia only increases violence against civilians in periods with existing conflict. In this setting, the predation mechanism would suggest locust swarms particularly reduce the risk of violent conflict in periods here such conflict has already been occurring.

Table 2 shows the estimates from fully interacting all right-hand side variables with a lagged version of the conflict outcome variable. Prior conflict increases the probability of any

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.

conflict event, particularly for protests and riots. In areas where there was no conflict the previous year, locust swarms decrease conflict risk for both violent conflict and protests or riots, but in areas with conflict the previous year, impacts of swarms differ by conflict type. The effect of violent conflict the previous year on conflict in the current year is nearly halved if a locust swarm occurs. Similarly, conflict in January-July of the same year increases conflict in the remainder of the year by less in areas experiencing locust swarms in those months, though the difference is not statistically significant. The point estimates also suggest that rainfall and temperature deviations decrease the effects of lagged violent conflict on current conflict, though these effects are not significant either. These results are broadly consistent with negative agricultural shocks reducing the motive for predation particularly in areas at prior risk of predation.

[Table 2 here]

In contrast, for protest or riot events the point estimates for the interaction of such events the previous year with locust swarms or rainfall deviation are positive, though again not statistically significant. This is consistent with the predation mechanism being less relevant for protests and riots, which may instead be particularly affected by changes in agricultural opportunity costs.

6.2 Spatial spillovers

The results so far suggest the predation mechanism may be more important than the opportunity cost mechanism in explaining the impact of locust swarms, but the opposite signs for the impacts of swarms and weather deviations on the risk of violent conflict in areas without prior conflict presents a puzzle. One possible explanation for the decrease in conflict risk in cells affected by locust swarms could be spatial conflict spillovers, if conflict is displaced to surrounding areas. Showler (2019) report instances of resource-based conflicts between farmers and pastoralists (similar to what McGuirk and Nunn (2021) report following droughts)as a consequence of population movements caused by the 2003-2005 locust upsurge in West Africa, indicating potential for such 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. The existence of nearby unaffected areas may be more likely for locust swarms due to the local variation created by their flight patterns, compared to highly spatially correlated rainfall and temperature. The predation motive could be particularly large for areas spared by swarms since years with locust outbreaks are typically more productive agriculturally, as the rainfall shocks in locust breeding areas leading to 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.

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.[16]

[Figure 3 here]

Table 2 further shows that the impact of locusts in the area around a cell on conflict

[16] 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.

within the cell does not vary by whether there was any conflict in the cell the previous year, when conditions might be most amenable to predatory attacks. The point estimates for the interaction of locusts around the cell and prior year violent conflict are positive but very noisy.

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 3 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. In addition to testing for potential spillovers, analysis at more aggregated spatial levels also controls for the possibility that large locust swarms exceed the boundaries of the 0.25° cells in which they are reported in the FAO data.

[Table 3 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 C4). 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.

These results indicate that if the negative effect of locust swarms on conflict risk is driven by the predation mechanism through decreased returns to fighting in locust-affected areas, such predatory conflict is not being displaced to surrounding areas.

6.3 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 4 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).[17] Point

[17]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). Xiong et al. (2017) report that from 2003-2014 croplands increased by 1 Mha per year on average. As a result, some areas with cropland will be inaccurately classified as non-agricultural in this analysis based on land cover

estimates for cells with no crop land or pasture land are negative but not significant.

[Table 4 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 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) and Hastings and Ubilava (2023) show that the onset of harvest reduces conflict risk by changing the opportunity cost in Afghanistan, Iraq, and Pakistan and in Southeast Asia, respectively. 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 5 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

in 2000, which would reduce the estimated difference in impact by cell land cover. Resuts in Table 4 are similar when definining crop cells as those with any cropland in either Ramankutty et al. (2010) or Xiong et al. (2017).

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 5 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 C3), 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 C4). 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.

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 C3). 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.

Table 5 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.[18] The results do not appear to be consistent with either the predation or opportunity cost mechanisms.

[18] 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 C4). 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.

Controlling for whether swarms arrive in other seasons of the year,[19] swarms arriving in the off season should have a limited effect 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.

Another possibility is that off-season swarms may affect expectations about returns to different activities. Predation by actors in surrounding areas may be deterred by reduced expected returns to fighting in an area where locusts have appeared. Conversely, farmers may increase their engagement in agriculture if they think an early locust swarm indicates a potentially productive year provided no further swarms arise, increasing perceived opportunity costs of fighting.

I test this using data on crop cultivation for 2003-2014 across Africa from Xiong et al. (2017) which uses an automated cropland mapping algorithm based on 250m resolution MODIS NDVI data and ground-based training samples. Seasonal patterns in locust swarm impacts on violent conflict are similar in crop cells in this time period as over the full sample (Table A3). Off-season swarms do not significantly change the share of cell area classified as fallow or cultivated, and the estimated magnitudes are relatively small. This pattern holds for swarms arriving in other parts of the agricultural cycle, though at those times cultivation decisions are already made so we would not expect significant impacts. Swarms in the

[19] 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 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.

growing season are associated with larger increases in fallowing and decreases in cultivation. Since the land use data are based on NDVI measures, this may reflect crop destruction by locusts rather than actual differences in land use since impacts of locusts on NDVI should be largest if they arrive in the growing season. Satellite-based measures of land use therefore do not suggest any change following the arrival of off-season locust swarms, though this may still be occurring in ways not capturing by the algorithm.

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 in much of the economics literature.

6.4 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 6 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 6 here]

This result suggests that locust swarms decrease the opportunity cost of fighting in the long term.[20] 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 variety of measures to cope with short-term food security and livelihood effects of locust outbreaks (Thomson and Miers 2002). In addition to seeking help from social netowrks and food aid, households commonly report selling animals and other assets, sending household members away, and consuming seed stocks as 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

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

the current and prior year. Consequently, there are no significant impacts of the upsurge in 2004 and 2005, the main years of the upsurge.[21]

[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 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). From 1997-2005 there is a 1.0% probability of any violent conflict event at the annual level across all sample cells, while from 2006-2018 the probability increases dramatically to 3.1%. Consequently, 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 percentage 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 C5). The pattern of increasing conflict risk over time also holds when using different definitions of conflict (Figure C6). There is a clear long-term increase in conflict risk in areas affected by the upsurge, particularly after 2010.

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

7 Discussion

The short-term impacts of locusts provide strong evidence that negative agricultural productivity shocks need not increase the risk of conflict, in contrast to most of the economic literature on this topic. Focusing on income-related mechanisms, the negative effect of a locust swarm on the short-term probability of conflict in an area suggests that the returns to fighting fall by more than the opportunity cost of fighting, making it a less attractive decision. This could be the case if a large share of the conflict in areas affected by locusts is predation over agricultural output, which is greatly reduced following a locust swarm, and is consistent with smaller magnitude effects of prior year conflict on current year violent conflict in areas affected by locusts. Negative effects of swarms the previous year on conflict risk would also be consistent with the predation mechanism. Harvests most commonly take place late in the year in the sample countries, meaning crop destruction by locusts would decrease agricultural output in the following year as well until the next harvest.

Patterns in impacts of swarms by timing of arrival relative to the agricultural cycle, however, do not align with expectations based on the predation mechanism. Decreases in conflict risk are larger for off and planting season swarms than for growing and harvest season swarms, despite locusts doing more damage to crops in these latter seasons. The smaller effects in growing and harvest seasons could reflect offsetting effects from reduced returns to fighting over agricultural outputs and from reduced returns to continuing work in agricultural production. If the reduced opportunity cost related to agricultural production is similar to the reduced returns to fighting over agricultural output, an increase in conflict initiated by affected farmers might cancel out a decrease in conflict initiated by external predators. But the large negative effects of off and planting season swarms on conflict risk cannot be explained by reduced agricultural output driving down the returns to fighting, implying another mechanism is in play.

Negative effects of locust swarms on local conflict risk are not explained by conflict spillovers. This is consistent with the literature on locust outbreaks which typically characterizes the impact of a locust swarm as a localized disaster (Joffe 2001; Hardeweg 2001; Krall and Herok 1997; Lecoq 2001), but contrasts with recent studies reporting conflict spillovers following weather shocks (Harari and La Ferrara 2018; McGuirk and Nunn 2021). Individuals engaged in agriculture in locust-affected areas should see their opportunity cost of fighting fall, and returns to fighting will be higher in neighboring unaffected areas than locally. Despite both of these mechanisms pointing to increased conflict risk in surrounding areas, locust swarms have no significant spillover effects.

Even though returns to conflict will be greater in unaffected areas around locations affected by locusts, potentially attracting predatory conflict, individuals residing in those areas should be less likely to initiate conflict given the greater average agricultural productivity in years with locust swarms due to the associated weather conditions (Hardeweg 2001). These offsetting impacts could lead to no change in the probability of conflict in areas surrounding cells affected locust swarms.

Indeed, the opportunity cost of fighting related to agricultural production is likely to be greater in years with many locust swarms in all locations spared by the swarms. Individuals affected by locust swarms, whose opportunity cost of fighting does fall, may be unable to mobilize around existing fighting groups if these are less active due to greater opportunity costs elsewhere during periods of locust outbreaks. The spatial variation in impacts of locust swarms may therefore limit spillovers in comparison to other agricultural shocks, such as price decreases or droughts, which affect opportunity costs and returns to fighting in similar ways across broader spatial areas.

The importance of the broader conflict environment, as noted in Hastings and Ubilava (2023), is emphasized by both the difference in short-term impacts on conflict by existence of conflict the previous year and by patterns in the long-term impacts of locust swarms on conflict risk. If swarms affect conflict risk through persistent changes in opportunity costs, it is not evident why impacts should not materialize until several years after the major 2003-2005 locust upsurge rather than being similar or decreasing over time. Increases in conflict risk due to the upsurge are significant and increase in magnitude after 2008, when violent conflicts began to occur more frequently in the sample countries. While the 2003-2005 locust upsurge is unlikely to be directly causing any of the spreading violent conflicts in this time period, by decreasing agricultural productivity in the long term it may have made affected areas more vulnerable to engaging in these conflicts given some other more proximate precipitating events. Decreasing the opportunity costs of fighting related to agriculture may not be sufficient to increase conflict risk until other factors—such as the possibility of joining active armed groups—push the net returns to fighting upward, or later shocks further decrease the returns to agriculture.

Another important consideration often overlooked in studies of agricultural shocks and conflict is that the opportunity cost of fighting also depends on the returns to non-agricultural activities. If locust-affected households have some alternative livelihood strategies when their agricultural production is destroyed, this puts a lower bound on how far the opportunity cost of fighting can fall. The reduced returns to fighting from agricultural destruction may then decrease the likelihood of engaging in conflict. Alternative livelihood strategies could include engaging in non-farm labor, migrating, or relying on relief and aid from governments, non-profits, or friends and family.

A desire to maintain peace so that relief can be delivered to locust-affected areas could help explain negative effects of swarms on conflict in the current and subsequent year. Locust outbreaks are high-profile events that attract a great deal of international attention, and relief efforts from a wide variety of national and international actors target affected areas in response to food insecurity concerns.

Anecdotal evidence indicates that migration, both to urban areas and to surrounding agricultural areas, is a common response to locust crop destruction (The World Bank 2020). This indicates that migration is a better outside option following an agricultural shock than fighting for many households. The departure of people from locust-affected areas may decrease the risk of conflict as there are fewer people to potentially engage in fighting. Though violent conflict does also occur in many low-density parts of Africa, cell population is positively and significantly correlated with the risk of violent conflict in the sample. While out-migration may increase the likelihood of conflict in nearby areas if it increases competition over local output and resources (as in McGuirk and Nunn (2021)), to the extent locusts are driving out-migration the evidence indicates that this is not leading to conflict spillovers.

Seasonality in returns to non-agricultural labor opportunities may contribute to larger decreases in conflict risk for off and planting season swarms. By the growing and harvest seasons, farmers have invested large amounts into their farm, may have taken on debt for inputs, and may also be short on food stores. Migrating or finding non-farm employment at that time may be difficult. So opportunity costs of fighting fall following locust swarms in these seasons but this is offset by the large fall in returns to fighting over agricultural output. Even if locust destruction in the off and planting seasons is limited, farmers may see swarms in these seasons as indicating an increased risk of swarms later in the agricultural cycle and choose to switch into non-farm employment. Individuals may be better able to shift out of agriculture if they can do so earlier in the agricultural cycle when they have more remaining food and income stores, have not invested as much into agricultural production, and have more time to obtain returns before returning to their farm the following year. This would imply that opportunity costs might not fall by as much following swarms in these seasons, and are outweighed by expected reductions in returns to fighting. I do not find evidence of significantly increased fallow or decreased cultivated crop area in years with off-season locusts swarms, but this may be due to limitations in the satellite-based land use measures and to difficulties separate changes in land use from impacts of locust destruction on agriculture.

This discussion highlights the limitations of focusing exclusively on changes to opportunity costs and returns to fighting related to agriculture. Considering the role of non-agricultural work in putting a floor on opportunity costs of fighting is particularly important when the opportunity cost and predation mechanisms affect conflict risk in opposite ways. Even with increased attention to non-agricultural work, however, the simple model of conflict outlined in this paper is limited as it does not account for other important factors, such as psychological responses, policy responses, or social bonding, which could also affect the likelihood of conflict following an agricultural shock.

8 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. 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. 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 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. Persistent decreases in agricultural productivity may reduce the opportunity cost of joining militant groups when these become active but not otherwise affect conflict risk.

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 by reducing opportunity costs of fighting, 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 weighing the costs and benefits of locust monitoring and control operations.

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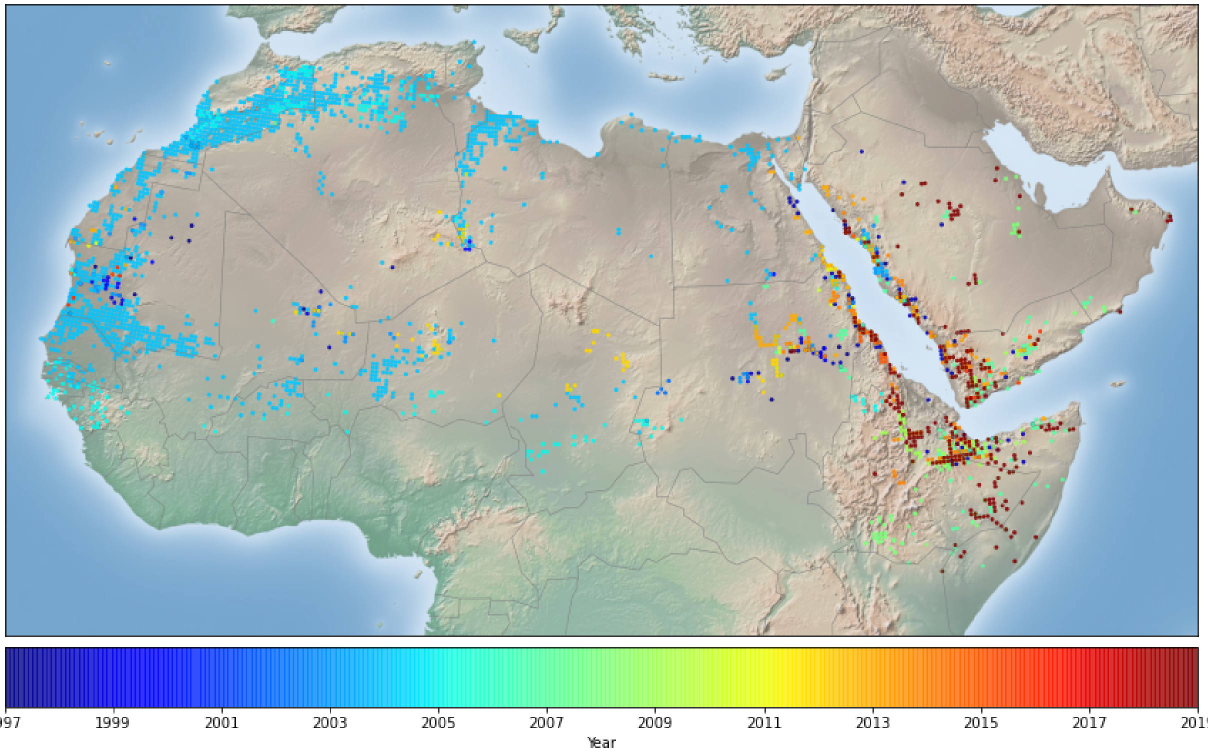
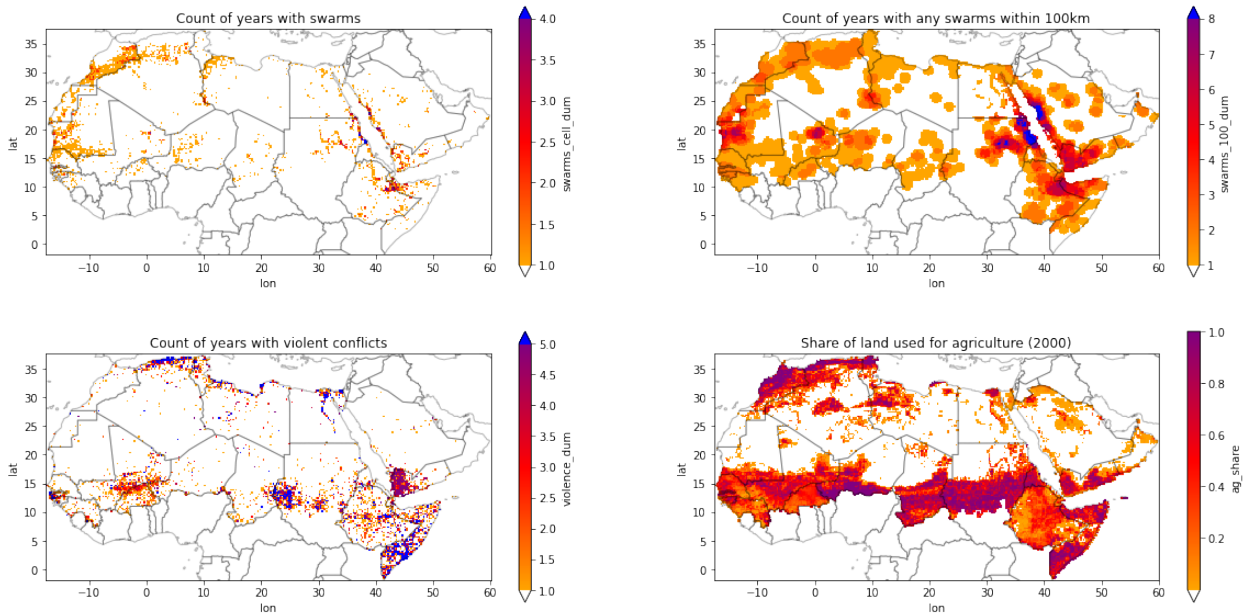
Figures

Figure 1: Desert locust observations by year, study period



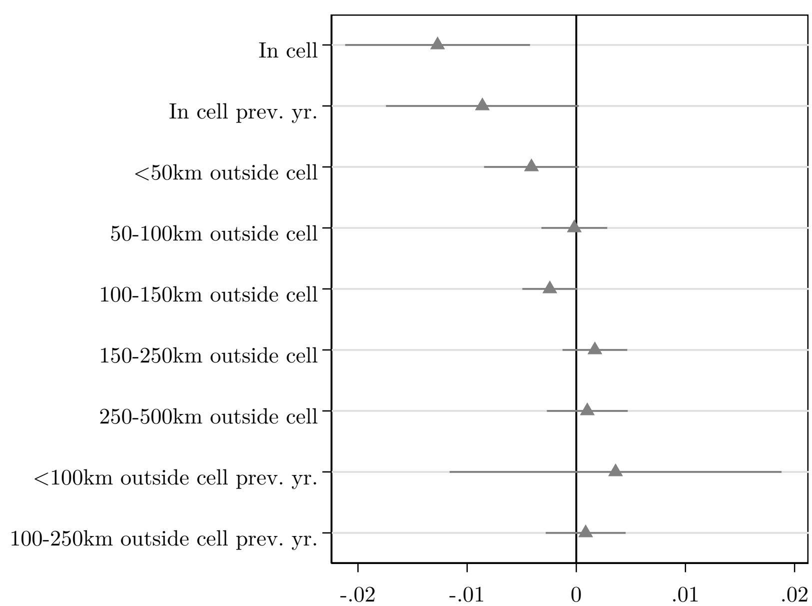
Map created by authors using swarms observations retrieved from the FAO Locust Watch database.

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



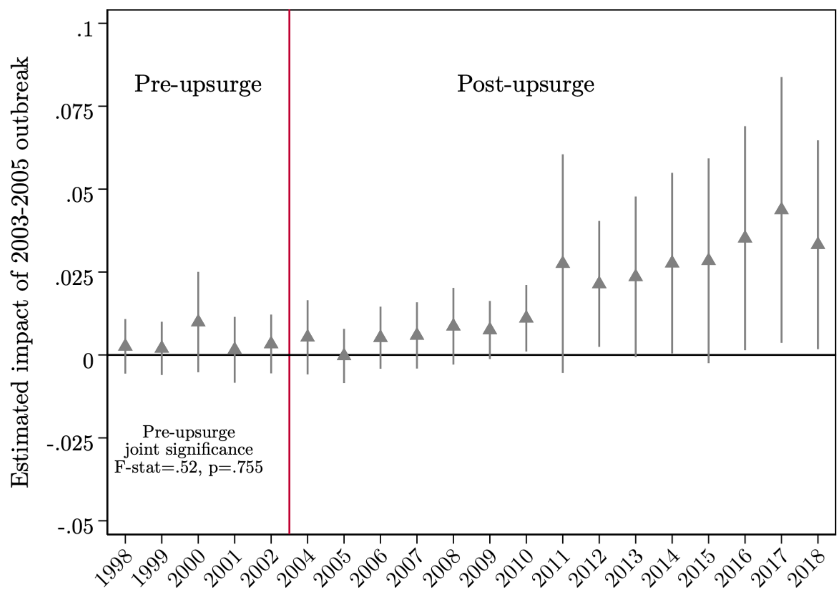
Land used for agriculture includes crop land and pasture land. This panel shows most clearly which countries in West, Central, and East Africa are excluded from the study sample.

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 C1.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Effect of locust swarms on the risk of conflict, by prior conflict

Outcome	(1) Violent conflict	(2) Violent conflict Aug.-Dec.	(3) Protest or riot
Any conflict event lag	0.330	0.531^{**}	0.677^{***}
	(0.276)	(0.214)	(0.126)
Any swarm in cell	-0.008^{***}	-0.005^{**}	-0.006^{*}
	(0.003)	(0.003)	(0.003)
Any swarm in cell ×	-0.141^{*}	-0.076	0.039
Any conflict event lag	(0.071)	(0.066)	(0.093)
Any swarm within 100km outside	-0.002	-0.002^{**}	-0.000
cell	(0.002)	(0.001)	(0.001)
Any swarm within 100km outside	0.016	0.055	-0.074
cell × Any conflict event lag	(0.098)	(0.114)	(0.070)
Total annual rainfall (100 mm)	0.003^{**}	0.002^{***}	0.002^{**}
	(0.001)	(0.001)	(0.001)
Total annual rainfall (100 mm)	-0.011	-0.004	0.021
× Any conflict event lag	(0.009)	(0.005)	(0.016)
Max annual temperature (deg C)	0.005^{**}	0.002	0.004^{***}
	(0.002)	(0.001)	(0.001)
Max annual temperature (deg C	-0.009	-0.024^{***}	-0.001
× Any conflict event lag	(0.008)	(0.006)	(0.008)
Observations	508284	508284	508284
Outcome mean	0.020	0.012	0.010
Swarm bands	Yes	Yes	Yes
Swarm and weather lags	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes
Country-year FE	Yes	Yes	Yes

Columns indicate which dummy dependent variable is used. In columns (1) and (2) the outcomes are any violent conflict and any protest or riot event, respectively, and the lagged versions are for any of the same type of conflict event the previous year. In column (3), the outcome is any violent conflict between August and December of the year, and the lagged version is for any violent conflict between January and July the same year. Observations are grid cells approximately 28km^2 by year. All columns include cell and country-year FEs and additional controls as in the main specification, fully interacted with the conflict lag. SEs clustered at the country level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: 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 C4. 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 4: 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 5: 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.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

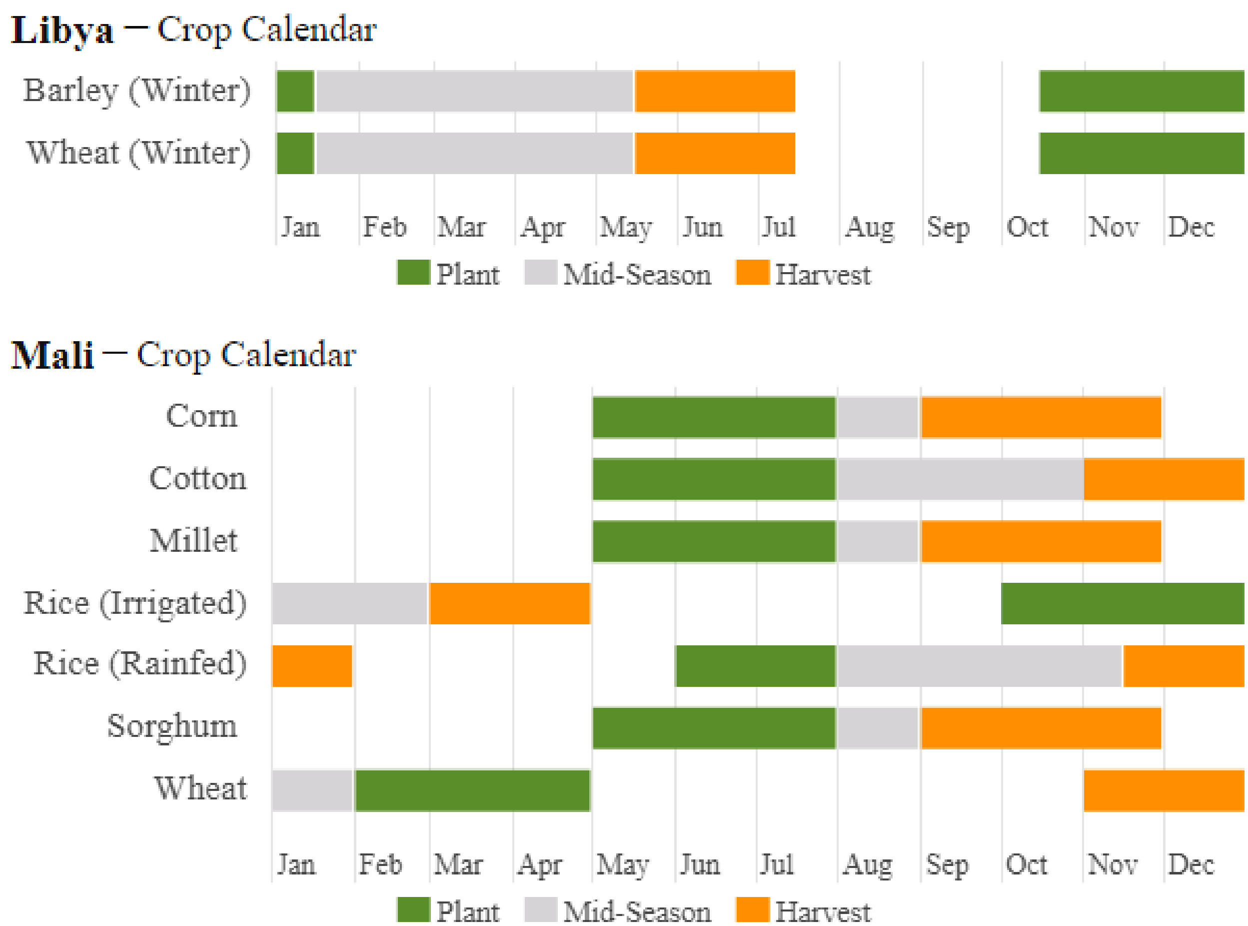
Table 6: Long-term effects of 2003-2005 locust upsurge on the risk of conflict

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

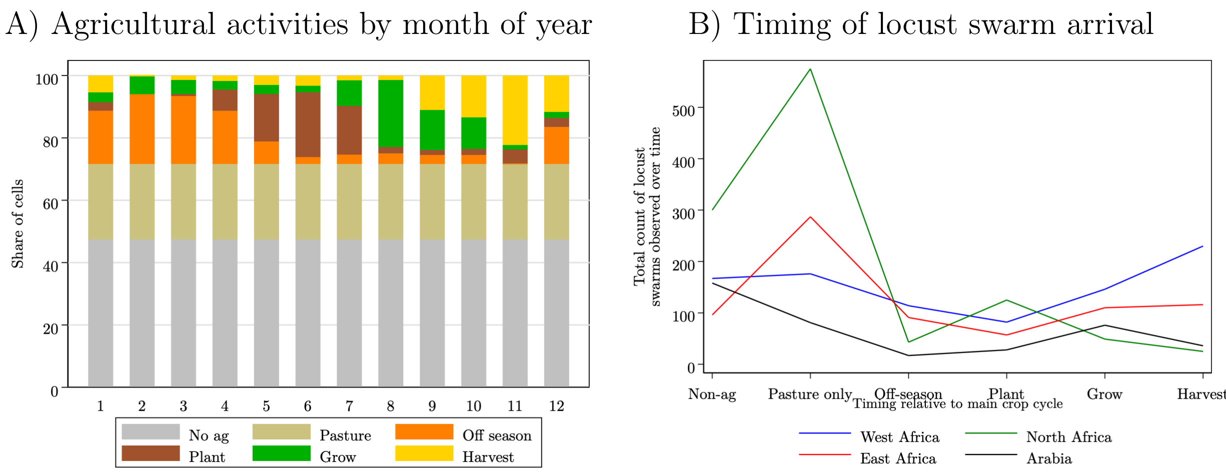
Appendix A: Additional Figures and Tables

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)
Any swarm in Jan-Jul 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
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

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.

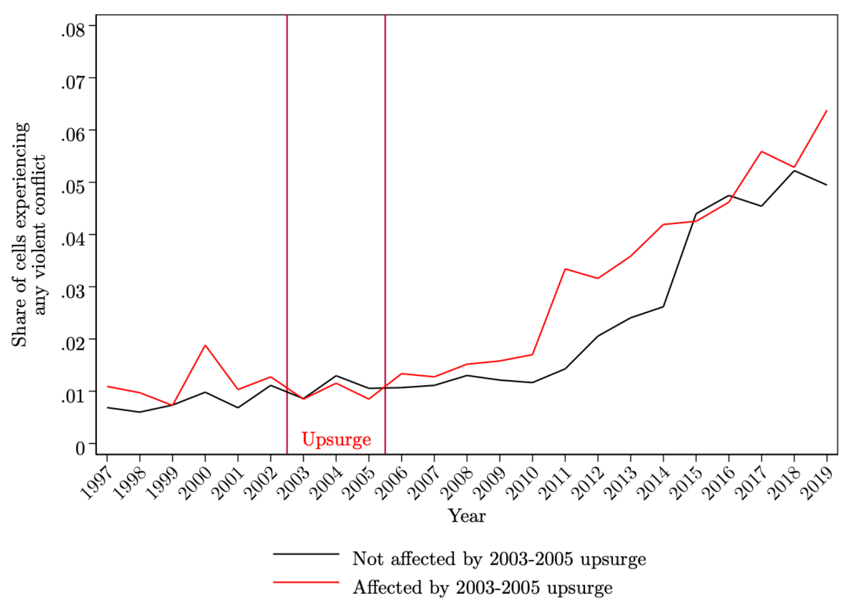
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A3: Effect of locust swarms on the risk of conflict, fallowing, and cultivation in crop areas from 2003-2014

	(1) Any violent conflict	(2) Percent fallowed	(3) Percent cultivated
Any off season swarm in cell	-0.015	0.028	-0.216
	(0.013)	(0.125)	(0.192)
Any planting season swarm in cell	-0.018	0.005	0.172
	(0.013)	(0.130)	(0.213)
Any growing season swarm in cell	-0.002	0.268	-0.370
	(0.005)	(0.202)	(0.359)
Any harvest season swarm in cell	0.003	-0.012	0.043
	(0.007)	(0.150)	(0.220)
Any swarm in cell previous year	-0.004	-0.066	0.240
	(0.006)	(0.070)	(0.216)
Any swarm within 100km outside cell	-0.001	-0.134	0.273
	(0.003)	(0.092)	(0.187)
Any swarm within 100km outside cell previous year	-0.005	0.056	0.010
	(0.007)	(0.278)	(0.305)
Observations	90220	90220	90220
Outcome mean, no swarms	0.039	5.489	16.630

The sample for these analyses is cells with any crop cultivation observed in the Xiong et al. (2017) data between 2003-2014. Columns indicate which dependent variable is used. The first column tests impacts of swarms by season on a dummy for any violent conflict. prior conflict on the probability of observing a locust swarm. Columns 2 and 3 test the impacts of locust swarms by season on the percentage of 250m cell pixels that are fallowed and cultivated in the year, respectively (measured from 0-100). Observations are grid cells approximately 28km^2 by year for 2003-2014. 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). Locusts consume any available vegetation, and swarms frequently lead to the total destruction of local agricultural output (**showler2019desert**). Damages from locust shocks can be extreme, with a small swarm covering one square kilometer can consume as much food in one day as 35,000 people. During the last locust upsurge in 2003-2005 in North and West Africa, 100, 90, and 85% losses on cereals, legumes, and pastures respectively were recorded, affecting more than 8 million people (Renier et al. 2015; Brader et al. 2006). Damages to crops alone were estimated at \$2.5 billion USD and \$450 million USD was required to bring an end to the upsurge (ASU 2020).

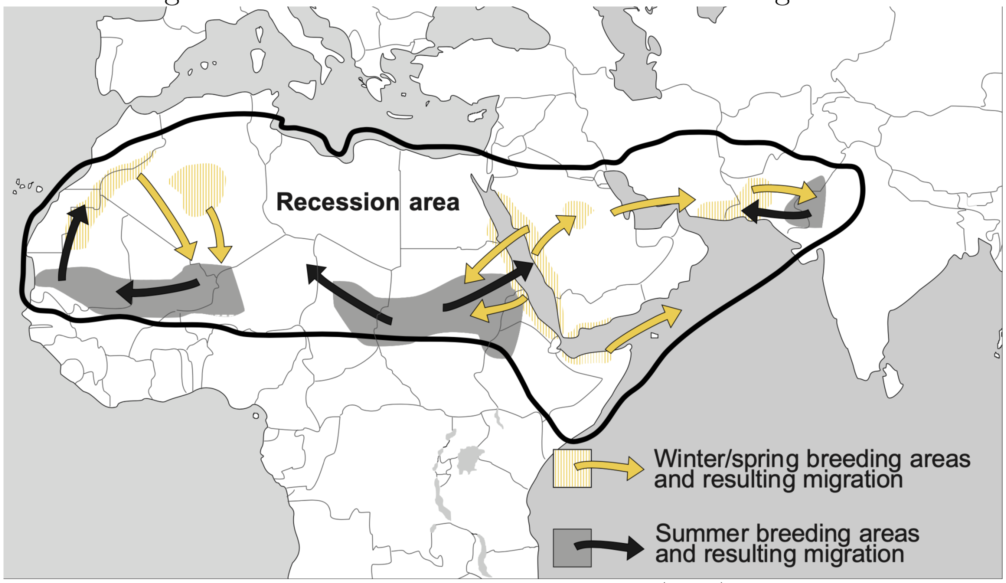
In the most recent upsurge from 2019-2021 in East Africa and the Arabian Peninsula, over 40 million people in 10 countries faced severe food insecurity due to crop destruction. Locust control operations undertaken by the United Nations Food and Agriculture Organization (FAO) and its partners, primarily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

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

Unique among grasshopper species, after reaching a particular population density desert locusts undergo a process of 'gregarization' wherein they mature physically and form large bands or swarms which move as a cohesive unit (Symmons and Cressman 2001). Locust bands may extend over several kilometers and alternate between roosting and marching, typically downwind (FAO and WMO 2016).

In this paper I focus exclusively on locust swarms, which form when bands of locusts remain highly concentrated when they reach the adult stage and become able to fly. This formation of swarms can lead to 'outbreaks,' where locusts spread out from their largely desert initial breeding areas. Locusts in swarms have increased appetites and accelerated reproductive cycles, and are thus particularly threatening to agriculture. The FAO distinguishes different levels of locust swarm activity (Symmons and Cressman 2001). 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. Few locust swarms are observed outside of major outbreaks, as conditions favoring swarm formation tend to produce large swarms which reproduce and spread rapidly and are very difficult to control.

Figure B1: Desert locust recession and breeding areas



Source: Symmons and Cressman (2001)

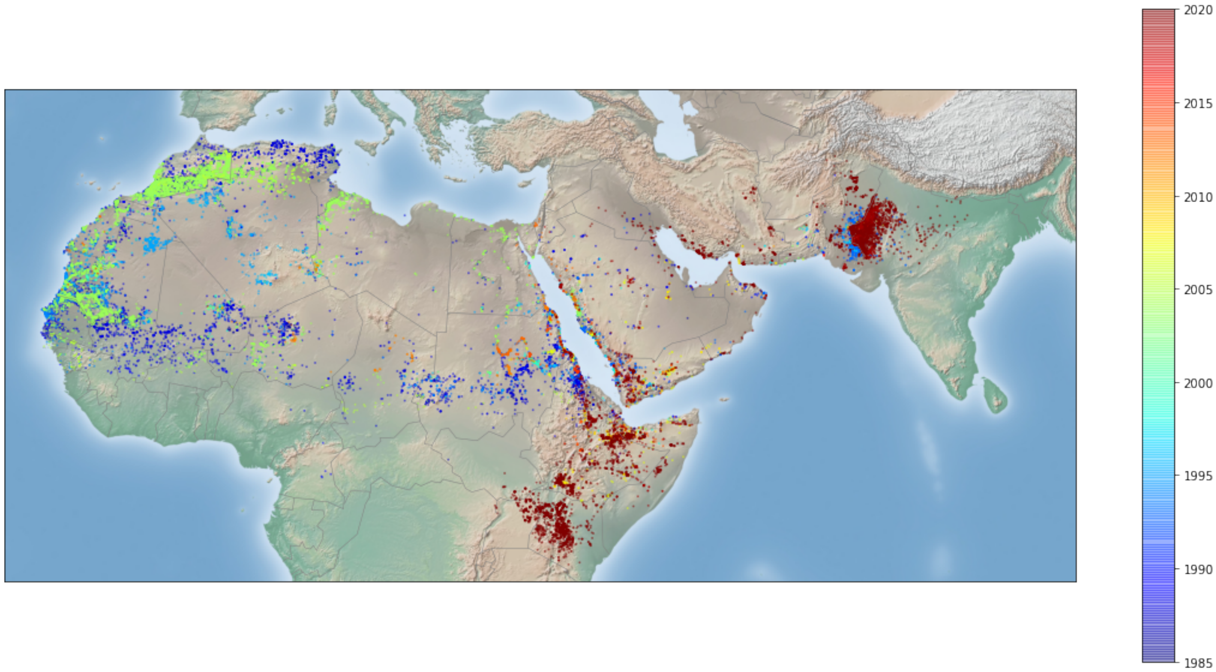
As illustrated by Figure B2, locust swarms are not observed with any regularity over time or space. Desert locusts are migratory, moving on after consuming all available vegetation, and outside of outbreak periods are ultimately restricted to desert 'recession' areas. Unlike many other insect species,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

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.

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

Desert locust control is most effective before locust populations surge, and the FAO manages an international network of early monitoring, warning, and prevention systems in support of this goal (Zhang et al. 2019). While improvements in desert locust management

Figure B2: Desert locust observations by year



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

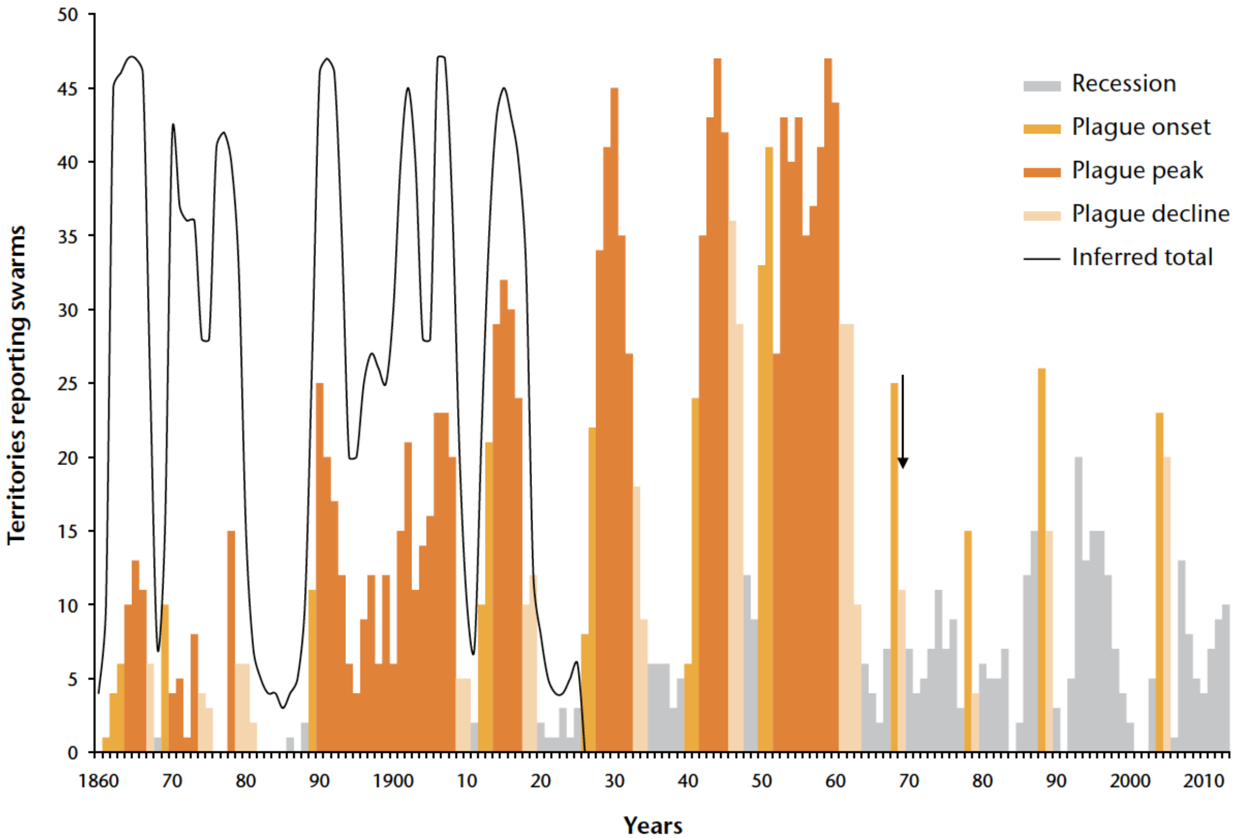
have been largely effective in reducing the frequency of outbreaks, many challenges remain. Desert locust breeding areas are widespread and often in remote or insecure areas. Small breeding groups are easy to miss by monitors, and swarms can migrate quickly. In addition, control operations are slow and costly, resources for monitoring and control are limited outside of upsurges, and the cross-country nature of the thread creates 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 1 square kilometers to several hundred (Symmons and Cressman 2001). About half of swarms exceed 50km^2 in size (FAO and WMO 2016), meaning swarms typically include over a billion individuals.

Swarms fly downwind from a few hours after sunrise to an hour or so before sunset when they land and feed. Swarms do not always fly with prevailing winds and may wait for warmer winds; seasonal changes in these winds tend to bring locusts to seasonal breeding areas at times when rain and the presence of vegetation is most likely, allowing them to continue breeding (FAO and WMO 2016). The localized nature of locust swarm shocks stems from these patterns of swarm movements. After taking off, 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.

These movement characteristics inform efforts to predict locust swarm movements, but these remain highly imprecise. The desert locust bulletins produced monthly by the FAO include forecasts of areas at risk of desert locust activity, but the areas described are quite

Figure B3: Desert locust observations by year



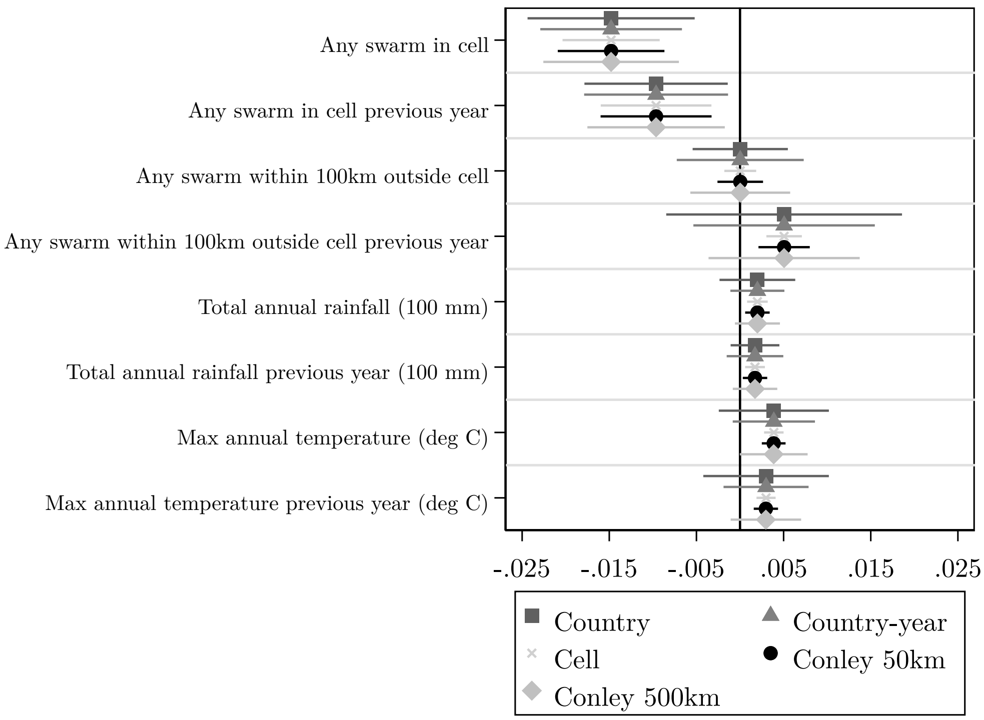
Source: Cressman and Stefanski (2016), Figure 6.

large, often encompassing several countries in periods with increased swarms. While breeding regions and the broad areas at risk over different time periods can generally be predicted with some accuracy (Latchininsky 2013; Samil et al. 2020; Zhang et al. 2019), predicting specific local variation in swarm presence remains a challenge due to the multiple factors influencing specific flight patterns (FAO and WMO 2016).

An important result of the local variation in locust swarm damages during outbreaks is that macro level impacts may be muted, since outbreaks occur in periods of positive rainfall shocks which tend to increase agricultural production in unaffected areas. Several studies find that impacts of locust outbreaks on national agricultural output and on prices are minimal, despite deveastating losses in affected areas (Joffe 2001; Krall and Herok 1997; Showler 2019; Thomson and Miers 2002; Zhang et al. 2019).

Appendix C: Robustness

Figure C1: 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 C1: 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.

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

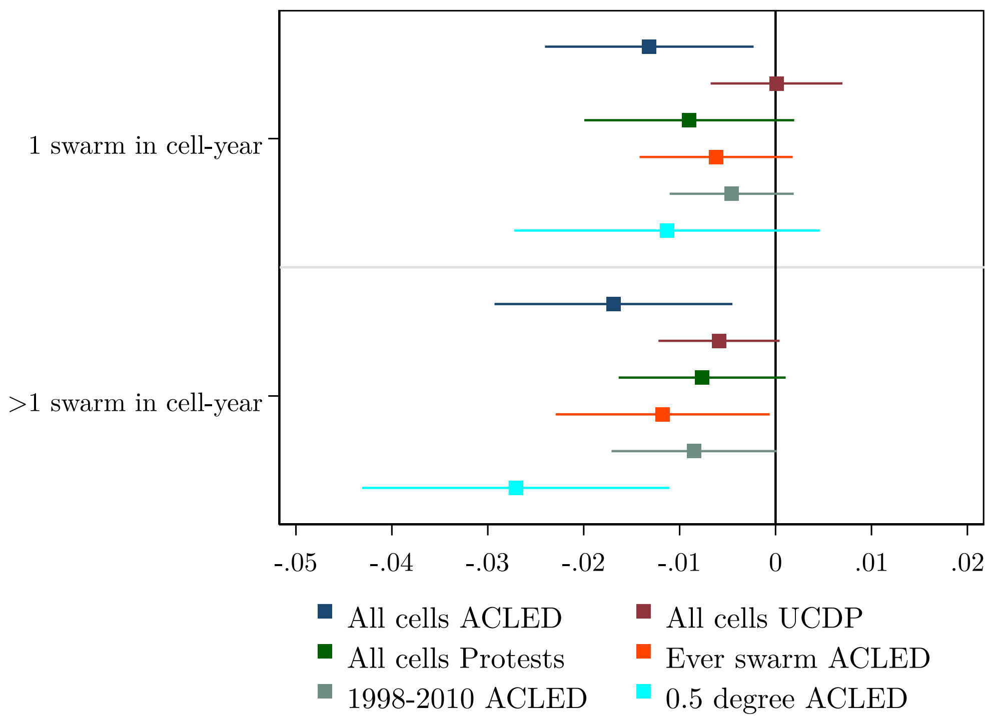
Table C2: Effect of swarms on the risk of conflict, omitting particular years and regions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Any swarm in cell	-0.015***	-0.007**	-0.014	-0.013**	-0.016**	-0.018**	-0.013***
	(0.005)	(0.003)	(0.017)	(0.006)	(0.006)	(0.006)	(0.004)
Any swarm in cell previous year	-0.009*	0.000	-0.022**	-0.006	-0.012**	-0.009	-0.007
	(0.004)	(0.002)	(0.008)	(0.004)	(0.005)	(0.006)	(0.005)
Any swarm within 100km outside cell	-0.001	0.001	-0.008	-0.001	-0.002	-0.000	-0.002
	(0.002)	(0.002)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)
Any swarm within 100km outside cell previous year	0.004	-0.000	0.012	0.006	0.009	0.006	-0.004*
	(0.008)	(0.001)	(0.012)	(0.010)	(0.010)	(0.011)	(0.002)
Total annual rainfall (100 mm)	0.003*	0.000	0.005*	0.004	0.001	0.004	0.004*
	(0.002)	(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	0.004**	0.000	0.002	0.003
	(0.002)	(0.001)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Max annual temperature (deg C)	0.006*	0.004	0.004	0.009	0.005	0.008	0.004*
	(0.003)	(0.003)	(0.005)	(0.006)	(0.004)	(0.005)	(0.002)
Max annual temperature previous year (deg C)	0.005	0.002	0.005	0.009	0.005	0.006	0.002
	(0.004)	(0.002)	(0.008)	(0.007)	(0.005)	(0.006)	(0.003)
Observations	508284	314663	266235	348010	399918	350581	426342
Outcome mean, no swarms	0.020	0.010	0.029	0.022	0.012	0.024	0.021
Proportional effect of swarms	-0.755	-0.627	-0.485	-0.598	-1.295	-0.736	-0.613
Regions	All	All	All	No N. Africa	No E. Africa	No W. Africa	No Arabia
Years	All	1998-2010	2008-2018	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 C2: 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 C3: 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)

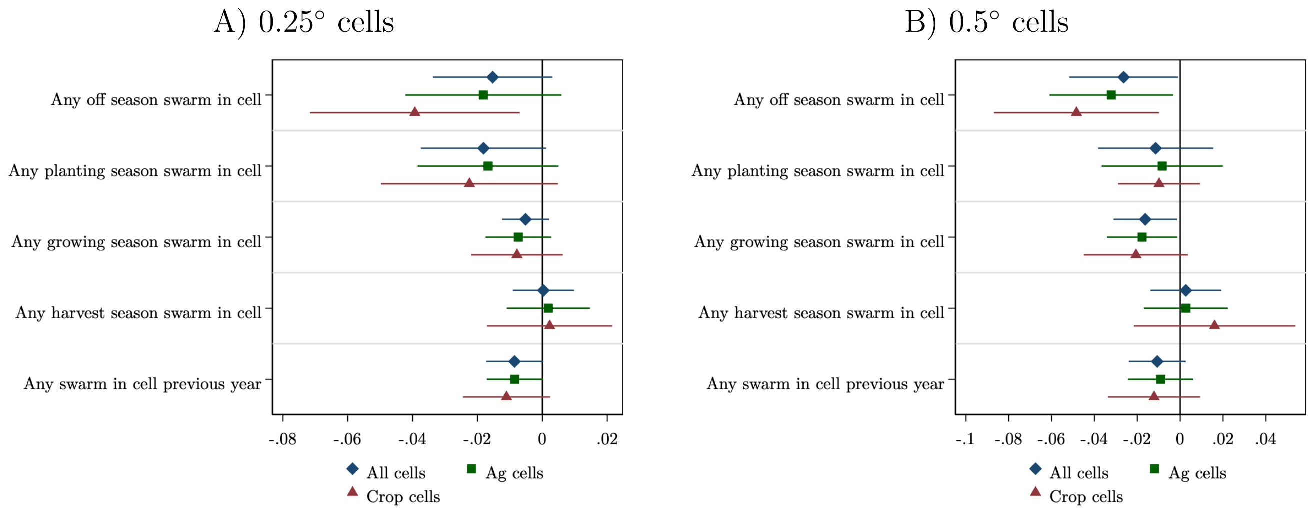
This table shows estimates of the impact of a locust swarm in the same year from Equation 1 using different measures of conflict as the outcome variable. All regressions include nearby swarm and weather controls along with country-year and cell FE. Observations are grid cells approximately 28km^2 by year. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C4: 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

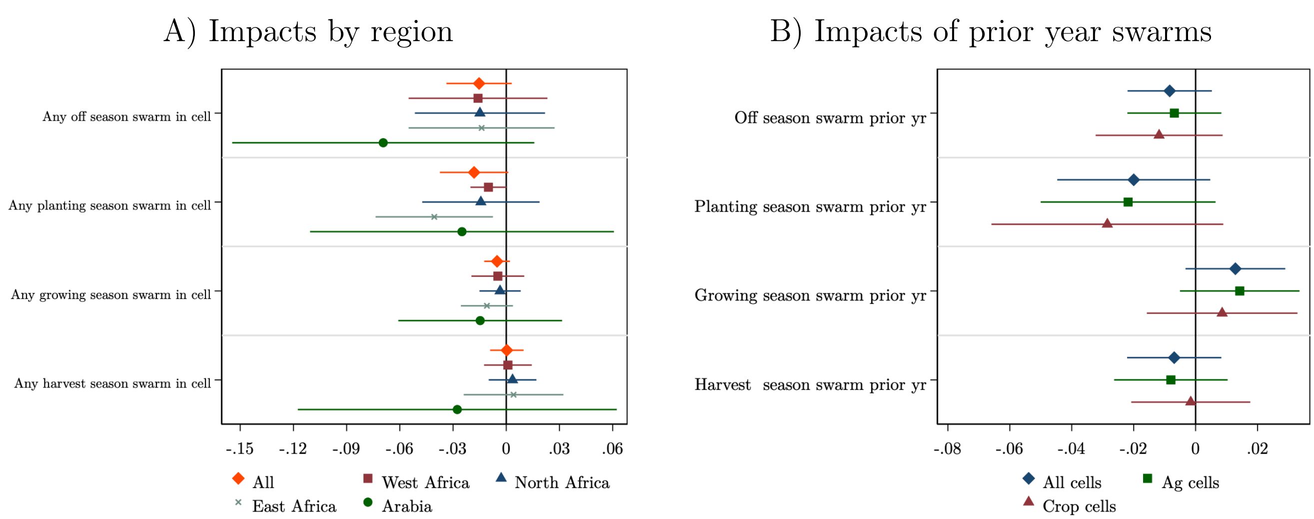
The dependent variable is the share of 0.25 degree cells in the aggregated area with any violent conflict event in a year. Similarly, swarm presence variables are the share of 0.25 degree cells in the aggregated area with any swarm in a year. Weather controls are means for total annual rainfall and max 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 C3: Effect of swarms on the risk of conflict by season and land cover, by cell size



The figure shows 95% confidence intervals for estimates from Table 5 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.

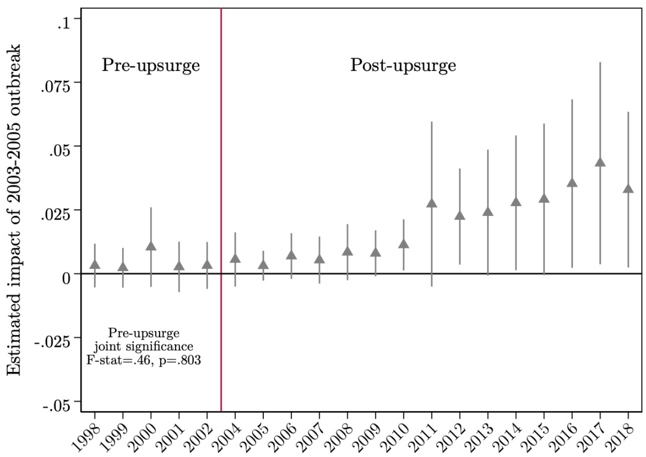
Figure C4: Seasonal effect of swarms on the risk of conflict, by region and prior year



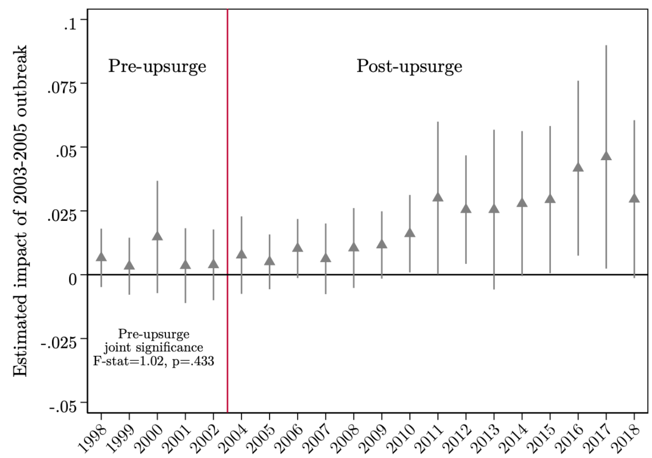
The figure shows 95% confidence intervals for estimates from Table 5 by region (Panel A) and for swarms the prior year by land cover in 2000 (Panel B). The outcome variable is a dummy for any violent conflict observed. Observations are grid cells approximately 28km^2 by year. Regressions also include controls for locusts in surrounding areas and weather as well as country-year and cell FE.

Figure C5: Effect of 2003-2005 upsurge on the risk of conflict by year in subsamples of cells

A) Cells within 250km of an upsurge swarm



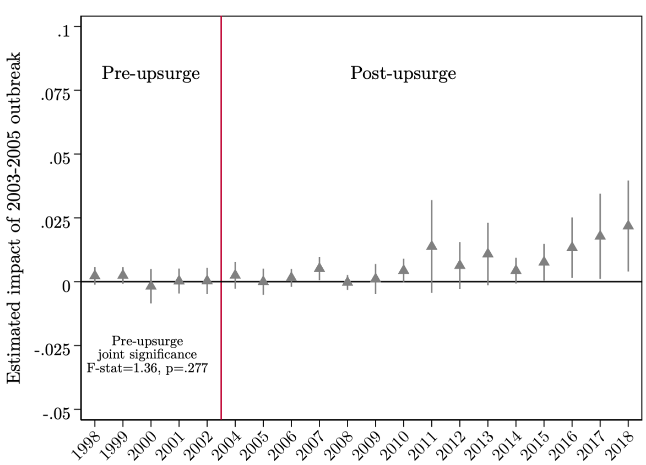
B) Agricultural cells within 250km of an upsurge swarm



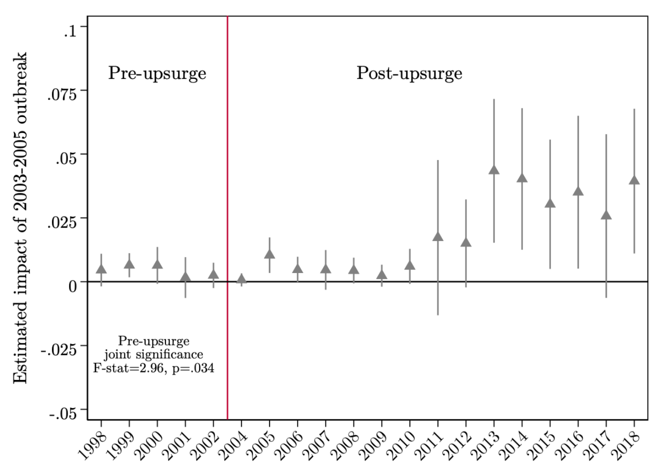
The dependent variable is a dummy for any violent conflict event observed. Coefficients are for the interaction of a dummy for being in a cell that had any swarm between 2003-2005 with year. The reference year is 2003, indicated by the red line. Bars represent 95% confidence intervals. The regression 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 C6: 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.