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

Pierre E. Biscaye[†]

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PRELIMINARY DRAFT

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Abstract

This paper tests whether severe agricultural production shocks affect the risk of violent conflict in the long-term, and how income-related mechanisms commonly cited in the literature explain short- and long-term impacts on conflict risk. I identify causal impacts of agricultural shocks using exogenous local variation in exposure to desert locust swarms driven by swarm breeding conditions and flight patterns in a fixed effects model with 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. The results indicate that a reduced incentive for predatory conflict outweighs reduced opportunity costs of fighting in the short term on average. In the long-term, cells affected by the 2003-2005 major desert locust upsurge are 58% more likely to experience violent conflict over the following 10-15 years, driven by growing season swarms in areas with cropland. The increased conflict risk is concentrated after 2010 in years and areas with groups engaged in civil conflict. 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
Keywords: desert locusts; natural disasters; conflict; agriculture; Africa

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[†] Department of Agricultural and Resource Economics, University of California at Berkeley; pbiscaye@berkeley.edu.

1 Introduction

A growing literature explores the effects of climate or weather on conflict risk, and finds consistent evidence that weather fluctuations increase the likelihood of conflict (see Hsiang and Burke (2013), Burke, Hsiang, and Miguel (2015), Koubi (2019), and Mach et al. (2019) for reviews). These studies raise concerns about an additional channel through which climate change may adversely affect societies and economies globally. Conflict between states has been rare in recent decades but the number of civil conflicts has been generally increasing—especially in Africa and the Middle East.[1] Violent conflict harms lives, health, and living standards of affected populations and can slow or reverse economic growth and development (Blattman and Miguel 2010). Understanding the drivers of conflict therefore has important implications for policy.

While the impact of weather fluctuations on conflict has been repeatedly demonstrated the mechanisms driving this impact are not fully understood.[2] The primary mechanism suggested in these studies is an 'opportunity cost' effect (following the model in Chassang and Padró i Miquel (2009)), where a decrease in agricultural labor productivity increases conflict risk by decreasing the opportunity cost of fighting for producers. This effect is argued to outweigh a decrease in the returns to fighting from a reduction in agricultural output—a 'predation' effect—given the labor intensity of low-income country agriculture (Dal Bó and Dal Bó 2011). Little attention is given to the predation channel given the generally positive estimated effects of weather shocks on conflict. These studies have generally been unable to test these mechanisms because weather shocks can affect a variety of economic and social outcomes (Dell, Jones, and Olken 2014; Sarsons 2015; Mellon 2022), in addition to reducing agricultural labor productivity and agricultural output. Buhaug et al. (2015) uses country-level data to show that agricultural output, instrumented by weather, does not significantly

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

[2]This is conclusion is repeated in the multiple reviews of the climate-conflict literature as well as in the recent VoxDev review of the literature on weather and climate adaptation in developing countries (Kala, Balboni, and Bhogale 2023).

affect violent conflict, casting doubt on these mechanisms.

Other studies showing evidence of opportunity cost and predation mechanisms in agriculture have primarily explored impacts on conflict risk of changes in global prices of agricultural goods (e.g., Dube and Vargas 2013; McGuirk and Burke 2020) rather than shocks to local agricultural production.[3] But changing the quantity of local agricultural output may have different effects on violent conflict than changing its value, particularly when much of production is for household consumption. Studies of the impacts of climate or weather on conflict have also focused on the short-term—impacts in the same year and up to two years afterward (e.g., Crost et al. (2018) and Harari and La Ferrara (2018))—whereas if the mechanism is a productivity decrease we may expect persistent impacts if productivity does not recover fully following a shock.

This paper tests whether reductions in opportunity costs of fighting related to agriculture can explain impacts of a severe negative shock to agricultural production on the risk of violent conflict in the short and long term. I identify agricultural production shocks using outbreaks of desert locust swarms. The unique characteristic of desert locusts is the formation of cohesive swarms when population density increases following repeated positive rainfall shocks in desert breeding areas. Swarms fly downwind as a unit and can arrive at any time of year depending on the timing of formation and distance from the breeding area. Daily swarm flight patterns result in more local variation in damages to agricultural production than rainfall and temperature deviations which tend to affect broad areas. Swarms continue migrating until they are controlled by pesticides or follow winds to areas with scarce vegetation, at which point they die out.

Locust swarms cause extreme levels of damage to agriculture and vegetation more generally without changing the probability of a future locust shock (Renier et al. 2015; Thomson and Miers 2002). Farmers have no effective recourse to prevent damages if a swarm arrives. These migratory pests do not affect infrastructure or physiology and therefore better

[3]McGuirk and Nunn (2021) is an exception, analyzing impacts of drought on conflict between pastoralists and farmers.

isolate income-related mechanisms through agricultural production for impacts on conflict than commonly analyzed temperature and rainfall deviations. Effects on labor productivity and output are also immediate, in contrast to temperature and rainfall deviations which take time to be recognized. The level of the destruction of agricultural production, transient nature of the shock, and lack of mitigation mechanisms available to affected areas also make oubreaks of locust swarms a useful natural experiment for analyzing how agricultural production shocks affect the risk of conflict, particularly in the long-term as productivity decreases may be more persistent following such a severe shock.

Using data on the location and timing of desert locust swarm observations from the Food and Agricultural Organization of the United Nations and of violent conflict events from the Armed Conflict Location & Event Data Project and Uppsala Conflict Data Program, I estimate a model of conflict at the annual level for 0.25° (around 28×28km) grid cells between 1997-2018 across Africa and the Arabian peninsula.[4] The identification exploits quasi-random variation in locust swarm exposure over time and space driven by weather conditions in locust breeding area and swarm flight patterns to identify causal impacts. The regressions include country-by-year and cell fixed effects, following the approach in several recent papers analyzing impacts of weather shocks on conflict (e.g.,Fjelde 2015; Harari and La Ferrara 2018; McGuirk and Burke 2020). I also control for current and lagged local weather realizations to isolate the effect of swarm arrival from general climatic trends which may have contributed to swarm formation in breeding areas.

I interpret the results through the lens of a simple model of occupation choice between production and conflict (similar to Chassang and Padró i Miquel (2009), Dal Bó and Dal Bó (2011), and McGuirk and Burke (2020)). In the model, agricultural shocks affect the risk of

[4] I include all countries where at least 10 locust swarms are reported during the sample period. Torngren Wartin (2018), an unpublished master's thesis from Stockholm University, uses related methods to estimate impacts of desert locusts on conflict in Africa. I became aware of it only after posting the first version of this working paper online. There are many differences between that paper and this paper. Torngren Wartin (2018) focuses on potential measurement issues around short-term impacts which I address in Section 6.1.2. As a result of this focus, he does not include discussion of long-term impacts and mechanisms that are the main contributions of this paper.

conflict by changing the returns to engaging in agricultural production and the returns to fighting over agricultural output. The former channel is the ‘opportunity cost’ mechanism commonly cited in the climate-conflict literature. The latter channel, sometimes referred to as the ‘predation’ mechanism, is more commonly discussed in studies of price shocks and conflict. The model predicts an increase in both short- and long-term conflict following agricultural destruction from a locust swarm, driven by decreases in opportunity costs of fighting related to agriculture.

As in recent papers in the climate and conflict literature I find that deviations from mean precipitation and temperature increase conflict risk in the short term, by 15-30%. 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%. Estimated effects of swarms are largest in agricultural areas and in cells with cropland in particular—as expected if swarms affect conflict risk through destruction of agricultural production. This result is robust to a variety of alternative specifications, including taking first differences to address concerns about spurious correlations in finite panels (Christian and Barrett 2023). In addition, negative impacts of locust swarms on conflict risk are robust to controlling for recent and surrounding conflict and to dropping countries cited by Showler and Lecoq (2021) as areas where insecurity has affected locust control operations during the sample period. The share of cells recording both violent conflict and locust swarms would need to have nearly double for the estimated effect to lose statistical significance. These tests indicate that the impact of swarms on conflict is not driven by endogenous underreporting of locust swarms in insecure areas, a concern raised by Torngren Wartin (2018). The negative effects of swarms are not driven by displacement of conflict to nearby areas: effects on conflict are local with no significant spillovers into surrounding areas up to 500km away.

I analyze long-term impacts of an agricultural shock on conflict using an event study of the 2003-2005 major desert locust upsurge, which accounts for 60% of swarm observations in the sample period. Cells that experienced a locust swarm during this outbreak are 57%

more likely to experience any conflict in a given year afterward relative to cells that were not affected by the upsurge. This result is robust to various restrictions on the set of unaffected cells included in the analysis and to using inverse weights for the propensity to have any swarm during the upsurge. The impact of the upsurge on conflict risk is generally increasing over time, concurrent with a general increase in conflict risk in the sample countries over this period. There are no significant effects from 2006-2012, but from 2013-2018 areas affected by the upsurge are 75% more likely to experience a violent conflict than unaffected areas.

In line with the model, both short- and long-term effects are driven by conflict involving non-state actors such as identity/ethnic militias, rebel groups, and terrorist groups, including violence against civilians. Impacts on protests and riots are similar to those on violent conflict, but impacts on conflict that does not involve non-state actors or that involves more large scale battles are limited. Following the classification in McGuirk and Burke (2020), these patterns indicate that the impacts are primarily on conflict over outputs—i.e., raids, theft, looting—rather than over factors of production or territory.

Negative short-term impacts of swarms on local conflict risk are not consistent with the model's predictions. They indicate that to the extent agricultural labor productivity falls following the arrival of a locust swarm, this does not increase conflict risk. Under the simple model, this implies that either other factors are preventing the opportunity cost of fighting from falling as far as agricultural labor productivity falls, or the returns to fighting fall be even more, or both. Negative impacts of locust swarms the previous year on current conflict are consistent with agricultural output available to capture remaining low and therefore limiting the incentive for predatory attacks. Swarms also particularly decrease the short-term probability of violent conflict in areas that experienced with fighting groups active in the previous year and in neighboring cells, consistent with this channel. Destruction of agricultural output reduces incentives for predatory conflict to extend over time and space. This may be a particularly important mechanism for locust swarms due to the extreme level of destruction of agricultural output, but highlights the role of the 'demand' side for fighting in determining impacts of an agricultural shock on conflict risk.

Seasonal patterns in the short-term impacts of locust swarms are similar across regions with very different crop calendars but also not consistent with effects driven by changes in agricultural labor productivity. 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, when damages are limited. Negative impacts may reflect perceived reductions in returns to fighting for armed groups or increased opportunity costs of fighting, due to increased agricultural labor demands to recover from the locust shock or a shift from agriculture to non-agricultural activities. In contrast, swarms arriving during the growing and harvest period have no statistically significant effect on conflict. Agricultural destruction is greatest in these periods so reduces both the opportunity cost of and the returns to fighting. These appear to cancel each other out and have no significant effect on conflict risk on average.

Other factors may also influence the opportunity costs of and net returns to fighting following a locust shock in the short term. Opportunity costs related to non-agricultural work, including the possibility of migration, should receive more attention: these set a floor on how far the opportunity cost of fighting may fall even if locusts greatly reduce agricultural labor productivity. For example, Kochar (1999) find that households in India smooth incomes in response to rainfall shocks by increasing off-farm employment. Short-term decreases in protests and riots following locust swarms cannot be explained by the predation mechanism as no capture of agricultural output is involved, but may reflect the displacement of population from locust-affected areas, a common consequence of the ensuing food insecurity. Other factors less frequently discussed in the economic literature on agricultural shocks and conflict such as psychological impacts (for example, through religious connotations of locust swarms), social cohesion, relief efforts, and the broader social and policy environment also likely play a role.

In contrast with the short-term impacts of locust swarms, the long-term increase in conflict risk in areas affected by the 2003-2005 locust upsurge is consistent with predictions in the simple model based on persistent decreases in agricultural labor productivity. Differences in long-term impacts by timing of swarm arrival during the upsurge relative to national crop calendars indicate that effects are driven by swarms that arrived during the crop growing season in cells with cropland, as expected if the mechanism is destruction of agricultural output. The model incorporates long-term effects of an agricultural shock by making productive assets a function of prior incomes: a negative shock to agricultural production is a shock to household wealth which decreases assets in following periods and therefore also agricultural labor productivity. But while future labor productivity may be lower, agricultural output is not as low as in the years the swarms arrive so does not have the same deterrent effect on predatory attacks, nor does it lead to the other mechanisms potentially active in the short-term such as temporary migration or increased relief. However, the model does not explain the pattern of long-term impacts, which are initially null but become large and statistically significant nearly a decade after the upsurge.

The pattern of long-term impacts emphasizes the importance of the broader conflict environment: whether there are groups actively engaged in civil conflict. Areas affected by the 2003-2005 upsurge are only significantly more likely to experience conflict in periods with active violent conflict in surrounding cells, again illustrating the importance of the 'demand' side of conflict. Increased activity of violent groups in certain periods both reduces the cost to individuals of engaging in fighting and indicates higher expected benefits. Given a persistent decrease in agricultural labor productivity following the upsurge, this results in increased likelihood of conflict in areas affected by the upsurge.

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) and on the role of agricultural seasonality in conflict (Crost et al. 2018; Guardado and Pennings 2021; Hastings and Ubilava 2023; Ubilava, Hastings, and Atalay 2022), testing the most commonly discussed mechanisms linking agricultural shocks to conflict. Using temporal and spatial variation in desert locust swarm presence, I find that an extreme agricultural shock decreases the short-term risk of conflict locally, with no evidence of conflict displacement or spillovers. Using a simple conceptual framework and patterns in the impacts of swarms on conflict, I show that how an agricultural shock affects conflict risk is not necessarily a simple function of the impact on opportunity costs related to agriculture. The presence of groups engaged in civil conflict influences the predation mechanism and plays an important role.

Second, I add to our understanding of the long-term economic and social effects of natural disasters (see Botzen, Deschenes, and Sanders (2019) and Klomp and Valckx (2014) for reviews). 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 an extreme shock to agricultural production increases 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 long-term consequences of natural disasters depend partly 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- and long-term impacts of locust swarms on conflict. Section 7 discusses the results in light of the conceptual framework and presents additional analyses testing the mechanisms behind the estimated effects. Section 8 concludes.

2 Background

2.1 Desert locusts

Desert locusts (*Schistocerca gregaria*) have been called the world's most dangerous and destructive migratory pest (Cressman, Van der Elstraeten, and Pedrick 2016; Lazar et al. 2016). Small numbers of desert locusts are always present in desert 'recession' areas from Mauritania to India, posing little threat to livelihoods.[5] But favorable climate conditions—periods of repeated rainfall and vegetation growth overlapping with the breeding cycle—can lead to exponential population growth. Unique among grasshopper species, after reaching a particular population density desert locusts undergo a process of 'gregarization' wherein they mature physically and begin to move as a cohesive unit (Symmons and Cressman 2001). In the hopper stage (pre-flight), locusts at high density from 'bands' which march together. In

[5] 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.

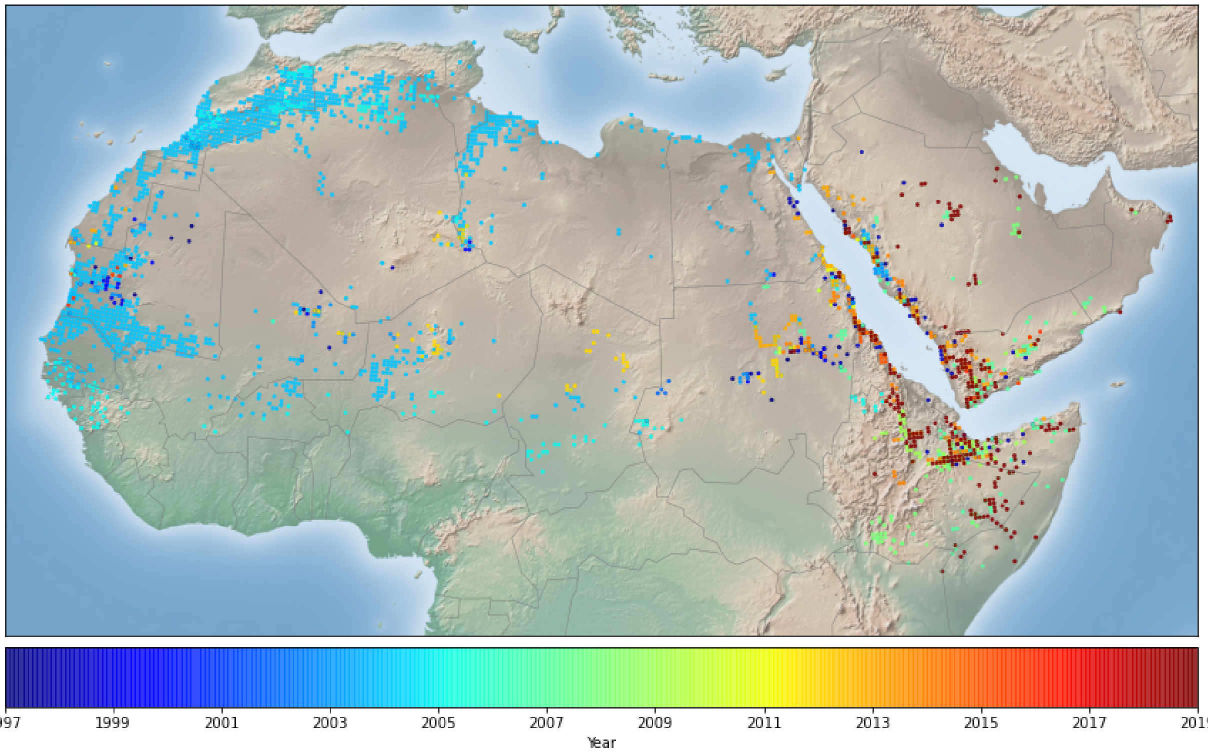
the adult stage after fledging and developing wings, gregarization leads to the formation of 'swarms' of flying adult locusts.

In this paper I focus exclusively on locust swarms, which are much more mobile and destructive than hopper bands or non-gregarious groups of adult or hopper locusts. Locust swarms vary in density and extent. The average swarm includes around 50 locusts per m^2 and can cover tens of square kilometers, including billions of locusts (Symmons and Cressman 2001). About half of swarms exceed 50km^2 in size (FAO and WMO 2016). Damages from locust swarms can be extreme.Locusts consume any available vegetation, and swarms frequently lead to the total destruction of local agricultural output (Showler 2019).

The threat from desert locusts is most severe during 'outbreaks' or 'upsurges'where locusts spread from their desert breeding areas. The most recent upsurge took place from 2019-2021 in East Africa and the Arabian Peninsula, following repeated cyclones in 2018 that lead to rapid population growth in breeding areas in Yemen and Saudi Arabia. Locust swarms spread from there, taking advantage of favorable breeding conditions to continue breeding and reaching parts of East Africa not affected by locusts in several decades. Over 40 million people in 10 countries faced severe food insecurity due to crop destruction as a result of this upsurge (Food and Agriculture Organization of the United Nations (FAO) 2022a), and the World Bank estimates that 8 million people were internally displaced (The World Bank 2020). During the previous major locust upsurge in 2003-2005 in North and West Africa, 100, 90, and 85% losses on cereals, legumes, and pastures respectively were recorded, affecting more than 8 million people (Renier et al. 2015; Brader et al. 2006).

Few locust swarms are observed outside of major upsurges, as conditions favoring swarm formation tend to produce large swarms which reproduce and spread rapidly. Figure 1 displays the locations of desert locust swarm observations in the FAO Locust Watch database by year for the sample countries and years for this analysis.Locust observations are recorded on the ground by national desert locust officers that monitor breeding conditions and locust movements, and are supplemented by reports from agricultural extension workers, government officials, and a variety of other sources.

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



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

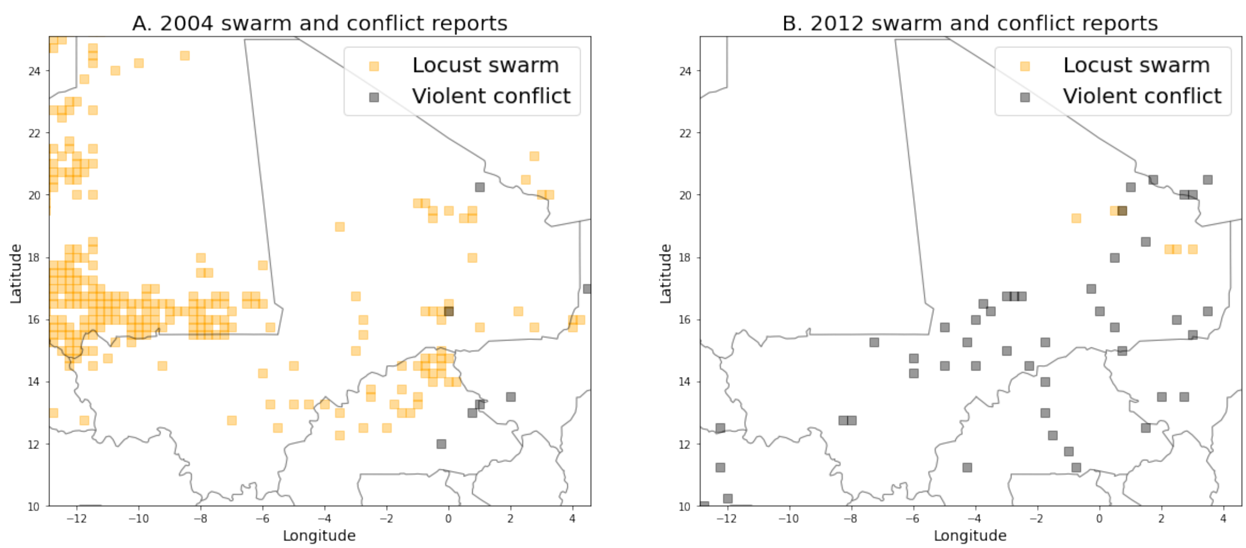
As illustrated by the figure, locust swarms are not observed with any regularity over time. The countries affected by the 2003-2005 upsurge are not the same as those that have experienced more recent outbreaks. Desert locusts are migratory, moving on after consuming all available vegetation, rather than becoming endemic. Locust swarms therefore do not permanently change in local agricultual pest risk.

Which locations are affected by locust swarms during an upsurge depends on which breeding areas fostered initial swarm formation and on wind patterns in the months following swarm formation. The 2003-2005 upsurge resulted from multiple small outbreaks in breeding areas from Mauritania to Niger in Summer 2003, followed by unusually heavy rainfall in late October in winter breeding areas in Western Sahara which supported further breeding. Wind patterns typically lead swarms to cycle through breeding areas in time for season breeding.

Swarms fly downwind and can easily move 100km or more in a day even with minimal wind (FAO and WMO 2016). [6] After leaving breeding areas, locust 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. Outside of breeding areas, these swarm flight patterns result in some areas in the flight path being spared any damages, even in the context of a major locust upsurge.

Panel A of Figure 2 illustrates the variation in areas affected by locust swarms over space, showing reports of locust swarms in 2004—the peak of the 2003-2005 upsurge—around Mali. Swarm reports are densely clustered in the breeding areas in southern Mauritania where locust swarms reproduced in summer 2004. Outside of this area there is considerable variation in where swarms were reported, with distances between reported swarm over time consistent with typical flight distances. I leverage the quasi-random variation over both time and space in the areas affected by swarms to identify their impact on conflict.

Figure 2: Reports of locust swarms and violent conflict around Mali, selected years



Note: The figure illustrates the grid cells in which locusts swarms and violent conflict events were reported for the area around the country of Mali. Panel A shows reports for 2004, the peak year of the 2003-2005 locust upsurge. Panel B shows reports for 2012, the only year after 2006 that locust swarms were reported in Mali. Locust swarm reports are from the FAO Locust Watch database. Violent conflict reports are from the Armed Conflict Location & Event Data Project (ACLED) database.

An important result of the local variation in locust swarm damages during upsurges is that macro level impacts may be muted, since upsurges occur in periods of positive rainfall

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

shocks which tend to increase agricultural production in unaffected areas. Several studies find that impacts of locust upsurges 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).

Locust upsurges 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 effects as well as being slow and costly to organize and requiring robust locust monitoring infrastructure.Control operations are most effective before locust bands reach the adult stage and form swarms, but this requires extensive monitoring activities. Knowledge of locust breeding patterns and swarm flight characteristics inform efforts to predict locust swarm formation and movements, but forecasts remain highly imprecise (Latchininsky 2013).

The characteristics of desert locust swarms make them a useful natural experiment for analyzing the impacts of agricultural production shocks on the risk of conflict. The arrival of a swarm is effectively a locally and temporally concentrated natural disaster where all crops and pastureland are at risk (Hardeweg 2001), but other aspects of the economy are importantly unaffected. Whereas impacts of temperature or rainfall deviations on conflict might go through other channels other than agricultural production, such as effects on infrastructure or physiology, impacts of locust swarms should be restricted to this channel.

The level of damage to agriculture from swarms arriving during the crop growing season and lack of tools for farmers to prevent damages imply more severe reductions in agricultural production than moderate weather fluctuations. Decreased wealth following such a catastrophic shock may be more likely to persist and affect agricultural labor productivity in following seasons, increasing the potential for long-term impacts on conflict through the opportunity cost channel. Further, the consequences of a locust swarm are immediately observable: swarms arrive and consume vegetation. In contrast, a deviation in rainfall or temperature during a growing season relative to historical norms is likely to be recognized with some delay even if forecasts are available. These characteristics may result in different occupational choice responses from farmers affected by locust swarms relative to weather deviations.

2.2 Agricultural production shocks and conflict

A variety of proximate and underlying causes has contributed to the increase in civil conflict in recent decades. A growing literature explores the impacts of climate or weather on conflict (see Burke, Hsiang, and Miguel (2015), Carleton, Hsiang, and Burke (2016), Dell, Jones, and Olken (2014), Hsiang and Burke (2013), Koubi (2019), and Mach et al. (2019) for reviews), primarily analyzing impacts of deviations of rainfall or temperature from historical norms. Most studies find that weather shocks increase short-term conflict risk, with meta-analyses finding a mean increase in the risk of conflict of between 5-10% for a one standard deviation increase in a weather shock variable and more consistent positive effects of temperature increases (Burke, Hsiang, and Miguel 2015; Carleton, Hsiang, and Burke 2016). These meta-analyses conclude that these results would be very unlikely if the true effect were zero or negative, and most studies reporting such effects use country-level data (e.g., Buhaug et al. 2015; Ciccone 2013; Couttenier and Soubeyran 2014; Klomp and Bulte 2013). These results have important implications for conflict risk as climate change increases the frequency and severity of weather shocks (Hsiang, Burke, and Miguel 2013; Mach et al. 2019). For example, Harari and La Ferrara (2018) estimate that increased frequency of growing season eather shocks will increase average conflict incidence by 7% over the next few decades. Burke et al. (2009) predicted that trends in rising temperatures would increase armed conflict incidence in Africa by 54% by 2030.

The majority of papers in this literature focus on income-related mechanisms for impacts on conflict risk. Arguments typically follow the models in Chassang and Padró i Miquel

(2009) and Dal Bó and Dal Bó (2011), discussing how weather affects agricultural labor productivity and therefore the opportunity costs of engaging in conflict for agricultural producers. Many studies use variation by land cover or timing relative to the crop cycle to support the claim that impacts of weather shocks on conflict are driven by changes in the opportunity cost of fighting (Caruso, Petrarca, and Ricciuti 2016; Crost et al. 2018; Harari and La Ferrara 2018; McGuirk and Nunn 2021; Von Uexkull 2014). Discussion of offsetting changes in the returns to conflict from capture of agricultural output is typically limited: the predation or rapacity mechanism is presented as being outweighed by the opportunity cost mechanism.

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

Because of these various possible mechanisms connecting weather shocks to an increase in conflict, these studies are not definitively able to test the impact of a shock to agricultural production on conflict risk. Reviews of the climate-conflict literature agree that the mechanisms remain unclear (e.g., Burke, Hsiang, and Miguel 2015; Hsiang and Burke 2013; Mach et al. 2019), and deepening insight into them is highlighted as the first priority for future climate-conflict research in Mach et al. (2020). The main advantage of analyzing the effects of locust swarms is that the only active mechanism should be the income channel through crop destruction, allowing a cleaner identification of the importance of the agricultural production and income mechanism relative than has been established in the climate-conflict literature.

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

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

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

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

Focusing on income channels, adverse agricultural shocks may affect long-term conflict risk if they cause persistent decreases in agricultural labor productivity. Two possible ways this could occur are through environmental degradation and reduction of household wealth and productive assets. Locust swarms do not persistently affect local environmental factors, but the reduction in agricultural production implies an income shock for affected areas, in addition to an agricultural labor productivity shock. Households use a variety of measures to cope with income shocks, including appealing to local informal support networks, selling assets, and sending individual member away to live or work elsewhere. For the latter two, the depletion of productive assets implies a persistent reduction in labor productivity. Lasting reductions in agricultural labor productivity could increase the risk of conflict due to reduced opportunity costs of fighting. Locust swarms may be more likely to generate long-term impacts than other weather shocks to agricultural production due to the severity of the income shock.

3 Conceptual framework

The primary models cited in the climate-conflict literature are Chassang and Padró i Miquel (2009) and Dal Bó and Dal Bó (2011). Both are models of occupational choice where actors allocate their labor between productive activities and fighting—over land in Chassang and Padró i Miquel (2009) and over output in Dal Bó and Dal Bó (2011). Chassang and Padró i Miquel (2009) considers only agricultural production, while Dal Bó and Dal Bó (2011) includes a labor-intensive sector and a capital-intensive sector, but both illustrate how shocks to these sectors affect the risk of conflict through changes in opportunity costs of fighting and returns to predation.[7] I present a stylized model of occupational choice drawing on these two models to generate hypotheses about the effect of agricultural shocks—and locust swarms in particular—on conflict through these two income-based mechanisms.

Consider a simple static model where two actors i and j make binary occupation decisions to maximize net returns in a given time period.[8] Actor i allocates one unit of labor to either agricultural production with net returns $F(S_i, X_i)$, non-agricultural work with net returns (wages) $w(S_i, S_j, X_i)$, or fighting to capture output or factors of production with net returns $R(X_i, S_j, X_j)$, where j indexes the other party. Net returns to all activities depend on actor and location characteristics X, as well as agricultural shocks S.

Let S take values between -1 and 1 with $S = 0$ indicating no shock, $S = -1$ indicating a strongly positive shock to agricultural production, and $S = 1$ indicating a strongly negative shock. Agricultural production is a concave function of S_i, with $\frac{\partial F}{\partial S_i} < 0$ and $\frac{\partial^2 F}{\partial S_i^2} < 0$: more severe shocks decrease agricultural production by a greater amount. A larger S_i therefore reduces i's agricultural labor productivity—the opportunity cost mechanism. Non-agricultural returns may also depend on S if the shock has more general economic effects beyond reduc-

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

[8]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 actors, but two are sufficient to build intuition and generate hypotheses.

ing agricultural production. As a simplifying assumption, I suppress the dependence of w on S, so that returns to non-agricultural work set a lower bound on how far the opportunity cost of fighting may fall following a negative agricultural shock. We can think of the returns from non-agricultural work as stemming from the most productive activity available to i outside of work on their own farm, including activities that might require migrating or coping mechanisms such as selling assets.

The potential returns 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. We thus have $\frac{\partial R}{\partial S_j} < 0$ and $\frac{\partial^2 R}{\partial S_j^2} < 0$. Returns are received with some probability π of success which depends on characteristics X_i and X_j. Costs of fighting are incurred with certainty and include economic, social, and emotional costs as well as risk of injury or death. If i decides to fight, j also incurs costs regardless of their own occupation decision. 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. It would be recorded in most conflict data as conflict against civilians.

An agricultural shock S_j to j affects i's returns to fighting by reducing the agricultural output that can be captured—the predation mechanism.[9] Capture of agricultural output may represent a significant share of the returns to fighting in agricultural areas. Banditry and raiding are common, notably targeting livestock but also high-value and easy to steal crops, across different African countries and particularly in periods of conflict. For example, 17% of households surveyed in the Mopti region of Mali in 2012 report banditry attacks (Masset et al. 2019). McGuirk and Burke (2020) summarize multiple examples of raiding and looting of food in different countries following food price spikes in 2008 and 2010-11 which are captured in the ACLED conflict data used in this paper.

The actor's problem can be presented as maximizing returns over first a choice of work sector Ag and second a decision to fight D, given some shock realizations S_i, S_j. For simplicity and intuition I ignore uncertainty in returns and suppose that decisions are made after

[9] For simplicity in this static model I set aside how S_i might decrease i's returns to fighting by for example reducing the resources they have available to engage in conflict.

the agricultural shocks are realized.

$$\max_{D,Ag}\left([F(S_i,X_i)(Ag_i)+w(S_i,S_j,X_i)(1-Ag_i)]\cdot(1-D_i)+R(X_i,S_j,X_j)\cdot D_i\right)$$
$$\text{subject to}\quad \frac{\partial F}{\partial S_i}<0;\quad \frac{\partial^2 F}{\partial S_i^2}<0;\quad \frac{\partial R}{\partial S_j}<0;\quad \frac{\partial^2 R}{\partial S_j^2}<0$$

This yields

$$Ag=1 \text{ iff } F(S_i,X_i)>w(X_i) \tag{1}$$

$$D=1 \text{ iff } R(X_i,S_j,X_j)>\max(F(S_i,X_i),w(X_i)) \tag{2}$$

An important implication of (1) is that sufficiently large S_i will induce a switch from agricultural production to non-agricultural work: $\frac{\partial Ag}{\partial S_i}<0$. This remains true even if non-agricultural returns to labor are decreasing in S, as long they are less affected than agricultural returns. The relevant opportunity cost of fighting is there not $F(S_i,X_i)$, as implied in much of the literature, but $\max(F(S_i,X_i),w(X_i))$ as indicated in (2).

The sign of $\frac{\partial D}{\partial S_i}$ is ambiguous, and depends in large part on the correlation between S_i and S_j. If $Corr(S_i,S_j)\leq 0$ or small, larger S_i will decrease i's opportunity cost of fighting related to agriculture without decreasing their returns to fighting. We would therefore have $\frac{\partial D}{\partial S_i}>0$.

If $Corr(S_i,S_j)>0$ and large, larger S_i will decrease i's opportunity cost of fighting related to agriculture but also be associated with a decrease in the returns to fighting. Which effect dominates will depend on the share of agricultural output in the returns to fighting and on the returns to non-agricultural work. Larger returns to non-agricultural work would result in $\frac{\partial D}{\partial S_i}<0$ as actors switch into their outside option rather than into fighting. Limited outside options would result in $\frac{\partial D}{\partial S_i}>0$, though this could be reversed if capture of agricultural output is the main source of returns to fighting.

The discussion so far has focused on short-term impacts of agricultural shocks through immediate changes in agricultural productivity. The model can allow for long-term effects if we consider some of the X variables affecting agricultural production $F(S, X)$ to depend on past agricultural shocks. Suppose agricultural assets A_t in period t depend on agricultural shocks $\{S_{t-s}\}_{s=1}^{\tau}$ in over the τ previous periods through impacts on income and coping mechanisms, with $\frac{\partial A_t}{\partial S_{t-s}} < 0$. We then have $F(S, X) = F(S_t, A_t(\{S_{t-s}\}_{s=1}^{\tau}), X_t))$, with $\frac{\partial F}{\partial A_t} > 0$ and therefore $\frac{\partial F}{\partial S_{t-s}} < 0$, a persistent reduction in agricultural productivity.

The implications of a past shock S_{t-s} for the decision to fight in period t are similar as in the short-term case for the impacts of S_t, as long-term impacts on agricultural productivity also affect the returns to fighting over agricultural output. The magnitude of the impact over time depends on whether reductions in productive assets persist or compound—a productivity trap—or whether they gradually recover. A productivity trap will be more likely for a more severe agricultural shock, ceteris paribus.

3.1 Hypotheses

This conceptual framework produces a set of hypotheses based on the characteristics of agricultural shocks from desert locust swarms. The key characteristics are the severity of the shock and its spatial correlation. First, locust swarms can consume all local vegetation, meaning $F(S_i, X_i)$ is close to 0. Locusts swarms also have limited other economic impacts which could reduce the returns to conflict beyond decreased returns from capture of agricultural output. Second, swarm flight patterns create local variation in damages, meaning that even within a particular grid cell the agricultural shock experienced from locusts may vary.

This suggests *Hypothesis 1*: locust swarms will increase the risk of conflict in affected cells in the same year. Opportunity costs related to agriculture fall dramatically, while the presence of nearby unaffected locations prevents the returns to fighting from falling as much.

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, the severity of the income shock from locust swarms could lead to a persistently lower stock of productive assets, reducing productivity and lowering the opportunity cost to fighting in the long-term. This suggests *Hypothesis 2*: locust swarms will increase the risk of conflict in affected cells in the long-term over the following years. Long-term decreases in agricultural labor productivity for affected areas should outweigh any decrease in returns to fighting in other nearby affected areas.

Another important characteristic of locust swarms is that the effect on agricultural production will depend on the timing of the swarm. Destruction of crops will be greatest for swarms arriving in the growing season between planting and the end of harvest, though damages in other parts of the year to tree crops and livestock grazing may also be large. If impacts on agricultural productivity are driven primarily by damages to crops, this suggests *Hypothesis 3*: impacts of locust swarms on conflict risk in both the short- and long-term will be concentrated in agricultural cells for swarms arriving during the crop growing season. These are the swarms that will particularly affect the opportunity cost of fighting related to agriculture.

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.Observations of locusts are recorded by national locust control and monitoring units on the ground, but incorporate reports from agricultural extension agents, government officials, and other sources. I consider only data on locust swarms, high density groups of gregarious locusts that move as a unit, and do not consider observations of locusts at lower density as these pose less of a threat to agriculture. Locust swarm presence is also less likely to be unreported than smaller locust groupings.

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 by compiling and validating reports from traditional media at different levels, from institutions and organizations, from local partners in each country, and from verified new media sources. The analysis focuses on events categorized by ACLED as "violent conflict," which includes battles, explosions, and violence against civilians. I test robustness to analyzing protest and riot events and to using data on larger-scale violent conflicts from the Uppsala Conflict Data Program (UCDP) (Sundberg and Melander 2013)[10], which may engage different mechanisms.

I collapse the data to raster grid with annual observations for cells with a 0.25° resolution (15 arcminutes, approximately 28×28km). 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.

Analyzing impacts at this spatial level reduces potential measurement error about the specific areas affected by swarm and conflict events allows me to leverage local variation in swarm presence created by their flight patterns.[11] In each cell and year I measure whether any locust swarm/conflict event was observed. To account for possible spatial spillovers, I also measure whether any swarms are observed in bands at different distances outside of the cell.

I categorize swarms as arriving during particular stages of the crop production cycle by matching the month in which a swarm is observed to country-level crop calendars for staple grains and main cash crops from The United States Department of Agriculture (USDA) (2022).[12] I define four main seasons: planting, growing, harvesting, and the off season between harvesting and planting. Figure A3 shows the share of sample cells at different stages of agricultural cycle by month and the counts of locust swarms observed by season

[10]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.

[11]About half of locust swarms exceed 50km^2 in extent. Most swarms will be contained within 0.25° cells (∼784km^2), but I test for robustness to analyzing data at the level of 0.5° cells (∼3136km^2).

[12]Figure A2 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.

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 total annual precipitation (in mm) and maximum temperature (in °C) using high-resolution monthly data from WorldClim available through 2018.[13] I also incorporate raster population data for every 5 years from CIESIN 2018, linearly 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). [14]

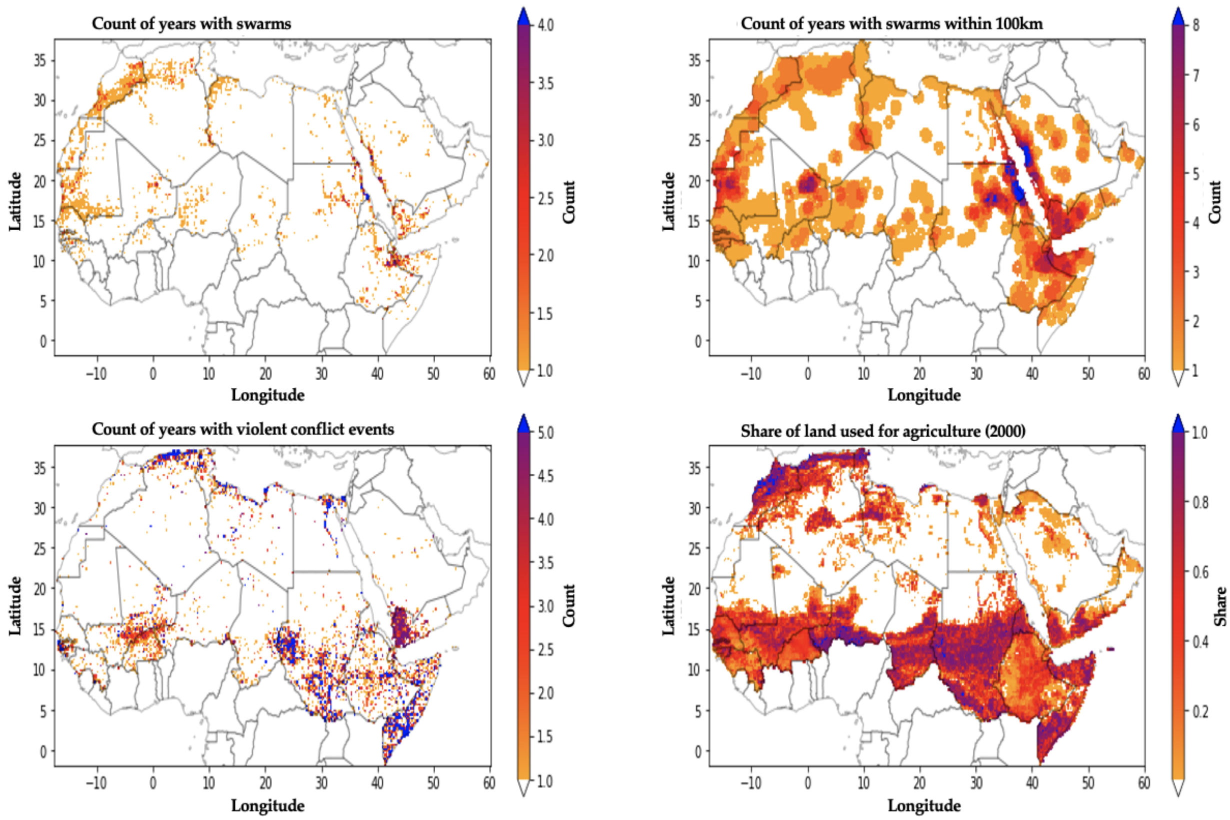
Since ACLED records conflicts beginning in 1997 and the weather data are available until 2018, I retain only data from 1997 to 2018. I restrict the analysis to countries with at least 10 locust swarm observations in this period. These countries include all of North Africa, most of the Arabian Peninsula, and countries along the Sahel. I drop unpopulated (largely desert and water) cells from the analysis.

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, but just 1.4% experience swarms in multiple years. Fifty-six percent of cells were within 100km of at least one locust swarm event. Fourteen percent of cells experienced at least one violent conflict event. About half the cells (53%) in the sample include some agricultural land: 52% have pasture land while 28% have crop land. Across all cells, mean pasture area is 19% of the cell and mean crop area is 5% of the cell. These variables are displayed in Figure 3, 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.

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

[14]The results by land cover are not sensitive to accounting for changes over time as documented in Xiong et al. (2017).

Figure 3: Distribution of swarm and violent conflict observations over sample countries



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

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:

$$Conflict_{cit} = \alpha + \beta Swarms_{cit} + \delta X_{ct} + \gamma_{it} + \mu_c + \epsilon_{cit} \tag{3}$$

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.[15] Standard errors (SEs) are clustered at the country level to allow for correlation in the errors within countries over time.[16]

This fixed effects model follows many others in the use of grid cell panel data to analyze the impact of weather on conflict in Africa, though these vary in the shocks they consider, in their specification of controls, and in the size of grid cells they analyze.[17] The country-year fixed effects flexibly control for factors varying over time at the country level that might affect conflict and the impact of locust swarms, such as the policy environment and national economic and social conditions. These fixed effects importantly control for trends in conflict risk, which increases over the sample period. The cell fixed effects control for time invariant cell characteristics, such as topography, agricultural suitability, distance from locust breeding areas, 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 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).

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

[16] 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 more tailored spatial and serial correlation following Hsiang (2010)'s approach.

[17] See for example Burke, Hsiang, and Miguel (2015), Fjelde (2015), Harari and La Ferrara (2018), McGuirk and Burke (2020), McGuirk and Nunn (2021), and Ubilava, Hastings, and Atalay (2022). Torngren Wartin (2018) uses a related approach with a similar econometric specification to analyze the impact of desert locusts on conflict. His analysis is at the level of 0.5° and 0.1° cells with the same fixed effects and somewhat different controls for lagged locust presence and weather. He considers locust swarms and bands together while I focus on more destructive swarms alone, and includes some African countries with very few locust swarm observations over time while excluding Arabian countries with extensive locust activity.

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. Although efforts are made to forecast locust swarm formation and movements, the predictions include a great deal of uncertainty and there are anyway no effective methods of defending vegetation against locust swarms. 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 3 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 3 separating out $Swarms$ into a series of dummy variables indicating the presence of locust swarms during particular periods of the crop calendar.

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

$$Conflict_{cit} = \alpha + \beta Swarms_{cit} + \xi Upsurge_{ci} \times Post_t + \delta X_{ct} + \gamma_{it} + \mu_c + \epsilon_{cit} \tag{4}$$

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 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 and to using inverse propensity weights based on the probability of reporting a locust swarm during the upsurge.[18]

6 Results

6.1 Short-term impacts

Table 1 presents estimates of Equation 3 analyzing short-term impacts on violent conflict events. Column 1 shows that the point estimates for contemporaneous and lagged weather are positive: deviations from mean annual temperature and rainfall within cells are associated with a higher probability of conflict, consistent with the literature on weather and conflict. Effects of rainfall and temperature in the same year are marginally statistically significant when clustering SEs at the country level.[19] The magnitudes of the effects of rainfall and

[18]I calculate propensity scores using a logit regression with a dummy for reporting a locust swarm during the upsurge on pre-2004 means for observations of swarms and different types of conflict, population, crop and pasture land shares, annual rainfall and maximum temperature, and country fixed effects. I calculate inverse propensity weights as $\frac{1}{p}$ for cells that reported a swarm during the upsurge and $\frac{1}{1-p}$ for cells that did not, where p is the estimated probability of reporting a swarm during the upsurge. I assign cells with estimated probabilities outside the range of common support a weight of 0.

[19]Figure C1 shows 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. 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 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.

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 conflict.

Table 1: Short-term impacts of locust swarms on the risk of conflict

	(1)	(2)	(3)	(4)
Any swarm in cell	-0.015***	-0.008**	-0.011***	-0.013***
	(0.005)	(0.004)	(0.003)	(0.004)
Any swarm in cell previous year	-0.009*	-0.002	-0.005	-0.009*
	(0.004)	(0.005)	(0.003)	(0.004)
Any swarm within 100km outside cell	-0.001	-0.001	-0.002	
	(0.002)	(0.004)	(0.001)	
Any swarm within 100km outside cell previous year	0.004	0.001	0.004	0.004
	(0.008)	(0.008)	(0.007)	(0.007)
Total annual rainfall (100 mm)	0.003*	0.005	0.003*	0.003*
	(0.002)	(0.004)	(0.001)	(0.002)
Total annual rainfall previous year (100 mm)	0.003	0.004	0.002	0.003
	(0.002)	(0.003)	(0.002)	(0.002)
Max annual temperature (deg C)	0.006*	0.008	0.004*	0.006*
	(0.003)	(0.006)	(0.002)	(0.003)
Max annual temperature previous year (deg C)	0.005	0.006	0.004	0.005
	(0.004)	(0.007)	(0.003)	(0.004)
Any violent conflict in cell previous year			0.231***	
			(0.044)	
Any violent conflict elsewhere in 1 degree cell			0.038***	
			(0.007)	
Observations	508284	50404	508284	508284
Outcome mean, no swarms	0.020	0.040	0.020	0.020
Proportional effect of swarms	-0.755	-0.210	-0.561	-0.641
Sample	All cells	Ever had a swarm in cell	All cells	All cells
Country-Year FE	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes
Additional surrounding swarm controls	No	No	No	Yes

Note: The dependent variable is a dummy for any violent conflict event observed. Observations are grid cells approximately 28×28km by year. Coefficients for swarms at different distances outside the cell in Column 4 are shown in Figure C5. SEs clustered at the country level are in parentheses. SEs for estimates in column (1) using different clustering approaches are reported in Figure C1.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In contrast to rainfall and temperature, locust swarms significantly *decrease* the probability of conflict in the same year. In years where a locust swarm is observed in a cell, the probability of observing any violent conflict event in that cell 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.

Among cells where a swarm is ever reported during the sample period, swarms decrease the risk of conflict by 21% relative to years with no swarms (Column 2). Cells where locust swarms have been reported have different characteristics than cells where they have not:

they have similar rainfall and temperature but smaller populations and are less likely to have any agricultural land and more likely to experience conflict. The smaller absolute and relative impact of swarms on conflict in this subsample indicates that other factors varying across years by country for these cells explain both a greater likelihood of swarms and a lower likelihood of conflict.[20]

Experiencing a locust swarm the previous year also reduces the risk of violent conflict, though this effect is not significant in the sample of cells that ever report a locust swarm.[21] Locust swarms in the 100km outside a cell do not significantly affect the risk of conflict within the cell.

6.1.1 Robustness

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, including replacing country by year fixed effects by linear trends at the country and sub-national region level, 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), addressing potential concerns about limitations in the specific locations locust swarms are recorded.

Christian and Barrett (2023) discuss concerns over spurious correlation problems in panel data with finite time series, and demonstrate how this can arise in analyses of the causes of conflict due to the serial correlation in common sources of conflict data. They show that estimating regressions after taking first differences can address a range of issues potentially causing spurious correlations. Following this recommendation, I find effects of locust swarms on the risk of violent conflict in the same year of similar magnitudes—a 35% decrease (Ta-

[20] One possibility is that the typically greater agricultural production in years with locust swarms due to increased rainfall is not well-captured by the cell rainfall and temperature controls. Greater agricultural production could decrease conflict risk by increasing opportunity costs of fighting.

[21] 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.

ble C2). The effects are not statistically significant when clustering standard errors at the country level ($p = 0.120$) but are significant with less conservative but still plausible clustering. I also estimate effects close to 0 and non-significant for placebo swarms randomly assigned each year with the same frequency that actual swarms are observed (Figure C2). The 95% confidence interval for the estimated impact from Table 1 is almost entirely outside the distribution of simulated placebo effects. These tests alleviate concerns about a potential spurious correlation from a large share of swarm observations occurring in the first half of the sample period before conflict risk increased across sample countries.

The estimated effect of swams remains statistically significant though decreases in relative magnitude when considering subsamples of cells with greater populations, with any agricultural land, that are within 100km of locations where swarms have been reported, and that have ever experienced violent conflict (Table C3). 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 C4).

Locust swarms also have a negative effect on other measures of violent conflict, including 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 C5). The estimated magnitude of the effect is largest for ACLED non-state conflict and smallest for UCDP major conflicts, consistent with impacts being driven by conflict initiated by non-state actors as presented in the conceptual framework. Swarms also decrease the likelihood of protest/riot events recorded by ACLED, which may involve different mechanisms than the effect on violent conflict. I return to this in Section 7.

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 C3).

6.1.2 Potential endogeneity in swarm reporting

A concern might be that violent conflict reduces the probability that locust swarms are recorded, since insecurity might limit monitoring operations or prevent local observations from being passed on. This concern is the focus of Torngren Wartin (2018)'s analysis of the impact of locusts on conflict, which uses the same data and a related empirical approach. Showler and Lecoq (2021) discuss insecurity as one of the main challenges for effective desert locust control operations by limiting access to areas where locusts may be active. They present evidence on how insecurity has affected locust operations from 1985-2020 across countries where locusts are active, and mention Chad, Mali, Somalia, Sudan, Western Sahara, and Yemen as countries with areas where insecurity has constrained locust control operations in certain periods since 1997.

Showler and Lecoq (2021) focus primarily on concerns for desert locust control operations rather than monitoring and reporting. Insecurity is likely less of a constraint for recording locust swarms, as methods listed in FAO locust monitoring guidelines could support swarm reporting in areas experiencing conflict.[22] Indeed, the FAO locusts data includes observations of locust swarms even in countries and periods where the authors indicate control operations have not been possible due to insecurity. For example, the authors mention that control operations in Western Sahara have been largely infeasible due to Polisario activity over the whole sample period, but 166 swarms have been recorded there in 9 different years from 1996-2018.

Table 2 Columns 1-2 test whether insecurity appears to reduce the probability locust swarms are reported. Violent conflict the previous year reduces the probability a locust

[22] Methods include conducting aerial surveys and using reports from local scouts, agricultural extension agents, security forces, and other sources (Cressman 2001). None of the monthly FAO locust swarm bulletins published during the 2003-2005 upsurge—the major locust event in the sample period—mention issues related to insecurity affecting locust monitoring efforts.

swarm is reported during the year by 0.5 percentage points, though violent conflict in the first half of a year does not significantly affect locust swarm reporting in the second half of the year. This suggest a potential relationship between violent conflict and locust reporting, but Column 3 of Table 1 and Column 4 of Table 2 show that the impact of swarms on the risk of conflict in the same year remains large and statistically significant when controlling for conflict in the previous year and for conflict in the surrounding 15 cells in the same year. The estimated impact falls from a 1.5 percentage point decrease in the risk of conflict to a 1.2 percentage point decrease. Estimates also remain statistically significant when restricting the sample to observations with no conflict the prior year and considering the impact of locust swarms in the first half of the year on violent conflict in the second half of the year (Table 2 Columns 5-7).

Results are largely unchanged when dropping the six countries Showler and Lecoq (2021) describe as having insecurity issues that have limited locust control operations during the sample period (Table 2 Column 8), indicating that these countries do not drive the results. In addition, locust swarms also significantly reduce the probability of any protest or riot event in a given year (Table C5), which are unlikely to affect locust monitoring efforts.

Finally, I simulate how the results would change under different assumptions about the share of cells experiencing conflict that are also experiencing but not reporting locust swarms. I simulate different 'missing swarm' scenarios by replacing the swarm presence dummy with a 1 for a random sample of cells with a violent conflict event within 50km of another cell recording a locust swarm,[23] varying the share of such cells in which I impute swarms. Estimated impacts of swarms on conflict are consistently negative (Figure C4 Panel A). Simulated estimates reject the null hypothesis that the effect of swarms is 0 at a 95% confidence level for up to 19% of conflict cells having imputed swarms and at a 90% confidence level for up to 23% (Figure C4 Panel B). In other words, 23% of cells experiencing conflict within 50km of

[23]The 50km from a locust swarm observation is incorporated to help ensure 'missing' locust swarms are imputed in cells that could plausibly have had a locust swarm unreported due to insecurity. Results are similar when using a 100km threshold—results available upon request.

Table 2: 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.	(8) Drop countries from Showler & Lecoq (2021)
Any violent conflict in cell previous year	-0.005*			0.237***				
	(0.002)			(0.046)				
Any swarm in cell			-0.015***	-0.012***	-0.008***			-0.012**
			(0.005)	(0.004)	(0.002)			(0.005)
Any swarm in cell previous year	-0.026***	-0.028***	-0.009*	-0.006*	-0.005	-0.006*	-0.005	-0.010*
	(0.009)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.005)
Any swarm within 100km outside cell	0.076***	0.028***	-0.001	-0.002**	-0.002**	-0.002	-0.002	-0.004***
	(0.008)	(0.007)	(0.002)	(0.001)	(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)	(0.001)	(0.008)	(0.007)	(0.006)	(0.006)	(0.004)	(0.001)
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)	
Observations	508284	508284	508284	508284	499306	508284	508284	341,655
Outcome mean	0.005	0.003	0.020	0.020	0.011	0.012	0.012	0.013
Weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: 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 C3. Column (8) drops Chad, Mali, Somalia, Sudan, Western Sahara, and Yemen from the analysis as countries discussed in Showler and Lecoq (2021) as having had insecurity issues potentially affecting desert locust control and monitoring operations during the study period. Observations are grid cells approximately 28×28km by year. All columns include cell and country-year FEs. SEs clustered at the country level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

a locust swarm observation would need to have been affected by but not reported a locust swarm for the estimated impact of locust swarms on violent conflict in the same year to no longer be statistically significant.

This share of cells experiencing conflict with unreported locust swarms is implausibly large. The share of cells within 50km of a locust swarm observation where any violent conflict is reported in a year that also report any locust swarm is similar in the countries Showler and Lecoq (2021) list as limiting locust control operations compared to all other countries in the sample: 27% compared to 34%. This suggests that perhaps 5-10% of conflict cell-years in these countries may be 'missing' locust swarm reports due to insecurity concerns. Imputing 'missing' swarms in 23% of such cells is well above this difference and would push the share of cells with conflict events within 50km of a swarm observations that also experienced a locust swarm to over 50%.

These results together indicate that while insecurity does affect locust control operations as documented in the locusts literature and may also limit monitoring activities, measurement error in locust observations correlated with conflict (resulting in reverse causality) does not drive the negative effect of locust swarms on conflict.

6.1.3 Conflict spillovers

Another possibility is that the negative impact of swarms on conflict within a cell is driven by conflict spillovers to neighboring 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 main regression specification includes as a control an indicator for any locust swarm observed within 100km outside the cell (∼28km on each side) in the current or previous year. The point estimates in Table 1 shows fairly precise null effects for locust swarms in the 100km outside a cell in the same year. Swarms outside the cell the previous year have positive point estimates but these are very noisy. This result is not sensitive to the choice of distances outside the cell to consider; the point estimate on the impact of swarms in a cell is very similar when including controls for swarms in different distances outside the cell up to 500km away (Table 1 Column 4).[24]

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

[24]Estimated impacts for swarms at different distances are close to zero and generally non-significant (Figure C5). 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.

event was recorded in any of the four 0.25° cells within a 0.5° cell. In addition to dampening the potential for spillovers outside a cell, analysis at more aggregated spatial levels also controls for the possibility that the area affected by locust swarms exceeds the boundaries of the 0.25° cells in which particular swarms are reported in the FAO data.

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

Note: 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 C6. 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.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Estimated impacts of locust swarms on conflict are negative and statistically significant when aggregating cells up to 1° ($\sim 110 \times 110$km), 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. Part of the decrease in relative impact of locusts on conflict risk at higher aggregations may reflect spillovers not captured by estimating impacts of swarms at increasing distances from a given cell. But the null effects of such swarms (Figure C5) suggests that the reduced proportional impact of swarms at higher aggregations likely results from reduced treatment intensity, as the share of total area affected by locusts within treated areas falls at higher levels of aggregation.

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 C6). 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.

6.2 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 and accounts of 59.5% of swarm observations. Trends for violent conflict events and locust swarms prior to the upsurge were similar across cells that were and were not affected by the 2003-2005 upsurge supporting the parallel trends assumption, and locust swarm presence is similar following the upsurge (Figure A1). Cells are also fairly well balanced on baseline (1997-2002) characteristics (Table A2).[25]

Table 4 presents the results from estimating Equation 4. 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. 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 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 subsample of cells with agricultural land within 250km from any swarm during the upsurge (Column 3), indicating the effect is not driven by comparing upsurge-affected areas to dissimilar areas.

In addition, the long-term effects remain statistically significant when weighting observations by the inverse of the propensity to have recorded a locust swarm during the 2003-2005 upsurge (Columns 2 and 4). The point estimates are somewhat smaller in magnitude but remain large. Among all cells, recording a locust swarm during the upsurge increases the probability of any violent conflict event in a given year after 2005 by 1.1 percentage points (57%) relative to unaffected cells after including inverse propensity weights (Column 3). Among cells with agricultural land within 250km from any upsurge swarm, conflict risk

[25]I include controls for characteristics with differences by upsurge swarm presence in Table C9 and discuss this in subsubsection 6.2.1.

increases by 35% (Column 4).

Table 4: Long-term effects of 2003-2005 locust upsurge on the risk of conflict

	(1)	(2)	(3)	(4)
Any swarm in cell	-0.009**	-0.021***	-0.008**	-0.031**
	(0.004)	(0.007)	(0.003)	(0.014)
Any swarm in cell previous year	-0.012**	-0.021**	-0.012	-0.028*
	(0.005)	(0.010)	(0.007)	(0.016)
Any upsurge swarm × Post	0.016*	0.011*	0.017**	0.011**
	(0.008)	(0.006)	(0.008)	(0.005)
Observations	508284	400671	174912	172410
Outcome mean post-2005, no 2003-2005 swarms	0.026	0.019	0.033	0.032
Proportional impact of upsurge post-2005	0.619	0.565	0.513	0.353
Country-Year FE	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes
Swarm band and weather controls	Yes	Yes	Yes	Yes
Inverse propensity weights	No	Yes	No	Yes
Sample	All cells	All cells	Ag cells w/in 250km of upsurge	Ag cells w/in 250km of upsurge

Note: The dependent variable is a dummy for any violent conflict event observed in a year. Observations are grid cells approximately 28×28km by year. Controls include current and prior year measures of the presence of any swarm within 100km, total rainfall, and maximum temperature. Inverse probability weights are calculated based on the probability of observing any swarm in 2003-2005. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

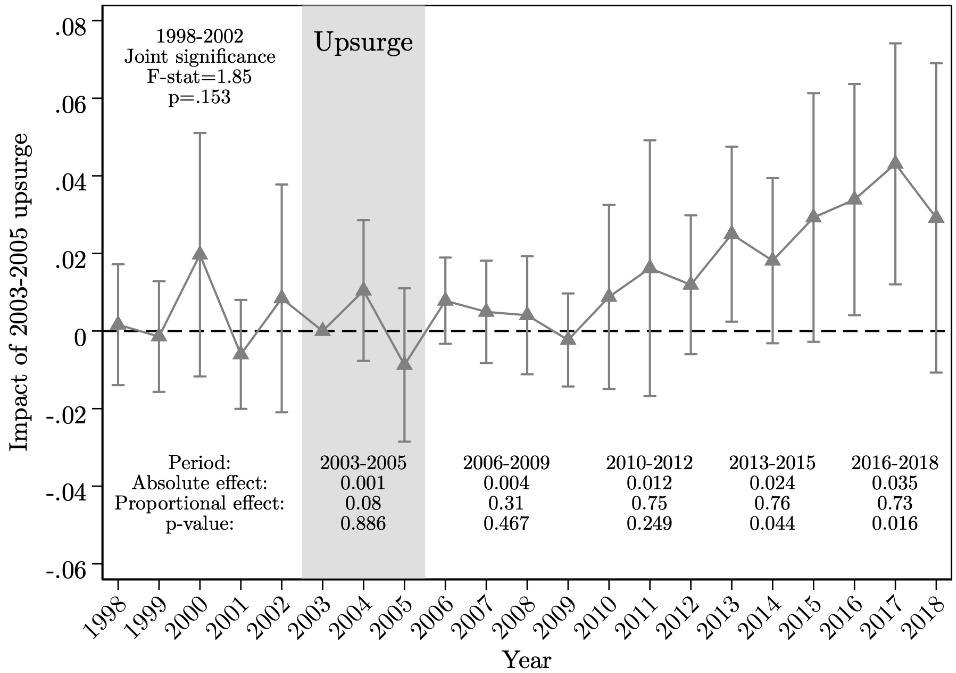
Figure 4 shows the results of an event study analysis of the 2003-2005 upsurge using inverse propensity weights.[26] There are no significant differences in the risk of conflict between areas affected by locust swarms during this upsurge and areas that were not in the years preceding the upsurge ($p = 0.153$), and point estimates are close to 0. This supports the assumption of parallel trends between these areas if not for the upsurge. The analysis controls for whether any swarms were observed in the current and prior year. Consequently, there are no significant impacts of the upsurge in 2004 and 2005, the main years of the upsurge.[27]

Estimated impacts of the 2003-2005 upsurge on conflict in the following years are almost all positive, and become larger in magnitude over time starting after 2009. Effects are not statistically significant during the upsurge itself or in the first 7 years afterward, controlling for current and prior year locust swarms in and around the cell, weather, and cell and

[26] Results are qualitatively similar without using weights (Figure C6), though the long-term impacts are statistically significant starting after 2009 instead of 2012.

[27] The coefficient for 2005, for example, is interpreted as the impact on conflict of having been affected by a swarm in 2003.

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



Note: 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, the first year of the upsurge period which is shaded in gray. 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 28×28km by year, weighted by the inverse of the inverse of the propensity to have recorded a swarm during the 2003-2005 upsurge. SEs are clustered at the country level. Estimates from the same specification with binned years are reported at the bottom of the figure. Proportional effects are relative to the probability of observing any violent conflict during the particular time period. *p*-values are for tests of the null of 0 impact of the upsurge in each period. Results without inverse propensity weights are shown in Figure C6.

country-by-year fixed effects. But being affected by locust swarms during the 2003-2005 upsurge increases the risk of conflict by 2.4 percentage points on average between 2013-2015 and by 3.5 percentage points on average between 2016-2018, and these effects are statistically significant. As civil conflict in the sample countries increased over time due to a variety of factors (Figure A1 Panel A), the proportional effect of the upsurge relative to the probability of conflict is stable at around a 75% increase in conflict risk.

6.2.1 Robustness

To test whether long-term impacts may be driven by general increases in conflict risk not captured by country-year fixed effects, I estimate the long-term impacts of placebo locust upsurges (Figure C7). I conduct 250 simulations where I randomly assign locust presence each year in proportion to the number of swarms actually observed, and use this to define a placebo upsurge treatment and estimate Equation 4. Average estimated effects of placebo upsurges post-2005 are roughly normally distributed with a mean and median of 0 and standard deviation of 0.02. The estimate from Table 4 Column 1 is 2.8 times as large as the largest estimate across the placebo simulations. This indicates that positive impacts in the long-term difference-in-differences specification are not driven by the increase in conflict risk in the years following the upsurge period.

The statistical significance of the estimated long-term impacts does not generally vary when clustering at the highest sub-national administrative level instead of the country level (Table C7), consistent with Figure C1 which shows that country SEs are more conservative than alternatives. Also similar to the short-run estimates, there are no significant differences in long-term impacts on conflict risk by the number of swarms recorded during the upsurge (Table C7 Column 2). The estimated magnitude is slightly larger for cells that experienced multiple swarms during the upsurge (61% of affected cells) compared to cells that experienced one (39%), consistent with greater destruction from multiple swarms, but I cannot reject that estimated effects are the same.

Average impacts of the upsurge in the following years remain large and are generally statistically significant across different sub-samples and specifications (Table C7 Columns 3-7). Estimates are larger in magnitude but noisier and smaller in relative terms in more populous cells. Estimates are similar in magnitude and remain significant when restricting the sample to cells within 100km of a swarm recorded during the upsurge swarm, and are larger and highly significant when including only cells in North and West Africa where the majority of the upsurge took place. Long-term effects remain large and positive after collapsing cells to the 0.5° and 1° levels and are significant when clustering SEs at the highest sub-national administrative level.

The difference-in-difference results are qualitatively similar with and without controls for current and previous year swarms and weather and with different time fixed effects

(Table C8). The magnitude of the average impact of being in a cell affected by the upsurge in the following years is smallest in the main specification with all the controls and country-by-year fixed effects, but the estimates are not significantly different across specifications.

Results are robust to allowing the effects of the main controls for current and previous year weather and locust swarm presence to vary after the upsurge, and estimated long-term impacts of the upsurge on conflict risk are if anything larger in magnitude (Table C9). Effects of these controls on conflict risk are not significantly different between the two time periods, with the exception of swarm presence and temperature in the current year. Variations in annual temperature have a smaller (but still positive) effect on conflict risk after 2005. Recording a locust swarm has a larger negative effect on conflict risk in the same year after 2005, which I return to in subsection 7.1.

Although cells affected by the 2003-2005 upsurge are largely similar to cells that were not in terms of pre-2003 characteristics (Table A2), small differences might affect long term trends in violent conflict risk. Cells affected by the upsurge are more likely to have recorded swarms within 100km in the years before the upsurge and are more likely to have had agricultural land in 2000. Affected cells also have larger populations before 2003, though the difference is not statistically significant. Estimated impacts of the upsurge on conflict risk over the following 14 years remain positive but are slightly smaller and lose statistical significance in the full sample of cells when including controls for agricultural land cover, swarm presence prior to the upsurge, and population (Table C9 Column 4). Differences in the estimate are driven by the inclusion of cell population as a control, as this is time-varying and therefore not absorbed by the cell fixed effects. Population is not significantly associated with conflict risk prior to 2005 but is strongly positively correlated afterward, in the period when conflict risk increased across the sample countries.

Differences in baseline population—though not statistically significant—therefore explain part of the post-upsurge difference in conflict risk in areas affected by the upsurge, as unaffected areas in the full sample of cells include many remote desert areas. But the estimated impact of recording any upsurge swarm remains statistically significant after controlling for population in the subsample of agricultural cells within 250km of an upsurge swarm observation (Table C9 Column 8), where the baseline population differences by upsurge swarm presence are much smaller. The estimated magnitude is nearly identical in the specification with no additional controls as in the specification with additional controls and effects varying post-2005. This indicates that there is a direct impact of the locust upsurge on long-term conflict risk not explained by differences in the population of cells that were affected by the upsurge.

Event study results are robust to including a population-by-year control to account for potential differences in conflict trends over time related to differences in population between cells that were and were not affected by the 2003-2005 locust upsurge (Figure C9). Having a population greater than 10,000 is associated with large and significant increases in conflict risk from 2014-2018 but otherwise does not differentially affect conflict risk over time.[28] Impacts of the upsurge on conflict over time follow the same pattern as in Figure 4, with large and significant increases in conflict risk starting after 2013 in both the full sample of cells and in agricultural cells within 250km of an upsurge swarm observation. The estimated magnitudes are slightly smaller but the similarity in results further indicates that the long-term impact on conflict risk of being in a cell affected by the upsurge is not driven by population differences.

Similar to the difference-in-difference sensitivity tests in Table 4, the pattern of impacts over time is similar across different samples (Figure C8). Non-significant differences prior to the upsurge and significant long-term impacts of increasing magnitues starting around 7 years after the upsurge are seen in the subsets of agricultural cells within 250km of a swarm during the upsurge, of all cells within 100km of an upsurge swarm, and of North and West African cells where most upsurge swarms were recorded. These tests indicate the results are not due to comparing cells affected by the upsurge to far away cells with different long-term

[28]Results available upon request.

conflict trajectories. The pattern of long-term results over time is also similar in 0.5° cells as in 0.25° cells though the estimates are noisier; they are smaller relative to conflict risk in the larger cells consistent with diluted impacts in large cells with more area not affected by swarms.

Long-term impacts on conflict risk are driven by non-state conflict involving actors such as identity/ethnic militias, rebel groups, and terrorist organizations. There is no significant effect of the upsurge on conflict involving no non-state actors in any year and the estimates are all close to 0 (Figure C10 Panels A and B). Impacts of the upsurge on the UCDP measure of violent conflict (at least one organized actor and result in at least 25 battle-related in a calendar year) are smaller in magnitude than the impacts on ACLED violent conflict and not statistically significant with the exception of 2015 and 2018 (Figure C10 Panel C). These results are consistent with the conflict over output by non-state groups following agricultural shocks presented in the conceptual framework. Reduced opportunity costs related to agricultural production following a severe productivity shock should also make individuals more willing to engage in protest activities. In line with this expectation, impacts of the locust upsurge on protest and riot events over time follow a similar pattern to the impacts on violent conflict events recorded by ACLED (Figure C10 Panel D).

In summary, there is a clear and large long-term increase in conflict risk in areas affected by the 2003-2005 locust upsurge, particularly after 2012. This should not be taken to mean that the upsurge directly caused additional conflict after so many years. Rather, it indicates that areas affected by the upsurge were made more vulnerable to engaging in future conflicts precipitated by other proximate factors which increased general conflict risk starting around 2011. This caused conflict events to be more likely to occur in upsurge-affected areas than nearby and similar unaffected areas in the following years. I discuss this interpretation further in the following section.

7 Mechanisms

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 are 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. Opportunity costs of fighting would therefore rebound more quickly than the returns to fighting following a locust swarm.

The short-term negative impacts 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.

Another important consideration 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. Over 8 million people were displaced across East Africa as a result of the 2019-2021 locust outbreak (The World Bank 2020). This indicates that 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.[29] 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.

Impacts of locust swarms on protest and riot events cannot be explained by reduced returns to fighting, as the predation mechanism does not apply for this type of conflict which does not (typically) aim to capture output. Since locust swarms decrease the probability of protest and riot events in the short term, mechanisms such as migration and relief efforts are likely playing an important role.

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

Over the long-term, positive impacts of swarms during the 2003-2005 upsurge on future conflict risk indicates either a persistent decrease in the opportunity costs of fighting in affected areas or a persistent increase in the returns to fighting. While the latter is possible if swarm destruction depletes an areas ability to defend itself from attacks, any such effect is likely to be outweighed by decreases in agricultural productivity.

Adoption of agricultural insurance is very 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 networks and

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

food aid, households commonly report selling animals and other assets, consuming less food, sending household members away, taking loans and cutting expenses, and consuming seed stocks as coping strategies. Many of these strategies would reduce the resources available for agricultural production in following years, decreasing agricultural productivity and the opportunity cost of fighting. Indeed, studies of the long-term impacts of locust upsurges in Mali find lasting negative effects on children's education (De Vreyer, Guilbert, and Mesple-Somps 2015) and health (Conte, Tapsoba, and Piemontese 2021). This reduced human capital could decrease opportunity costs of fighting generally and not just through reduced agricultural productivity.

The opportunity cost 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 strategies would be expected to most adversely affect agricultural productivity. 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 can be explained by the persistent decrease in returns to conflict in the year after a swarm, and by short-term persistence in other mechanisms such as population displacement, receipt of food relief, and increased religiosity. 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.

More puzzling is why the long-term impacts of the 2003-2005 upsurge on conflict risk are delayed, only becoming significant after 2010. The fact that this coincides with a general increase in the risk of conflict across the sample countries (Figure A1) indicates that the broader conflict environment shapes the returns to fighting.

7.1 Predation and the broader conflict environment

The net returns to fighting are likely to be greater when fighting with a group. Having a group increases attacking power and also reduces the social and emotional costs of fighting relative to fighting alone. Consequently, the broader conflict environment will affect how an agricultural shock affects the likelihood of conflict. For example, increased returns to fighting following a positive agricultural shock should on average increase conflict risk more in settings with pre-existing groups capable of fighting. Similarly, a reduction in agricultural productivity will be more likely to increase conflict risk when existing fighting groups reduce the costs of fighting.

Hastings and Ubilava (2023) report evidence of the importance of the conflict environment: they find that the onset of rice harvest in Southeast Asia only increases violence against civilians in years and areas with existing conflict. They argue that in the absence of existing fighting groups, the costs of engaging in predatory conflict during the rice harvest remain too high relative to the potential returns from fighting without a group. Bazzi and Blattman (2014) analyze export commodity price increases over time in developing countries, and find that these do not affect the onset of new conflict but reduce the risk and duration of conflicts. This would be consistent with an opportunity cost mechanism where individuals quit fighting groups when the returns to other activities increases, though they note that other explanations such as increased state resources and capacity play a role.

The potential importance of the broader conflict environment is suggested by the long-term impacts of locust swarms on conflict risk. While the 2003-2005 locust upsurge is unlikely to be directly causing any of the spreading violent conflicts after 2010, by decreasing agricultural productivity in the long term it may have made affected areas more vulnerable to engaging in these conflicts given some other more proximate precipitating events. 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.

I test for differences in swarm impacts by the broader conflict environment by fully interacting the regression models with dummy variables for any violent conflict in the cell in the previous year and for any violent conflict in the 15 other cells in the broader 1° cell. Table 5 shows the estimates from separate regressions for each of these measures of the broader conflict environment for all sample cells and those where a locust swarm was ever recorded in the sample period. Conflicts in the previous year and in surrounding cells have very large but noisy estimated impacts on the probability of any conflict event in a cell in the current year.[30] The negative impact of locust swarms on conflict risk in the same year is only statistically significant for areas with no conflict in the previous year or surrounding cell in the full analysis sample; in the sample of cells where a locust swarm was ever recorded the effects are smaller and not significant. Locust swarms significantly reduce the effect of prior year conflict on conflict in the current year, and this drives the negative average effect of swarms. Swarms reduce the effect of conflict in the previous year by 43% in the full sample of cells and by 26% in the sample of cells ever recording a swarm.

Swarms could potentially affect whether there is any conflict in the area surrounding a cell. Though I find no evidence of conflict spillovers, interactions between swarms and surrounding conflict in the same year should be interpreted as correlations rather than causal. There is no significant difference in the effect of conflict in the surrounding cells on conflict within a cell by the presence of locust swarms, but the point estimates are negative and large in magnitude at around 20% of the estimated effect of surrounding conflict when there are no swarms. These results are broadly consistent with negative agricultural shocks reducing the motive for predation particularly in areas at prior risk of predation.

Table 6 shows the estimates from testing whether long-term impacts of the 2003-2005 upsurge vary by the broader conflict environment. The results indicate that positive impacts of the upsurge on conflict risk in the years following the upsurge are driven entirely by effects in areas with generally greater conflict risk, consistent with Figure 4 showing impacts delayed until years when conflict risk was greatest in the sample countries.

Because the upsurge affects long-term conflict risk, it is not orthogonal to conflict in the previous year nor likely to surrounding conflict in the same year. These results should therefore be considered as illustrative of differences in upsurge impacts by the broader conflit

[30] Clustering SEs at the country level implies very conservative interpretations of statistical significance.

Table 5: Short-term effect of locust swarms on the risk of conflict, by prior and surrounding conflict

	(1) All cells	(2) Ever had a swarm in cell	(3) All cells	(4) Ever had a swarm in cell
Any swarm in cell	-0.008***	-0.001	-0.012***	-0.002
	(0.003)	(0.004)	(0.004)	(0.005)
Any conflict in cell previous year	0.330	0.507*		
	(0.276)	(0.258)		
Any swarm in cell × Any violent conflict in cell previous year	-0.141*	-0.133*		
	(0.071)	(0.079)		
Any conflict elsewhere in 1° cell			0.138	0.272
			(0.114)	(0.171)
Any swarm in cell × Any conflict elsewhere in 1° cell			-0.029	-0.041
			(0.021)	(0.029)
Observations	508284	50404	508284	50404
Outcome mean	0.020	0.039	0.020	0.039
Nearby swarm and weather controls	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes
Country-year FE	Yes	Yes	Yes	Yes

Note: The dependent variable is a dummy for any violent conflict event observed in a year. Observations are grid cells approximately 28×28km by year. All columns include cell and country-year FEs and additional controls as in the main specification, fully interacted with the conflict lag in columns 1 and 2 and with the surrounding conflict dummy in columns 3 and 4. Columns 1 and 3 include all cells in the sample while columns 2 and 4 include only those where a locust swarm was ever recorded. SEs clustered at the country level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

environment rather than accurately estimating differences in the causal impacts. Though I cannot interpret the point estimates with confidence, they imply that conflicts are significantly more likely to persist and to spead to surrounding areas in areas affected by the locust upsurge years before.

The long-term results are consistent with lasting reductions in agricultural productivity reducing opportunity costs of fighting in affected areas and making them more susceptible to engaging in conflict when other factors further influence the net returns to fighting. Reduced opportunity costs of fighting translate into increased conflict in the long term but not the short term because of other offsetting factors in the short-term. In the short term, swarm destruction reduces the perceived net returns to fighting over output. Out-migration and the possibility of receiving relief increase the short-term opportunity costs of fighting and increased religiosity may increase the perceived costs of fighting. In both the short- and long-term however it is clear that impacts of swarms on conflict risk depend on the broader conflict environment.

Table 6: Long-term effect of locust swarms on the risk of conflict, by prior and surrounding conflict

	(1) All cells	(2) Ag cells w/in 250km of upsurge	(3) All cells	(4) Ag cells w/in 250km of upsurge
Any swarm in cell	-0.015**	-0.022*	-0.019**	-0.030*
	(0.006)	(0.012)	(0.008)	(0.014)
Affected by 2003-05 upsurge	0.004	0.002	0.002	0.001
	(0.005)	(0.004)	(0.004)	(0.004)
Any violent conflict in cell previous year	0.195	0.058		
	(0.359)	(0.403)		
Any swarm in cell × Any violent conflict in cell previous year	-0.158**	-0.170**		
	(0.059)	(0.063)		
Affected by 2003-05 upsurge × Any violent conflict in cell previous year	0.156***	0.142***		
	(0.020)	(0.024)		
Any violent conflict elsewhere in 1 degree cell			0.221	0.192
			(0.160)	(0.184)
Any swarm in cell × Any violent conflict elsewhere in 1 degree cell			-0.005	0.001
			(0.019)	(0.024)
Affected by 2003-05 upsurge × Any violent conflict elsewhere in 1 degree cell			0.059***	0.055**
			(0.018)	(0.021)
Observations	400671	172410	400671	172410
Outcome mean, no 2003-2005 swarms	0.015	0.025	0.015	0.025
Outcome mean post-2005, no 2003-2005 swarms	0.019	0.032	0.019	0.032
Country-Year FE	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes
Weather and nearby swarm controls	Yes	Yes	Yes	Yes
Inverse propensity weights	Yes	Yes	Yes	Yes

Note: The dependent variable is a dummy for any violent conflict event observed in a year. Observations are grid cells approximately 28×28km by year. All columns include cell and country-year FEs and additional controls as in the main specification, fully interacted with the conflict lag in columns 1 and 2 and with the surrounding conflict dummy in columns 3 and 4. Columns 1 and 3 include all cells in the sample while columns 2 and 4 include only those where a locust swarm was ever recorded. SEs clustered at the country level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

7.2 Agricultural destruction and seasonality

Another important consideration for the impact of an agricultural shock on conflict is seasonality. Caruso, Petrarca, and Ricciuti (2016), Crost et al. (2018), and Harari and La Ferrara (2018) find that the impact of weather shocks on conflict risk varies depending on whether the timing of the shock is such that it is likely to decrease agricultural productivity in Indonesia, the Philippines, and the African continent respectively. Guardado and Pennings (2021) and Hastings and Ubilava (2023) show that the onset of harvest reduces conflict risk by increased the opportunity cost for agricultural producers in Afghanistan, Iraq, and Pakistan and in Southeast Asia, respectively. The impacts of locust swarms on conflict should operate primarily through first order effects on agricultural output.[31]

Indeed, short-term impacts of locust swarms on conflict concentrated in agricultural areas, based on measures of land cover in 2000 from Ramankutty et al. (2010) (Table A3).[32] Point estimates for the impact of swarms on conflict in cells with no crop land or pasture land are negative but not significant. 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.The impact of swarms is 2 times larger in cells with pasture land than in cells with none.

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. This implies that impacts of swarms on conflict may vary by the timing of swarm arrival relative to the local crop calendar.

Decreases in agricultural productivity will depend on timing. Crop destruction—and therefore the reduction in opportunity costs related to agriculture—will be largest for swarms arriving during the growing and early harvest months between when crops have sprouted and before harvest is completed. Off-season swarms may affect livelihoods through destruction of livestock pasture, tree and perennial crops, and forest resources, but should not affect crop production.

One way off-season or planting season locust swarms may affect opportunity costs is through their association with agricultural productivity for the upcoming season. Farmers in sample countries are anecdotally aware that years with locust swarms are typically also years with great crop yields due to correlated positive rainfall shocks in desert breeding areas

[31] 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.

[32] 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 in 2000, which would reduce the estimated difference in impact by cell land cover. Resuts in Table A3 are similar when definining crop cells as those with any cropland in either Ramankutty et al. (2010) or Xiong et al. (2017).

and agricultural areas. Cells that only experience swarms in the off season or planting season may therefore have *higher* agricultural productivity—and therefore higher opportunity costs of fighting—than in other years. Though the effect on agricultural productivity should be captured by the weather controls in the regressions, farmers may still respond to off-season swarms by increasing engagement in agriculture independently of following weather realizations.

Changes in the perceived returns to fighting will also vary by swarm timing, as the agricultural output available to capture will be affected in the same way as opportunity costs related to agriculture. But these seasonal changes may be small for several reasons. First, groups planning predatory attacks to capture output may have incomplete information about when and where locust swarms have caused damages. Second, since areas affected by a swarm are often affected by multiple swarms in the same year,[33] meaning any swarm presence during the year may reduce expectations about available output to capture. Third, potential psychological impacts like increased religiosity, which may increase the costs of engaging in proscribed behaviors like fighting over output, are likely to be affected more by the presence of swarms than by their specific timing. Consequently, reports of a locust swarm in a particular area at any time may decrease perceived net returns to fighting by outside groups, with less variation by the amount of agricultural destruction caused.

To build intuition, Table 7 presents potential ways impacts of locusts swarms on conflict risk could vary by timing of swarms relative to the crop calendar. The table summarizes the hypothesized direction and rough magnitude of impacts of locust swarms on opportunity costs of fighting related to agriculture for individuals in the affected area and on perceived returns to fighting for potential aggressors by season. I present impacts on perceived returns to fighting as not varying by season, which is equivalent to having any variation by season cancelled out by additional seasonal variation in opportunity costs. In parentheses, I note how off season and planting season swarms may be associated with increased agricultural

[33]On average, cells where swarms are reported record 3.9 different swarm events in that year.

productivity, and what this would implies for impacts on conflict risk.

Table 7: Hypothesized changes in opportunity costs and perceived returns to fighting by swarm timing

Season of swarm arrival	Off	Planting	Growing	Harvest	Prior year
Affected individual's opportunity cost of fighting	. (↑)	↓ (.)	↓↓↓	↓↓↓	↓
Aggressor's perceived returns to fighting	↓↓	↓↓	↓↓	↓↓	↓↓
Change in conflict risk	↓↓ (↓↓↓)	↓ (↓↓)	↑	↑	↓

Note: Hypothesized direction and magnitude of impacts of locust swarms on opportunity costs of fighting related to agriculture in the affected area and on perceived returns to fighting by a potential aggressor by timing of swarms relative to the crop calendar.

The combination of the opportunity cost and returns to fighting effects determines the net expected effect on conflict risk, following the conceptual framework. The table illustrates how locust swarms may increase conflict risk if they arrive in the growing and harvest seasons but decrease it if they arrive in other seasons. The average impacts of locust swarms would then depend on the share of locust swarms arriving at different stages of the crop calendar and the relative magnitudes of swarms across seasons.

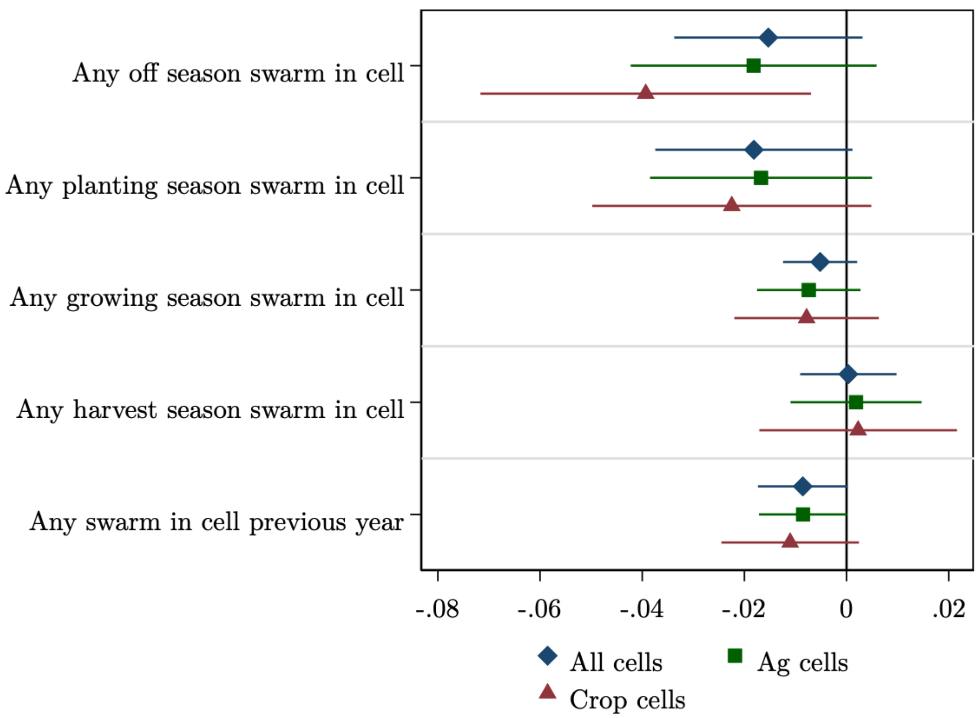
Figure 5 presents the estimated impacts of swarms arriving in different seasons for subsets of cells by land cover.[34] Cells with any crop land (nearly all of which also include pasture land) account for 28.3% of the sample and 36.2% of swarm observations. The count of swarms observed across different points in the agricultural cycle is similar, though somewhat higher in the growing and harvest seasons than in the off or planting seasons (Figure A3). Seasonality may also be relevant in cells with pasture land; cells with either pasture or crop land account for 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. The null effect

[34]Specific coefficients and standard errors are shown in Table A5.

suggests that the offsetting impacts of crop destruction on opportunity costs and returns to fighting approximately cancel out.

Figure 5: Effects of locust swarms on the risk of conflict by swarm timing and land cover



Note: Coefficients and 95% confidence intervals for regressions of a dummy for any violent conflict event in a cell on different indicators of swarm presence. Colors indicate the subsample of cells included in the regression. The results are shown in Table A5. The regression includes controls for current swarms, weather, and cell and country-by-year FE. Observations are grid cells approximately28×28km by year. SEs are clustered at the country level.

Swarms arriving in the off-season between harvest and planting of major crops significantly decrease the risk of conflict in cells with crop area, by 3.9 percentage points (83%). This drives a large average effect across all cells. The difference in impacts between crop cells and agricultural cells in general indicates off-season swarms have a negligible impact in pastoral areas. Since this effect is not operating through destruction of agricultural production,[35] the reduced conflict risk suggests a combination of reduced perceived returns to fighting and increased perceived opportunity costs of fighting as outlined in Table 7. Out-

[35]Annual crops (such as staple grains) take up the large majority of crop land in the sample countries overall so swarm damages to perennial and tree crops should be relatively small. 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.

siders may be deterred from attacking an area experiencing any locust swarm, while farmers in the affected cell may see the swarm as a sign of a potentially productive agricultural season.

Although the estimated impact magnitude in crop cells is largest for off-season swarms, 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). A similar combination of mechanisms as for off-season swarms could explain this result.

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 point estimates are negative, contrary to the hypothesis in Table 7 which supposed the reduced opportunity cost from crop destruction of swarms in this season would outweigh the reduced returns to fighting over output. Migration of affected populations and holding out for relief programs may also contribute to the negative effect.

The pattern of results is similar when analyzing impacts at the level of 0.5° cells rather than 0.25° (Figure C11 Panel A). At the 0.5° 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 negative and significant in all samples, contrary to expectations. Estimated effects by season are also similar across regions, despite differences in crop calendars (Figure C11 Panel B). 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.

The heterogeneity in swarm impacts by timing relative to the agricultural calendar shown in Figure 5 broadly aligns with expectations outlined in Table 7 and clearly indicates that mechanisms other than changes in opportunity costs related to agricultural production determine the effects of swarms on violent conflict.

I also test for differences in long-term impacts of the 2003-2005 upsurge by the timing of swarms during that upsurge. If long-term impacts operate through persistently lower agricultural productivity, these should be driven by swarms arriving during the crop growing cycle and actually reducing household agricultural production. We should see limited long-term effects of upsurge swarms outside growing cycle.

Table 8 presents the results from modifying Equation 4 to separately consider cells where 2003-2005 upsurge swarms were recorded inside and outside the main crop cycle for the country (Figure A4 shows the count of upsurge swarms recorded by crop cover and timing.). As previously, these are interacted with being in a year after 2005 to capture the effect of upsurge swarms that arrived at different times. The regression controls for current and prior year swarms inside the cell and in the 100km outside the cell as well as current and prior year rainfall and maximum temperature, as previously. In addition, all right-hand side variables are interacted with a dummy for whether the cell includes any cropland. I test for whether the impacts of swarms at different times vary by cropland cover.

Effects of current year swarms on conflict and prior year swarms are driven by impacts in cells with cropland (Table A3), in line with expectations for impacts through upsurge crop destruction. Impacts are larger for crop cells than for non-crop cells, and the difference is significant for upsurge swarms that arrived in the crop growing cycle for the country. Areas affected by upsurge swarms that arrived in months when crops are grown are 3.6 percentage points more likely to experience violent conflict in a given year after the upsurge ended, a large and statistically significant effect. Impacts are larger for upsurge swarms in crop cells that arrived during the crop cycle than for those arrived outside the crop cycle, but the distance is not significant—in general the estimates are somewhat imprecise due to the smaller numbers of cells falling into the different categories of upsurge swarm time and any cropland. Impacts of upsurge swarms in crop cells outside the main growing season may be due to damages to pasture (present in all crop cells) and permanent crops such as trees.

While the estimates are somewhat imprecise, they are consistent with long-term impacts of the upsurge driven by destruction of agricultural production during the upsurge. This suggests that persistent reductions in agricultural productivity following this destruction likely do explain the long-term impact of the upsurge on increased risk of violent conflict.

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 in the short term. 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, though further work could explore differences in areas that may be more likely to experience spillovers.

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 and validate the variation in impacts by swarm timing relative to the agricultural calendar.

Decreased conflict risk is driven primarily by swarms arriving in the off and planting seasons when impacts on opportunity costs of fighting are limited while perceived returns to fighting for predatory groups fall. Other mechanisms such as migration, psychological impacts, or holding out for relief programs may also help explain the negative effect. Geographically disaggregated data on relief efforts (or more general aid flows) could be useful to explore whether these play a role in reducing risk of fighting following an agricultural shock 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 production shocks have more adverse effects on food security. Psychological mechanisms are underexplored in the literature on conflict. Future work could analyzing impacts of agricultural shocks on psychological factors such as aspirations, beliefs, and religiosity, as well as correlations between these factors and conflict risk to determine the potential importance of these mechanisms.

Data on population movements could help test migration as a mechanism for coping with negative agricultural shocks rather than turning to fighting. 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).

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 around 50% 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. Differences by whether upsurge swarms arrivd during the crop growing cycle and by cropland cover suggest the results are driven by persistent decreases in agricultural productivity. These may reduce the opportunity cost of joining militant groups when these become active but not otherwise affect conflict risk. Analyzing long-term changes in agricultural productivity, labor supply, household wealth, and migration would help clarify how impacts on opportunity costs change over time. In general, these results highlight how failing to support communities affected by disasters to fully recover can create conditions for future conflict.

Both the short- and long-term impacts of locust swarms hihglight the importance of the broader conflict environment in determining the impact of an agricultural production shock on conflict. The net returns to fighting will vary by whether there are existing fighting groups with which to engage. Long-term impacts of upsurge swarms are concentrated in periods and areas with increased conflict risk, while in the short-term locust swarms make prior year conflict less likely to persist by reducing current year returns to fighting.

Beyond contributing to our understanding of the relationship between agricultural productivity shocks and conflict risk, the findings are also relevant for considering multilateral policy around climate change mitigation and adaptation. Climate change is increasing the frequency and severity of agricultural shocks, including by creating conditions suitable for desert locust swarm formation. These shocks impose additional costs on society through their impacts on conflict risk which should be considered when weighing the costs and benefits of potential actions to address risks from agricultural shocks. For example, desert locusts do not respect country boundaries and require international coordinate for adequate monitoring and control. Although they do not increase conflict risk in the short-term, the long-term impact on conflict should be considered in determining policy around locust monitoring and control operations.

Table 8: Long-term effect of locust swarms on the risk of conflict, by timing of upsurge swarms

	(1)	(2)
Current year swarm	-0.010**	-0.017
Non-crop cell	(0.004)	(0.011)
Current year swarm	-0.040***	-0.039***
Crop cell	(0.012)	(0.013)
p, diff.=0	0.003	0.013
Prior year swarm	-0.008*	-0.008
Non-crop cell	(0.005)	(0.010)
Prior year swarm	-0.038*	-0.037*
Crop cell	(0.020)	(0.020)
p, diff. in swarm lag effect	0.127	0.155
Out-season upsurge swarm × Post	0.009	-0.008
Non-crop cell	(0.015)	(0.009)
Out-season upsurge swarm × Post	0.023	0.015
Crop cell	(0.017)	(0.015)
p, diff. in Out-season upsurge swarm effect	0.482	0.266
In-season upsurge swarm × Post	-0.006	-0.009
Non-crop cell	(0.004)	(0.006)
In-season upsurge swarm × Post	0.036*	0.038**
Crop cell	(0.018)	(0.016)
p, diff. in In-season upsurge swarm effect	0.043	0.032
p, Non-crop out-season = in-season	0.323	0.885
p, Crop out-season = in-season	0.538	0.241
Observations	400671	172410
Outcome mean post-2005, no upsurge	0.019	0.032
Country-Year FE	Yes	Yes
Cell FE	Yes	Yes
Surrounding swarm and weather controls	Yes	Yes
Inverse propensity weights	Yes	Yes
Sample	All cells	Ag cells w/in 250km of upsurge

Note: The results in each column are from a single regression of a dummy for any violent conflict event on different indicators of swarm presence and controls all interacted with a dummy for any crop land cover in a cell. The columns indicate the subset of cells considered. For each interaction, I show the coefficient for the swarm variable when there is no cropland, the sum of this coefficient and the interaction with land cover, and the p-value for the test that the coefficient on the interaction is equal to 0. I include p-values for the tests that the effects of upsurge swarms arriving at different times are the same by crop land cover. In-season upsurge swarm × Post is a dummy for being a cell that recorded any 2003-2005 upsurge swarm during the crop cycle, in a year after 2005. Out-season upsurge swarm is similar but for upsurge swarms outside the crop cycle. Observations are grid cells approximately 28×28km by year. Controls include current and prior year measures of the presence of any swarm within 100km, total rainfall, and maximum temperature and their interactions with the crop cell dummy. Inverse probability weights

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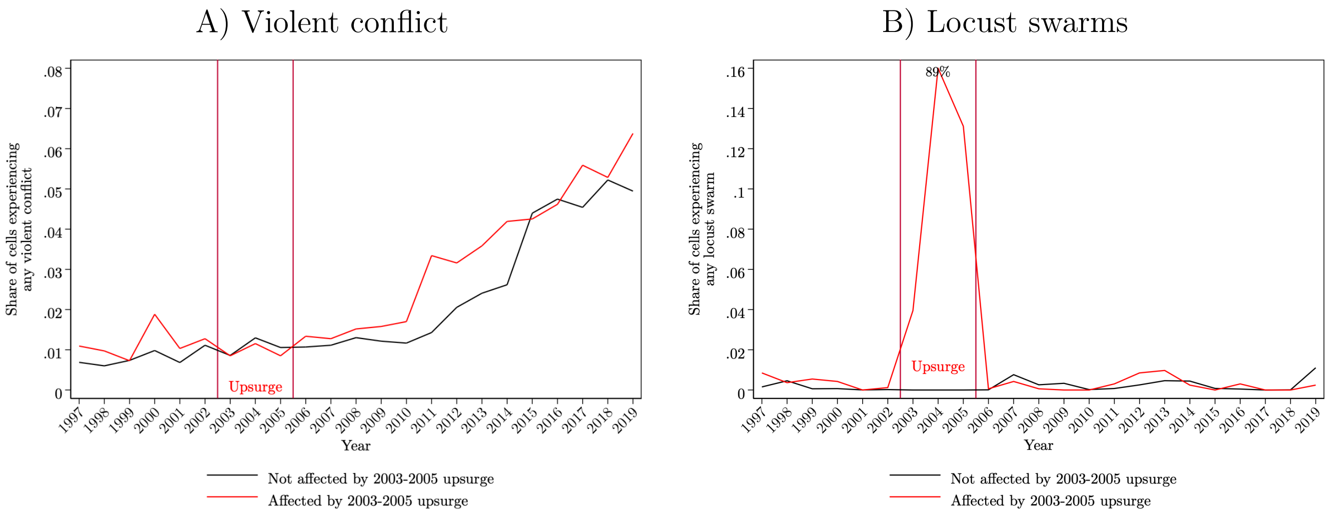
Appendix A: Additional Figures and Tables

Table A1: Summary statistics

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

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

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



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

Table A2: Baseline balance by presence of any locust swarm in 2003-2005

			Difference by any locust swarm in 2003-2005			
	N	Control Mean (SD)	All cells (SE)	All cells (SE)	Ag cells w/in 250km of upsurge (SE)	Ag cells w/in 250km of upsurge (SE)
Mean years with violent conflict event in cell, 1997-2002	24461	0.008	0.004	0.005	0.002	0.007
		(0.058)	(0.004)	(0.005)	(0.007)	(0.008)
Mean years with locust swarm in cell, 1997-2002	24461	0.001	0.003***	-0.003	0.001	-0.011
		(0.016)	(0.001)	(0.004)	(0.001)	(0.011)
Mean years with locust swarm w/in 100km outside cell, 1997-2002	24461	0.024	0.024	0.028**	0.004	-0.000
		(0.075)	(0.015)	(0.014)	(0.014)	(0.022)
Mean population (10,000s), 1997-2002	24460	1.368	0.935	0.543	0.190	0.197
		(6.540)	(0.759)	(0.491)	(0.841)	(0.519)
Mean total annual rainfall (100 mm), 1997-2002	24207	2.399	0.037	-0.002	-1.078**	-0.368
		(3.699)	(0.461)	(0.309)	(0.459)	(0.325)
Mean max annual temperature (deg C), 1997-2002	24207	37.576	-1.362	-0.082	0.422	0.563
		(5.194)	(0.967)	(0.498)	(0.587)	(0.527)
Any cropland or pasture in cell	23924	0.522	0.230***	0.133**	0.000	0.000
		(0.500)	(0.073)	(0.058)	(.)	(.)
Share of cropland or pasture in cell	23924	0.230	0.109**	0.027	-0.024	-0.076***
		(0.321)	(0.047)	(0.042)	(0.028)	(0.029)
Any cropland in cell	23924	0.285	0.066	0.057	-0.099	-0.006
		(0.451)	(0.072)	(0.048)	(0.097)	(0.053)
Share of cropland in cell	23924	0.047	0.010	0.023	-0.035	0.009
		(0.131)	(0.010)	(0.017)	(0.023)	(0.022)
Any pasture in cell	23924	0.512	0.239***	0.135**	0.012	0.004
		(0.500)	(0.074)	(0.057)	(0.008)	(0.004)
Share of pasture in cell	23924	0.183	0.099**	0.004	0.012	-0.085***
		(0.273)	(0.046)	(0.032)	(0.041)	(0.023)
Weights			No	Yes	No	Yes

Note: The table shows results from separate bivariate regressions of baseline (1997-2002) outcomes on whether any locust swarm was observed in a cell between 2003-2005. The rows indicate which dummy dependent variable is used. The first two columns include all sample cells, while the second two restrict the sample to cells with any agricultural land that were within 250km of a swarm observation in 2003-2005. Columns (2) and (4) include inverse probability weights based on the probability of observing any swarm in 2003-2005. Observations are grid cells approximately 28×28km by year. 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, 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

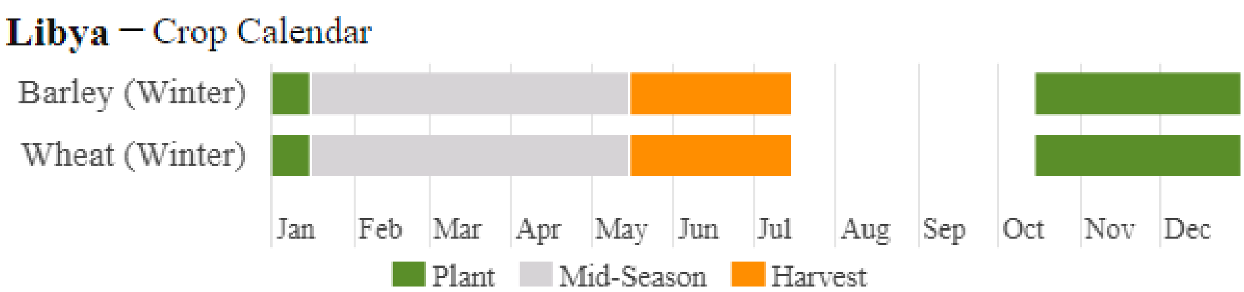
Note: The dependent variable is a dummy for any violent conflict event observed. Observations are grid cells approximately 28×28km by year. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

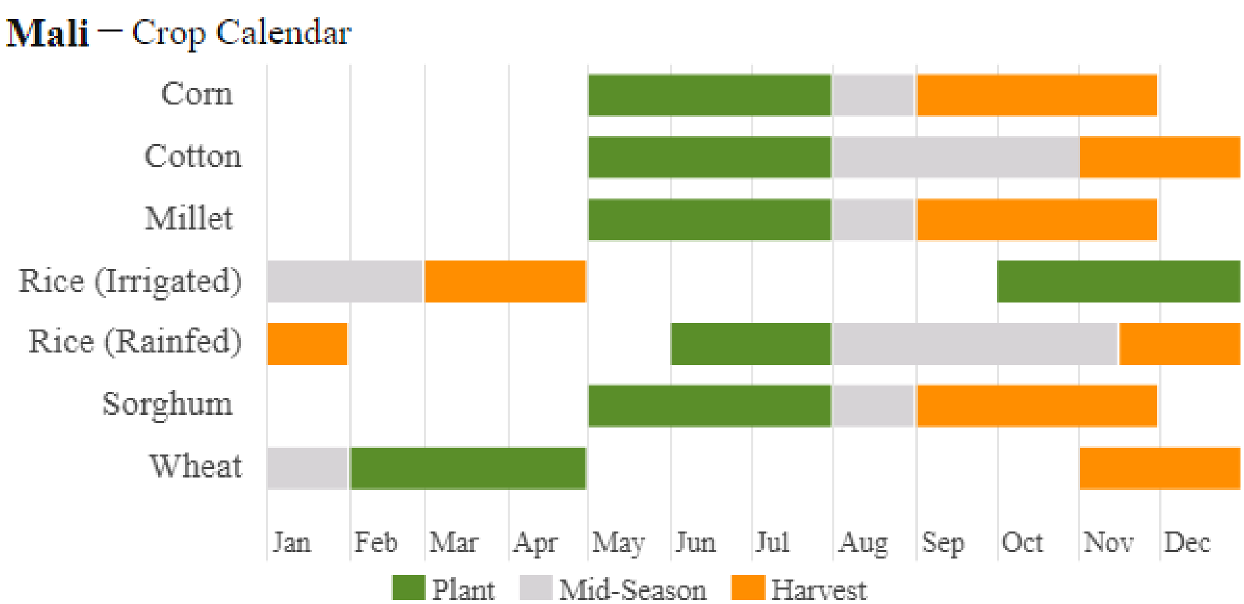
Table A4: Effect of locust swarms on the risk of conflict, fallowing, and cultivation in crop areas from 2003-2014

	(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

Note: 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 28×28km 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 A2: Example crop calendars

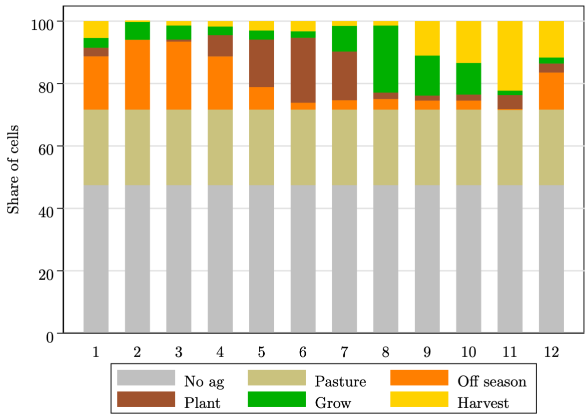




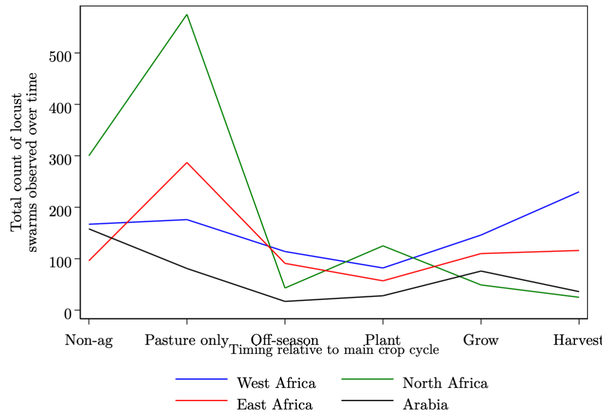
Source: U.S. Department of Agriculture Foreign Agricultural Service, International Produlsion Assessment Division (USDA 2022).
Note: The Libya crop calendar is fairly representative of other North African countries, and the Mali crop calendar is fairly representative of other West African countries.

Figure A3: Timing of locust swarm arrival by phase of crop calendar and region

A) Agricultural activities by month of year



B) Timing of locust swarm arrival



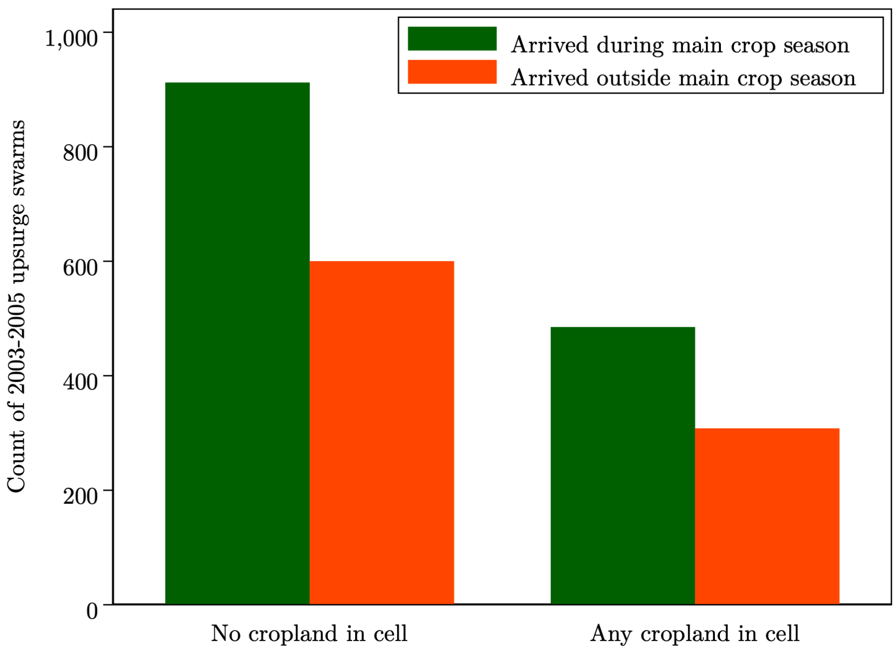
Note: Agricultural activities by month are determined by assigning each cell with any crop land the primary activity for that month in the country in which it is located, using USDA 2022 crop calendars. Land cover in the year 2000 is from Ramankutty et al. (2010). Locust swarm observations are matched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

Table A5: 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

Note: 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 28×28km by year. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure A4: Count of locust swarms recorded during the 2003-2005 upsurge by swarm timing and land cover



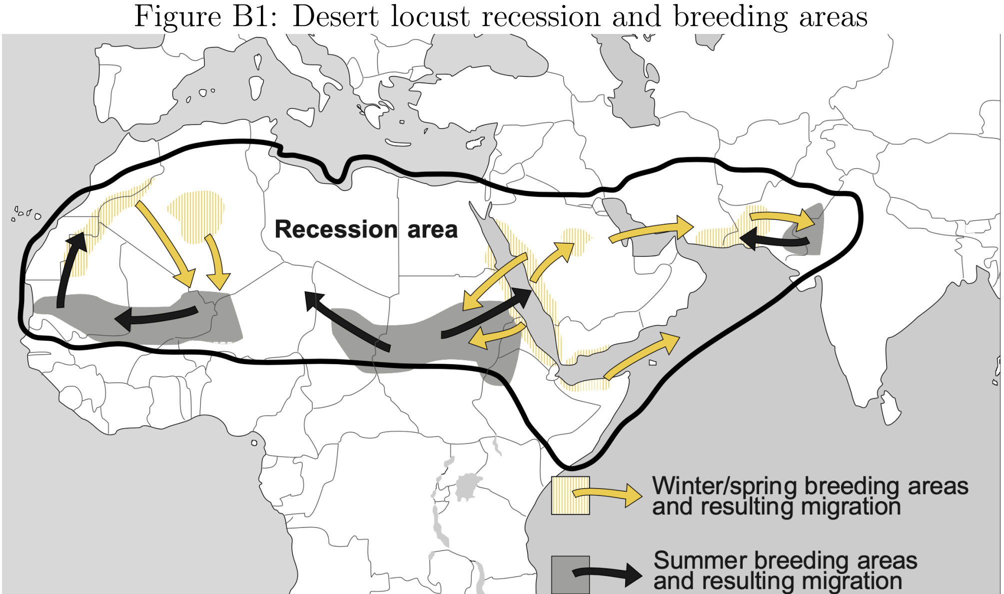
Appendix B: Desert locusts background

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

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

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

Figure B1: Desert locust recession and breeding areas



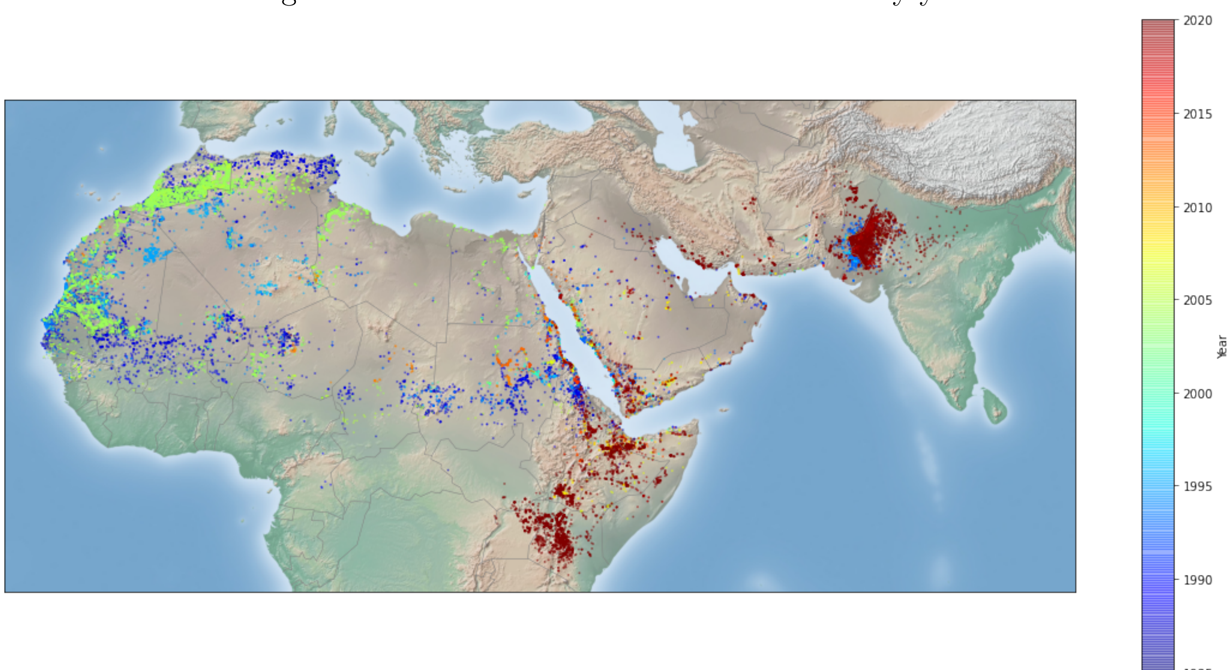
Source: Symmons and Cressman (2001).

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

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 widespead locust infestations. Few locust swarms are observed outside of major outbreaks, as conditions favoring swarm formation tend to produce large swarms which reproduce and spread rapidly and are very difficult to control.

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

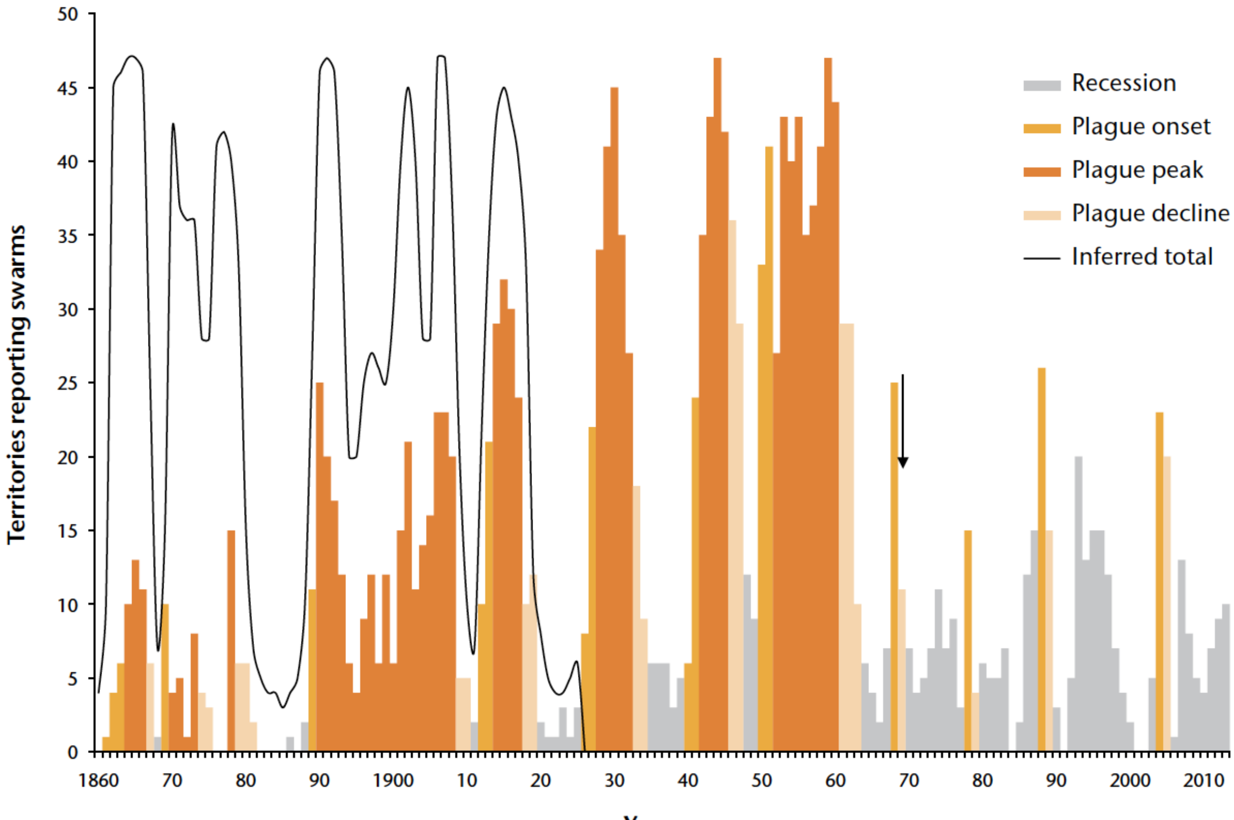
Figure B2: Desert locust swarm observations by year



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

The frequency of large-scale outbreaks has fallen since around the 1980s, in large part due to increases in coordinated preventive operations (Cressman and Stefanski 2016), as shown by the figure below. Given their tolerance for extreme heat and responsiveness to periods of heavy precipitation, however, climate change might create conditions conducive to more frequent desert locust outbreaks.

Figure B3: Desert locust observations by year



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

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

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

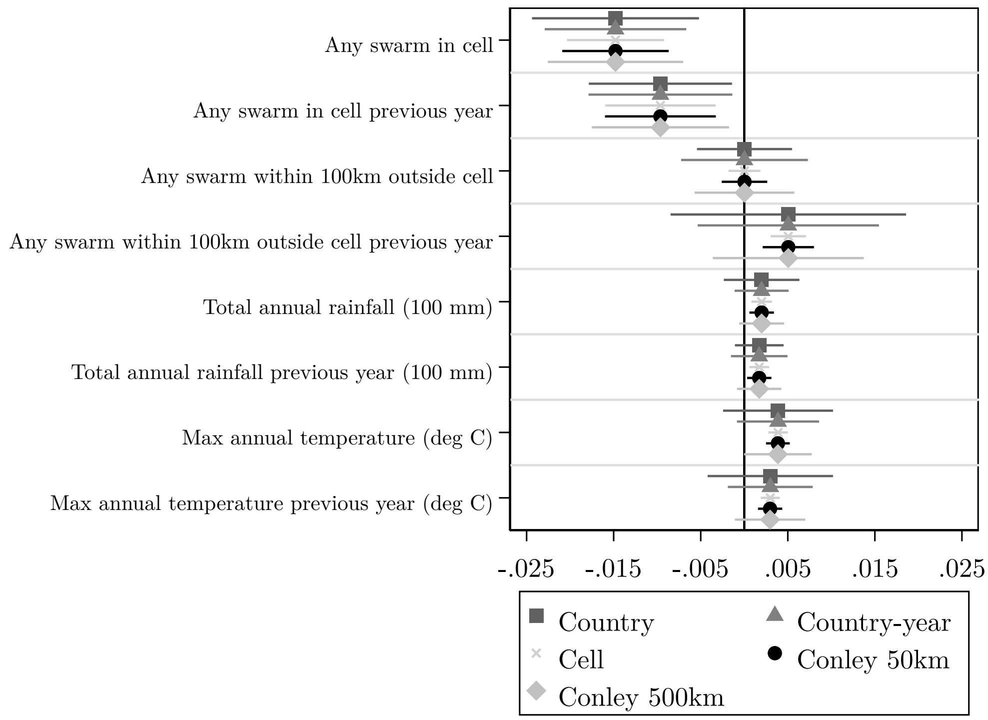
Swarms fly downwind from a few hours after sunrise to an hour or so before sunset when they land and feed. Swarms do not always fly with prevailing winds and may wait for warmer winds; seasonal changes in these winds tend to bring locusts to seasonal breeding areas at times when rain and the presence 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 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 3 with different SEs



Note: The figure shows 95% confidence intervals for estimates from Table C3 column (1) applying different clustering for the SEs. The outcome variable is a dummy for any violent conflict observed. Observations are grid cells approximately 28×28km by year. Regressions also include country-year and cell FE.

Table C1: Effect of swarms on the risk of conflict, varying controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Any swarm in cell	-0.009	-0.010	-0.009	-0.015***	-0.015***	-0.013***	-0.011**	-0.014***	-0.014**
	(0.008)	(0.006)	(0.008)	(0.005)	(0.005)	(0.004)	(0.006)	(0.005)	(0.005)
Any swarm within 100km outside cell		0.001			-0.001	-0.001	-0.003	-0.006*	-0.008
		(0.004)			(0.002)	(0.001)	(0.002)	(0.003)	(0.005)
Any swarm in cell previous year			-0.008		-0.009*	-0.007*	-0.008	-0.009	-0.007
			(0.005)		(0.004)	(0.004)	(0.006)	(0.005)	(0.005)
Any swarm within 100km outside cell previous year					0.004	-0.000	0.008	0.002	0.000
					(0.008)	(0.002)	(0.009)	(0.005)	(0.003)
Observations	562539	562539	562539	508284	508284	507922	508284	508284	508283
Adj-R^2	0.316	0.316	0.316	0.320	0.320	0.385	0.275	0.320	0.282
Outcome mean, no swarms	0.020	0.020	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	-0.755	-0.700
Swarm Bands	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Swarm Lags	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Weather	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Cntry-year	Cntry-year	Cntry-year	Cntry-year	Cntry-year	Region-year	Year	Cntry trend	Region trend
Location FE	Cell	Cell	Cell	Cell	Cell	Cell	Cell	Cell	Cell

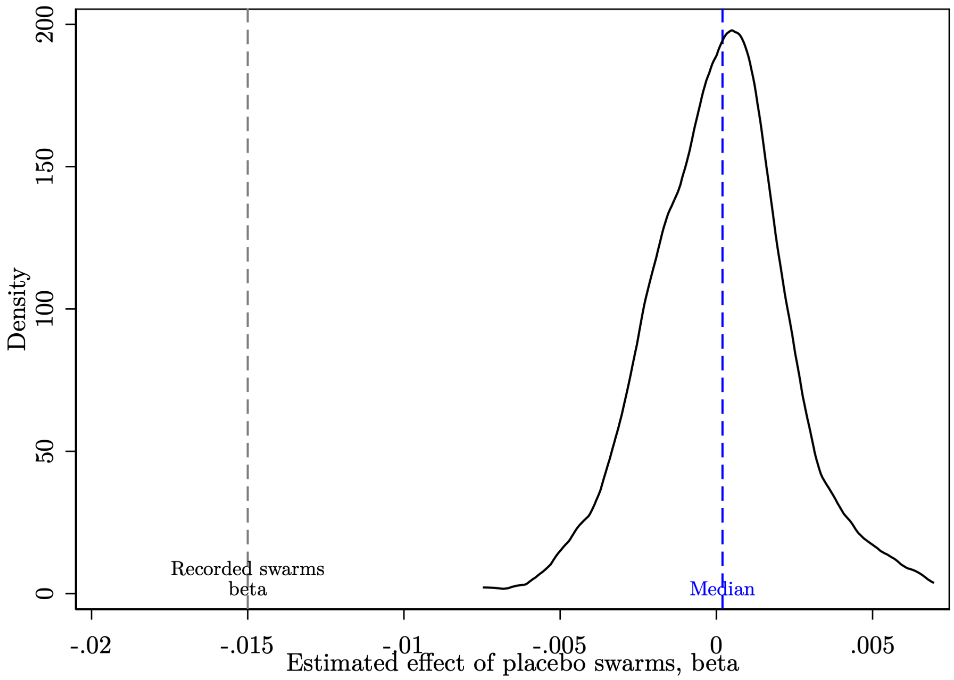
Note: The outcome variable is a dummy for any violent conflict observed. The main independent variable is a dummy for any locust swarms observed. Observations are grid cells approximately 28×28km by year. Coefficients for weather controls are not shown. 'Cntry-year' and 'Region-year' indicated country and region by year fixed effects, respectively. 'Cntry trend' and 'Region trend' indicate linear trends in year at the country and year level, respectively. 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, first differences

	(1)	(2)	(3)	(4)
Δ any swarm in cell	-0.004	-0.004	-0.007	-0.007**
	(0.003)	(0.003)	(0.005)	(0.004)
Δ any swarm in cell previous year	-0.004	-0.004	-0.006	-0.006
	(0.003)	(0.004)	(0.004)	(0.004)
Δ any swarm w/in 100km outside cell	-0.007*	-0.007***		
	(0.004)	(0.002)		
Δ any swarm w/in 100km outside cell previous year	-0.004**	-0.004***		
	(0.002)	(0.001)		
Δ total annual rainfall (100 mm)	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Δ total annual rainfall previous year (100 mm)	-0.000	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Δ max annual temperature (100 mm)	0.000	0.000	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Δ max annual temperature previous year (100 mm)	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	484076	484076	484076	484076
Outcome mean, no swarms	0.021	0.021	0.021	0.021
Proportional effect of Δ swarms	-0.188	-0.188	-0.357	-0.357
Country-Year FE	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes
Level of SE clustering	Country	Region	Country	Region

Note: The table reports results from Equation 3 after taking first differences for all variables. The outcome variable is therefore the change in whether any violent conflict is observed between the current and the previous year. The main independent variable is the change in whether any locust swarms is observed between the current and the previous year. Other variables are interpreted analogously, with lagged variables representing the change between previous year and the year before that. Observations are grid cells approximately 28×28km by year. SEs are clustered at either the country level or the region (highest sub-national administrative level), as indicated in each column.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure C2: Effect of placebo swarms on the short-term risk of conflict



Note: The figure shows the results from 250 simulations of randomly assigning placebo swarms each year in the same frequency as actual locust swarms are observed, plotting the density of estimated coefficients for placebo swarms. The blue dashed line shows the median across simulations, and the gray dashed line shows the estimate for the true swarm observations from Table 1 Column 1. The dependent variable is a dummy for any violent conflict. The independent variable is a dummy for any placebo locust swarm. Other controls are as in Equation 3. Observations are grid cells approximately 28×28km by year. SEs are clustered at the country level.

Table C3: 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

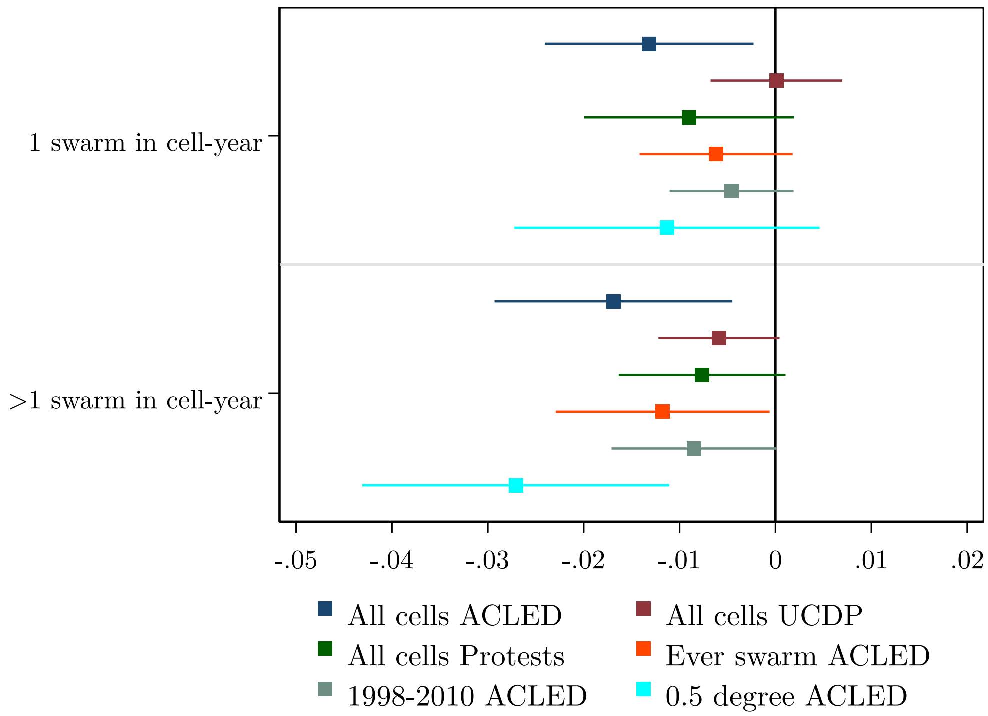
Note: The dependent variable is a dummy for any violent conflict event observed. Observations are grid cells approximately 28×28km by year. SEs clustered at the country level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C4: 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

Note: The dependent variable is a dummy for any violent conflict event observed. Column (1) replicates column (1) from Table C3. 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 28×28km 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 C3: Impacts of one vs. multiple swarms in a year on violent conflict risk



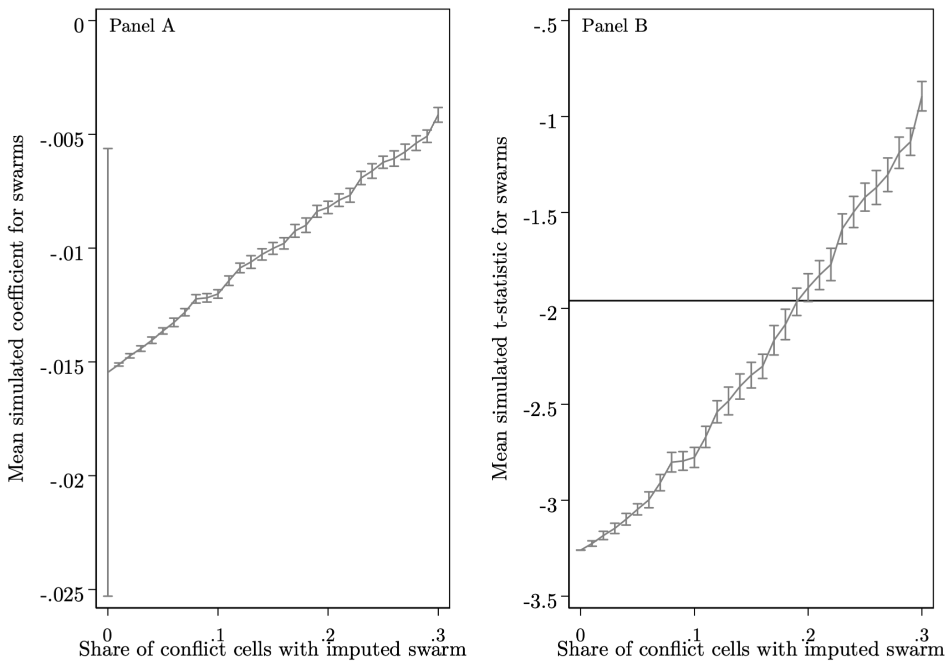
Note: The figure shows 95% confidence intervals for estimates of the main regressions specification replacing the swarms dummy with dummy variables for either 1 swarm observed in a year or more than 1 swarm, across different outcomes and specifications. The outcome variables are all dummy variables for 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 28×28km—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 C5: 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 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 violent non-state conflict ACLED	508284	0.017	-0.012***
		(0.131)	(0.004)
Any violent non-state conflict UCDP	508284	0.004	-0.002
		(0.063)	(0.001)
Any violent state conflict ACLED	508284	0.006	-0.007**
		(0.077)	(0.003)
Any violent state conflict UCDP	508284	0.007	-0.001
		(0.086)	(0.002)
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)

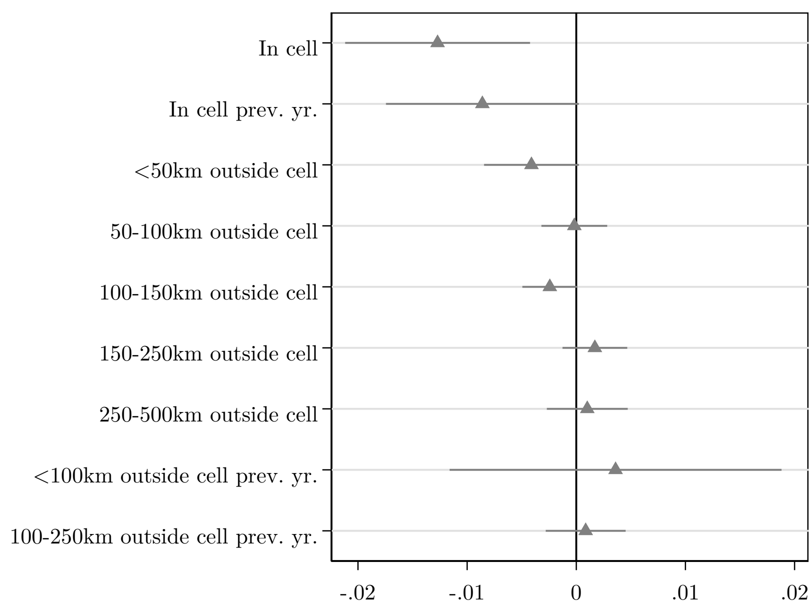
Note: This table shows estimates of the impact of a locust swarm in the same year from Equation 3 using different measures of conflict as the outcome variable. All regressions include nearby swarm and weather controls along with country-year and cell FE. Observations are grid cells approximately 28×28km by year. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure C4: Results of simulating 'missing' swarms in cells experiencing conflict



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

Figure C5: Effect of locust swarms at varying distances from the cell



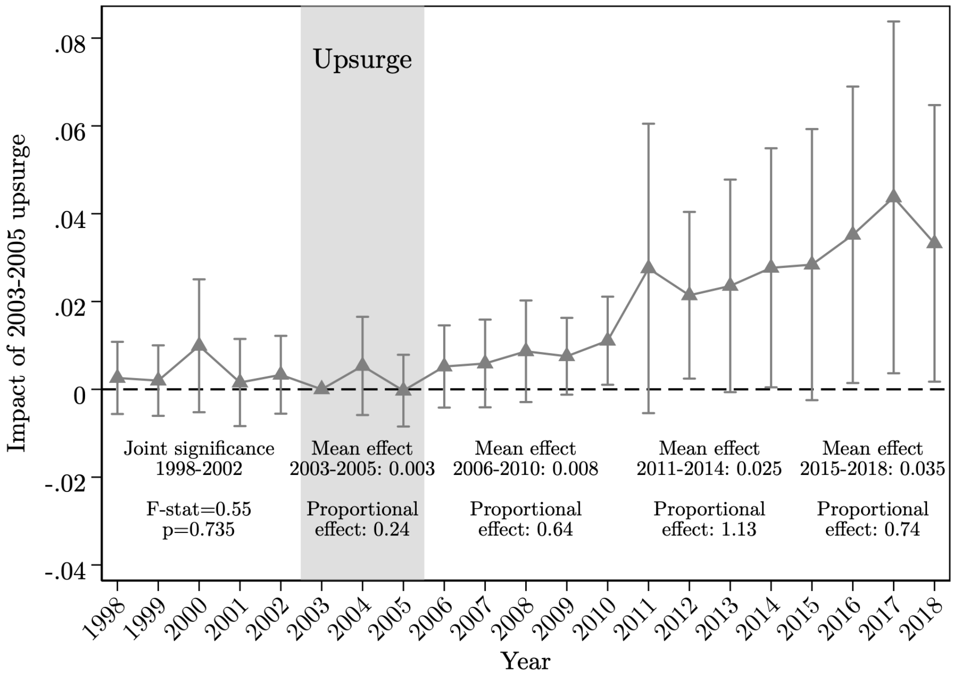
Note: The figure shows point estimates and 95% confidence intervals for estimates of the impact of locust swarms by location relative to the cell on the probability of violent conflict in the cell. Observations are grid cells approximately 28×28km by year. All regressions include weather controls as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

Table C6: 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

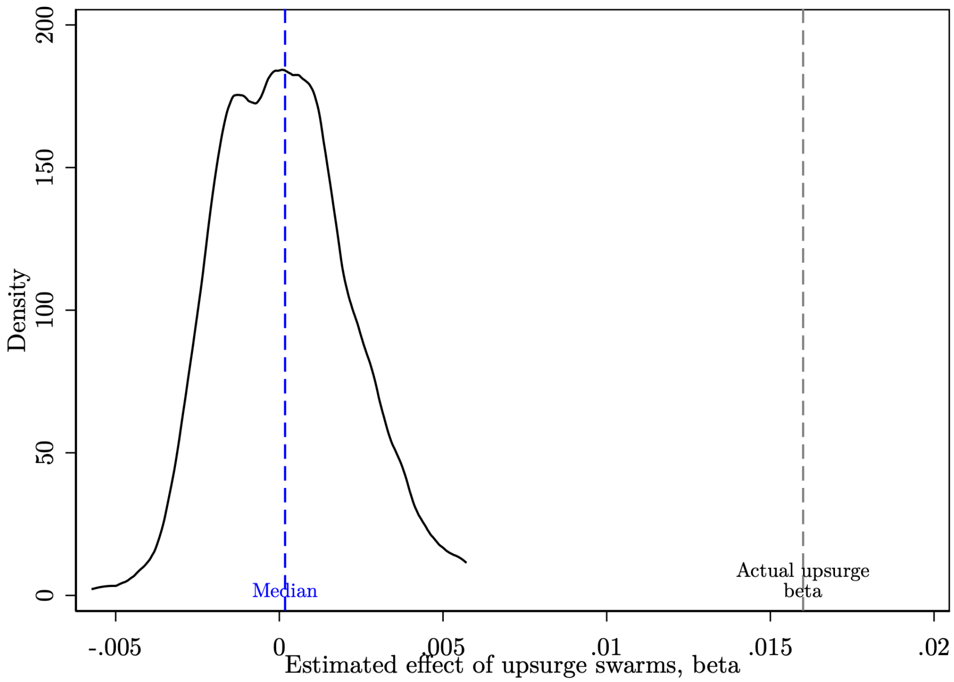
Note: The dependent variable is the share of 0.25 degree cells in the aggregated area with any violent conflict event in a year. Similarly, swarm presence variables are the share of 0.25 degree cells in the aggregated area with any swarm in a year. Weather controls are means for total annual rainfall and max annual temperature across cell-years within the aggregated area. Column (1) replicates Column (1) from Table C3. 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 C6: Effects of 2003-2005 locust upsurge on the risk of conflict by year, no inverse propensity weights



Note: 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, the first year of the upsurge period which is shaded in gray. 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 28×28km by year, with no weights. SEs are clustered at the country level. Estimates from the same specification with binned years are reported at the bottom of the figure. Proportional effects are relative to the probability of observing any violent conflict during the particular time period. Results with inverse propensity weights are shown in Figure 4.

Figure C7: Effect of placebo upsurge on the long-term risk of conflict



Note: The figure shows the results from 250 simulations of randomly assigning placebo swarms during the 2003-2005 upsurge (and other years) in the same frequency as actual locust swarms are observed, plotting the density of estimated coefficients for cells affected by placebo upsurge swarms. Approximately 7% of cells are assigned a placebo upsurge swarm. The blue dashed line shows the median across simulations, and the gray dashed line shows the estimate for the true upsurge observations from Table 4 Column 1. The dependent variable is a dummy for any violent conflict. The independent variable is a dummy for being in a year after 2005 and having had any placebo upsurge swarm. Other controls are as in Equation 3. Observations are grid cells approximately 28×28km by year. SEs are clustered at the country level.

Table C7: Long-term effects of 2003-2005 locust upsurge, robustness to different subsamples

	(1) All cells	(2) All cells by count of swarms	(3) >=10k pop.	(4) W/in 100km of upsurge	(5) North & West Africa	(6) 0.5° cells	(7) 1° cells
Any swarm recorded during upsurge × Post	0.011		0.018	0.010	0.016	0.023	0.033
	(0.006)*		(0.012)	(0.005)*	(0.007)**	(0.014)	(0.023)
	[0.006]*		[0.012]	[0.005]**	[0.006]***	[0.013]*	[0.018]*
1 swarm recorded during upsurge × Post		0.009					
		(0.008)					
		[0.008]					
2+ swarms recorded during upsurge × Post		0.013					
		(0.007)*					
		[0.007]*					
Observations	400671	400671	122077	223191	314435	109828	32113
Outcome mean post-2005, no upsurge	0.019	0.019	0.047	0.023	0.013	0.056	0.125
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Current swarm and weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inverse propensity weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The dependent variable is a dummy for any violent conflict event observed in a year. Observations are grid cells approximately 28×28km by year. Controls include current and prior year measures of the presence of any swarm in the cell and within 100km, total rainfall, and maximum temperature. Inverse probability weights are calculated based on the probability of observing any swarm in 2003-2005. SEs in parentheses are clustered at the country level. SEs in brackets are clustered at the highest sub-national administrative level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C8: Long-term effects of 2003-2005 locust upsurge, robustness to different controls and FE

	(1)	(2)	(3)	(4)	(5)	(6)
Any upsurge swarm × Post	0.011*	0.015**	0.011*	0.015**	0.014*	0.014*
	(0.006)	(0.007)	(0.006)	(0.007)	(0.007)	(0.007)
Observations	400671	438830	400671	438830	400625	400680
Outcome mean post-2005, no upsurge	0.019	0.020	0.019	0.020	0.019	0.019
Time FE	Cntry-yr	Cntry-yr	Cntry-yr	Cntry-yr	Region-yr	Year
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Current swarm controls	Yes	No	No	Yes	Yes	Yes
Current weather controls	Yes	No	Yes	No	Yes	Yes
Inverse propensity weights	Yes	Yes	Yes	Yes	Yes	Yes

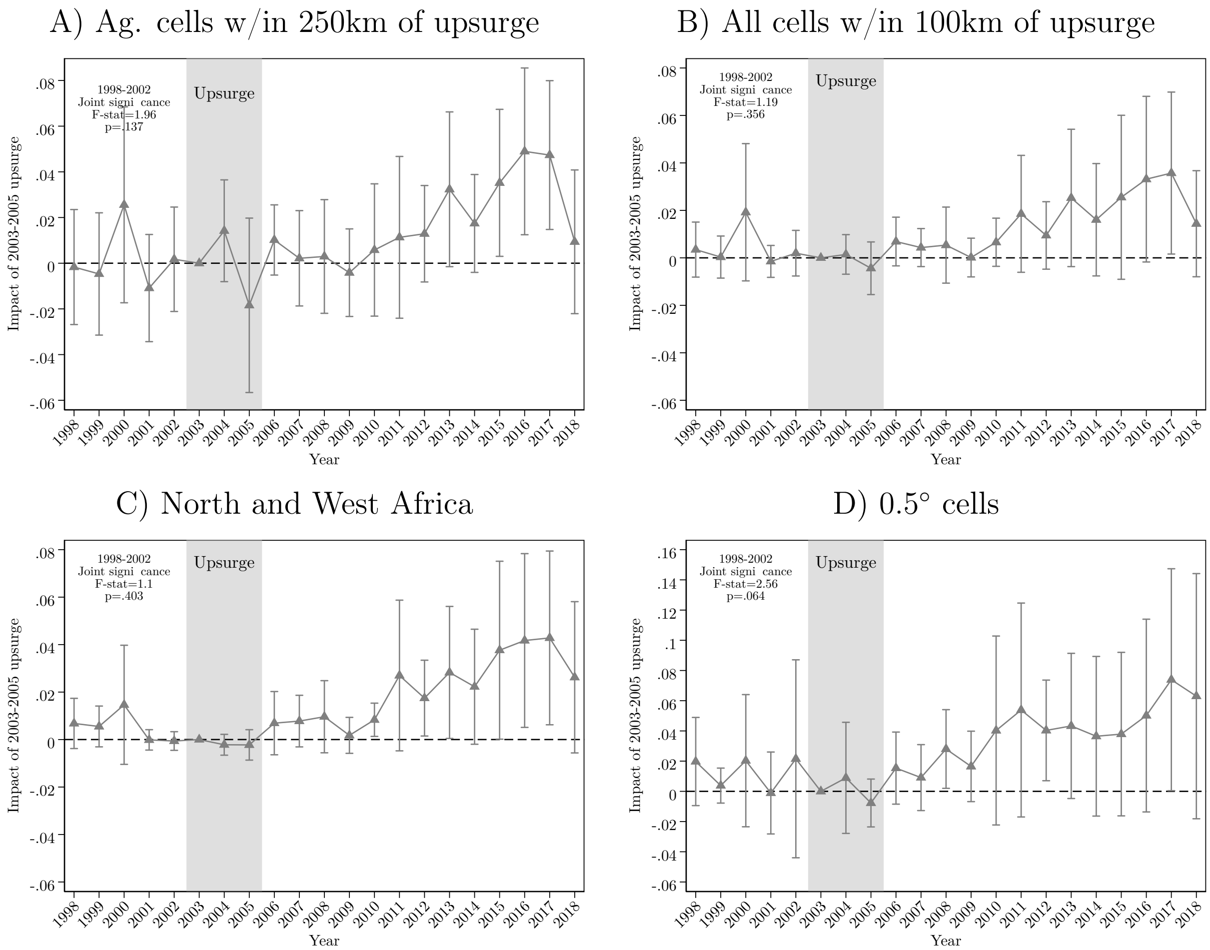
Note: The dependent variable is a dummy for any violent conflict event observed in a year. Observations are grid cells approximately 28×28km by year. Where specified, controls include current and prior year measures of the presence of any swarm in the cell and within 100km, of total rainfall, and of maximum temperature. Inverse probability weights are calculated based on the probability of observing any swarm in 2003-2005. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C9: Long-term effects of 2003-2005 locust upsurge, robustness to additional controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Any upsurge swarm	0.011*	0.008	0.013*	0.007	0.011**	0.007	0.017***	0.010*
$\times$ Post	(0.006)	(0.007)	(0.007)	(0.007)	(0.005)	(0.007)	(0.006)	(0.006)
Any swarm in current yr			-0.029**	-0.032**			-0.045**	-0.048**
$\times$ Post			(0.010)	(0.011)			(0.017)	(0.018)
Total annual rainfall			0.003	0.002			0.001	-0.002
(100 mm) $\times$ Post			(0.006)	(0.008)			(0.006)	(0.007)
Total annual rainfall prev. yr			-0.006	-0.007			-0.006	-0.006
(100 mm) $\times$ Post			(0.006)	(0.007)			(0.006)	(0.007)
Max annual temp.			-0.008**	-0.005			-0.014**	-0.006
(deg C) $\times$ Post			(0.004)	(0.003)			(0.006)	(0.007)
Max annual temp. prev. yr			0.004	0.002			0.008	0.002
(deg C) $\times$ Post			(0.006)	(0.007)		(0.006)	(0.007)	
Any swarm w/in 100km				-0.003				0.001
pre-2003 $\times$ Post				(0.007)				(0.013)
Any cropland or pasture				0.009				
$\times$ Post				(0.006)				
Population >10,000				0.033***				0.040***
$\times$ Post				(0.010)				(0.013)
Observations	400671	362510	400671	362510	172410	155990	172410	155990
Outcome mean post-2005, no upsurge	0.019	0.019	0.019	0.019	0.032	0.032	0.032	0.032
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Current swarm and weather controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inverse propensity weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Additional controls	No	Yes	No	Yes	No	Yes	No	Yes
Full interaction with Post	No	No	Yes	Yes	No	No	Yes	Yes
Sample	All cells	All cells	All cells	All cells	Ag cells w/in 250km of upsurge	Ag cells w/in 250km of upsurge	Ag cells w/in 250km of upsurge	Ag cells w/in 250km of upsurge

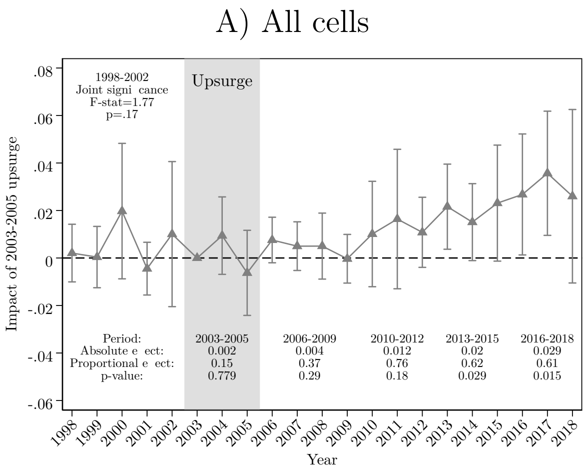
Note: The dependent variable is a dummy for any violent conflict event observed in a year. Observations are grid cells approximately 28×28km by year. Controls in all regressions include current and prior year measures of the presence of any swarm in the cell and within 100km, total rainfall, and maximum temperature. Additional controls when specified are dummies for any swarm recorded in the cell before 2003, any crop or pasture land in the cell in 2000, and having a population over 10,000. Regressions either interact the Post-2005 dummy with only the upsurge dummy or also with all controls. Inverse probability weights are calculated based on the probability of observing any swarm in 2003-2005. SEs are clustered at the country level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

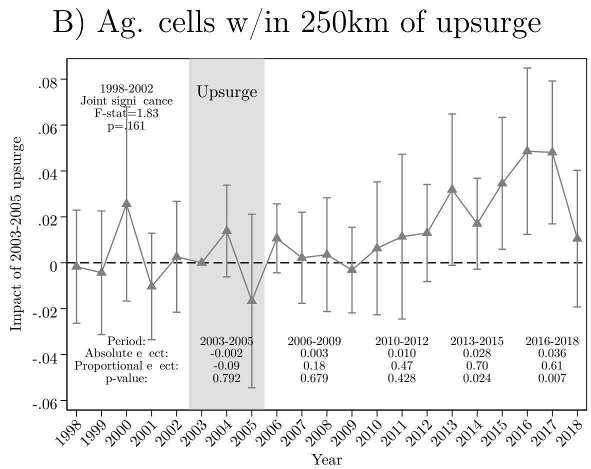
Figure C8: Effect of 2003-2005 upsurge on the risk of conflict by year, robustness to different subsamples



Note: Event study results for impacts of the 2003-2005 upsurge on conflict risk over time in different samples. 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, the first year of the upsurge period which is shaded in gray. Bars represent 95% confidence intervals. The regression includes controls for current swarms, weather, and cell and country-by-year FE. Regressions include inverse probability weights calculated based on the probability of observing any swarm in 2003-2005. Observations are grid cells approximately 28×28km by year, except in Panel D where they are 56×56km. SEs are clustered at the country level.

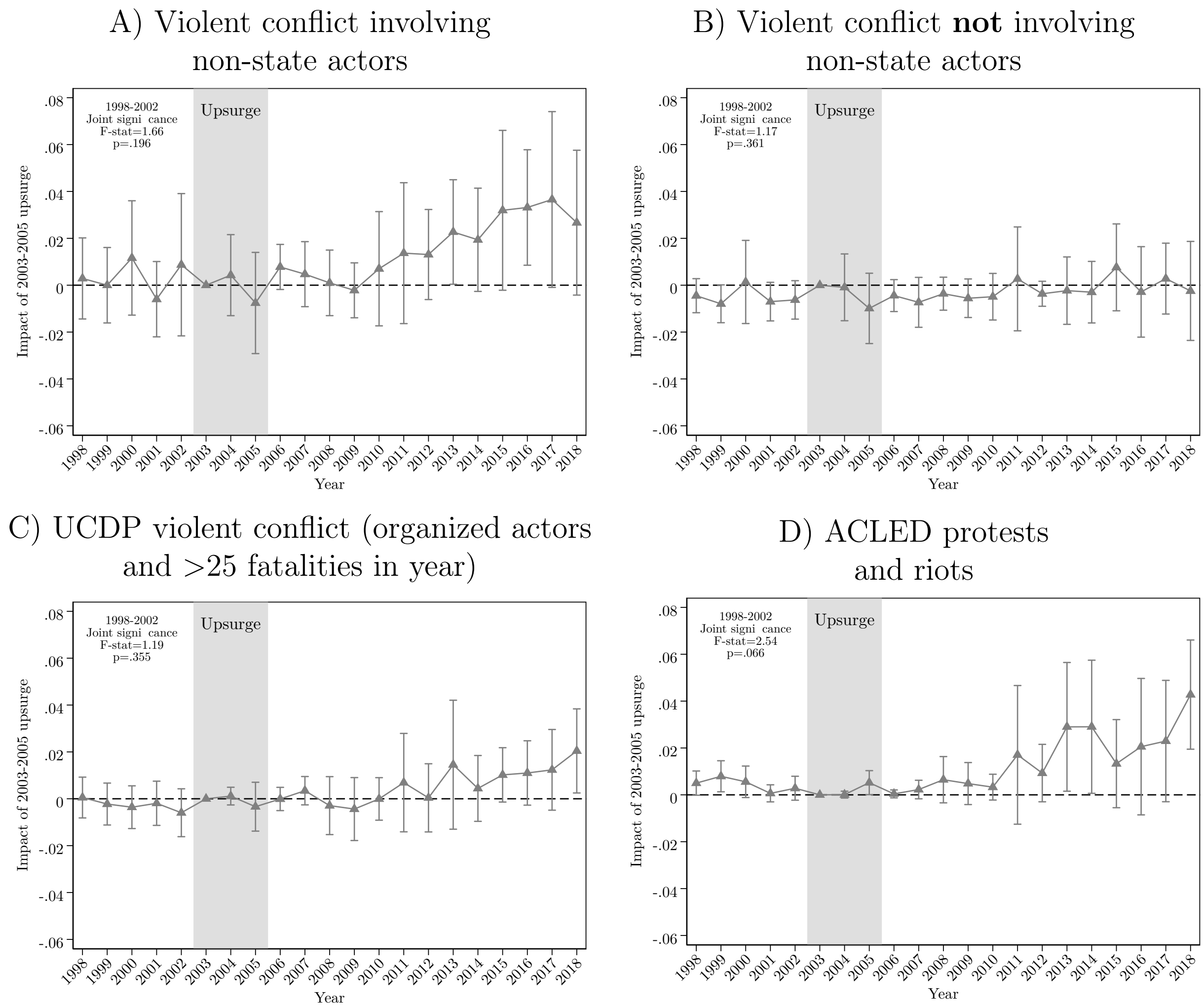
Figure C9: Effect of 2003-2005 upsurge on the risk of conflict by year, robustness to controlling for population





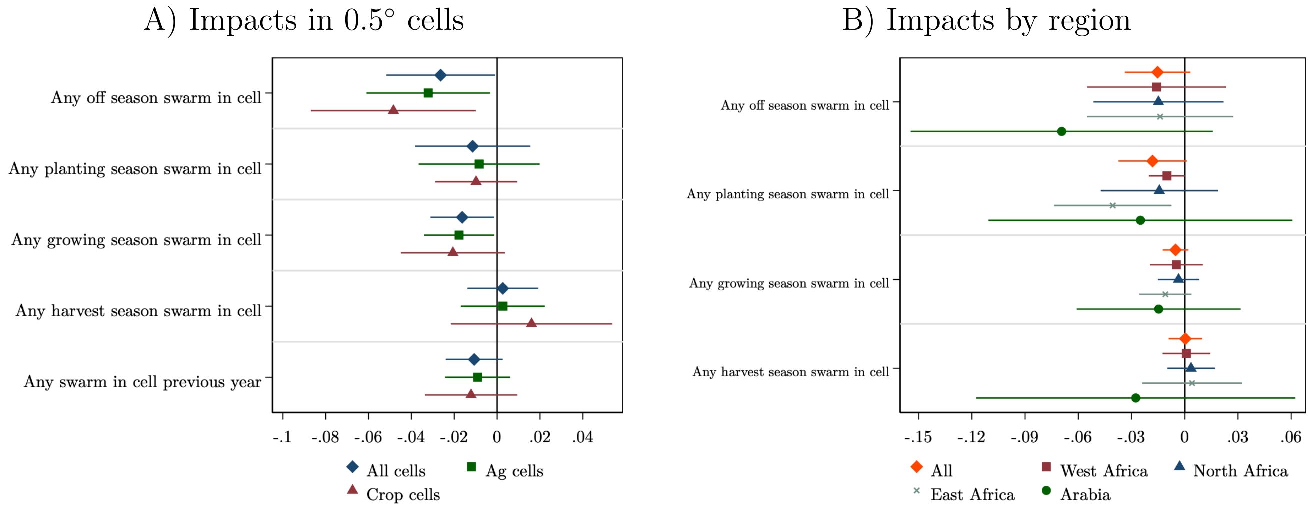
Note: Event study results for impacts of the 2003-2005 upsurge on conflict risk over time including cell population by year controls, using a dummy for whether the cell population is over 10,000. The regression also includes controls for current swarms, weather, and cell and country-by-year FE. The dependent 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, the first year of the upsurge period which is shaded in gray. Bars represent 95% confidence intervals. Regressions include inverse probability weights calculated based on the probability of observing any swarm in 2003-2005. Observations are grid cells approximately 28×28km by year. SEs are clustered at the country level.

Figure C10: Effect of 2003-2005 upsurge on different conflict types by year



Note: Event study results for impacts of the 2003-2005 upsurge on conflict risk over time for different conflict measures. The dependent variable is a dummy for any 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. Bars represent 95% confidence intervals. The regression includes controls for swarms and weather in the current and previous year and cell and country-by-year FE. Regressions include inverse probability weights calculated based on the probability of observing any swarm in 2003-2005. Observations are grid cells approximately 28×28km by year. SEs are clustered at the country level.

Figure C11: Seasonal effect of swarms on the risk of conflict, by cell size and region



Note: The figure shows coefficients and 95% confidence intervals from regressing a dummy for any violent conflict on different indicators of swarm presence across different subsamples. Observations are grid cells by year. Panel A shows results for 0.5° cells—approximately 56×56km—across land cover categories. Panel B uses the baseline 0.25° cells and shows differences by region. Regressions also include controls for locusts in surrounding areas and weather as well as country-year and cell FE.