Agricultural Shocks and Long-Term Conflict Risk: Evidence from Desert Locust Swarms

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Abstract

How do transient agricultural shocks affect the local risk of violent conflict over time? This paper studies this question using data on exposure to desert locust swarms—effectively an agriculture-specific natural disaster—across 0.25° grid cells in Africa and the Arabian peninsula from 1997-2018. Using difference-in-differences and event study approaches, I find that locust swarms significantly increase the annual probability of violent conflict over the following 14 years. Average long-term effects of past swarm exposure are large: a 0.8 percentage points (43%) greater annual likelihood of experiencing any violent conflict, equivalent to the effect of a 1.6°C higher temperature in the year. The persistent effects suggest a wealth mechanism decreasing permanent income and agricultural productivity and lowering the long-term opportunity cost of fighting. Consistent with this, I find that swarm exposure significantly reduces future cereal yields. Increases in conflict risk are concentrated in years with active fighting groups in neighboring areas—when a reduced opportunity cost of fighting is combined with opportunities to fight. Patterns of long-term impacts on violent conflict are similar for severe droughts, indicating the mechanisms are not specific to locust shocks. Long-term impacts of transient economic shocks on conflict risk add further motivation for policies mitigating the risk of such shocks and promoting household resilience and long-term recovery.

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

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1 Introduction

Violent civil conflict—between actors within states and sometimes spilling over—has been increasing in recent decades, especially in Africa and the Middle East.[1] Such conflict harms lives, health, and living standards of affected populations and can slow or reverse economic growth and development as time and investment are allocated to destruction rather than production (Blattman and Miguel 2010; Fang et al. 2020), with potentially broader impacts through economic instability and migrant flows. Understanding the drivers of civil conflict therefore has important implications for policy. A large economic literature explores the impacts on conflict risk of transient agricultural shocks which do not permanently affect potential land productivity. This is a primary concern given the prominence of agricultural livelihoods in many of the areas most affected by civil conflict and the threat to agriculture posed by climate change. Studies of this relationship focus on short-term impacts, and those that analyze shocks to agricultural production are limited in their ability to identify causal mechanisms.[2]

This paper analyzes the dynamic impact of a severe transient shock to agricultural production—exposure to a desert locust swarm—on conflict risk and tests for evidence of a long-run permanent income or wealth mechanism. Desert locusts are the world's most dangerous and destructive migratory pest (Cressman, Van der Elstraeten, and Pedrick 2016; Lazar et al. 2016) and effectively constitute an agriculture-specific natural disaster. The arrival of a locust swarm often leads to complete destruction of agricultural production and other vegetation (Symmons and Cressman 2001; Thomson and Miers 2002), without the effects on infrastructure or human physiology which may result from weather shocks. Desert locusts swarms—with billions of locusts covering tens of square kilometers—make daily flights as a cohesive unit, typically downwind. Swarm movements can be predicted but with a great deal of uncertainty and there are no effective means for farmers to prevent damages even with awareness of the potential threat of locust swarms. This creates quasi-random variation in the areas exposed to agricultural destruction in a swarm's migratory path. Swarms continue migrating and reproducing until they are controlled by pesticides

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

[2]Several studies have found that shocks to agricultural prices increase conflict incidence (e.g., Dube and Vargas 2013; Fjelde 2015; McGuirk and Burke 2020; Ubilava, Hastings, and Atalay 2022). Impacts on agricultural productivity are speculated to explain the widely-studied relationship between climate or weather deviations and conflict risk (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), though weather may affect conflict through mechanisms other than agriculture and some studies find results that are not consistent with effects through agricultural productivity (e.g., Bollfrass and Shaver 2015; Sarsons 2015).

or reach areas with scarce vegetation, where they die out. They do not increase long-term risk from pests in affected areas or otherwise affect agricultural production fundamentals. Climate change is creating conditions more conducive to swarm formation (McCabe 2021), potentially undoing progress from increased international monitoring and control efforts in recent decades. These characteristics make locust swarms a useful natural experiment for analyzing how transient agricultural production shocks affect the risk of conflict.

Using data on the location and timing of desert locust swarm observations from the Food and Agricultural Organization of the United Nations (FAO) and of conflict events from the Armed Conflict Location & Event Data Project (ACLED) and Uppsala Conflict Data Program (UCDP) I estimate a model of conflict at the annual level for 0.25° (around 28×28km) grid cells between 1997-2018 across Africa and the Arabian peninsula.[3] As severe agricultural shocks may have persistent effects on wealth and productivity which could affect conflict risk, I define exposure to a locust swarm as a permanent treatment. I estimate dynamic impacts of swarm exposure on different types of conflict using event study designs from the recent literature on difference-in-differences with staggered treatment timing (Borusyak, Jaravel, and Spiess 2021; Callaway and Sant'Anna 2021; Roth et al. 2023). Regressions include cell and country-by-year fixed effects and control for annual rainfall, temperature, and population to account for potential time-varying differences in cells affected by locust swarms, and I test the sensitivity of the results to weighting observations based on their estimated propensity to have been exposed to any locust swarm (Stuart et al. 2014). I explore patterns in calendar time using an event study of the 2003-2005 major desert locust upsurge, which accounts for 73% of swarm exposure events in the sample period, and estimate average long-term impacts on and heterogeneity by different cell characteristics using in two-way fixed effects regressions.

Locust swarms increase the annual probability of any violent conflict event occurring in a 0.25° grid cell by 0.8 percentage points (43%) on average in years after exposure to the swarm, compared to unaffected areas. The event studies show no significant impacts of locust swarms on violent conflict in the year of exposure but increases in all following years up to 14 years after exposure. Impacts are entirely driven by cells with crop or pasture land, and by swarms arriving in crop cells during the main growing season in particular. The estimated effects of having been affected by a locust swarm are large relative to the effects of annual weather deviations. Experiencing 100mm higher rainfall than average in a year increases the

[3] I include all countries where at least 10 locust swarms are reported during the sample period. Torngren Wartin (2018), an unpublished master's thesis from Stockholm University, estimates short-term impacts of desert locusts on conflict in Africa using similar data. Torngren Wartin (2018) focuses on potential measurement issues around short-term impacts which I discuss in Section 8. He does not consider long-term impacts of locust swarms or mechanisms that are the main contributions of this paper.

risk of violent conflict by 0.3 percentage points, and a 1°C higher temperature increases it by 0.5 percentage points. The results are robust to a variety of alternative specifications.

I interpret the results through the lens of a commonly-used model of individual occupation choice between production and conflict (Chassang and Padró i Miquel 2009; Dal Bó and Dal Bó 2011). In the model, transient agricultural shocks affect the short-term risk of conflict by changing both the returns to engaging in agricultural production—the *opportunity cost* mechanism—and the returns to fighting over agricultural output—the *predation* mechanism. The predation mechanism is particularly relevant for violent conflict over outputs (i.e., banditry), and less so for conflict over factors of production (land in particular) or non-violent conflict such as on protests. I extend the model to allow past agricultural production shocks to affect conflict risk through a permanent income or *wealth* mechanism. Adoption of insurance against negative agricultural shocks is very low in the study area, leading households to undertake costly consumption smoothing strategies and reducing household wealth (financial, physical, and human capital).[4] This wealth effect can decrease household permanent income as households are less productive in the long-run, leading to persistent reductions in the opportunity cost of fighting.

Null effects of locust swarms on violent conflict in the same year contrast with effects of rainfall and temperature increases, though other studies similarly report delayed impacts of weather shocks on conflict (Crost et al. 2018; Harari and La Ferrara 2018). There are a few potential explanations for this difference. First, weather deviations affect conflict risk through mechanisms other than agricultural productivity such as impacts on physiology, psychology, and infrastructure.[5] I find that the association between rainfall and violent conflict does not vary significantly by agricultural land cover, suggesting these channels may be more important than effects on agricultural production. Second, the level of destruction of locust swarms reduces the resources available for fighting and the returns to fighting at the same time as it decreases the opportunity costs of fighting. I find similar null effects of locusts on factor conflict and protests in the same year indicating it is not just the predation mechanism and reduced returns to banditry that explains the effect. Third, the fall in opportunity costs following locust exposure may be limited by out-migration (a common response to locust destruction and by relief efforts. I find evidence that international agricultural aid flows increase to countries after exposure to locust swarms, which could dissuade affected

[4]See for example Alderman, Hoddinott, and Kinsey (2006), de Janvry et al. (2006), Dercon (2004), Dercon and Hoddinott (2004), Dinkelman (2017), Fafchamps, Udry, and Czukas (1998), Hallegatte et al. (2020), Hoddinott and Kinsey (2001), Hoddinott (2006), Maccini and Yang (2009), and Townsend (1995) on coping strategies LMIC agricultural households use to respond to uninsured shocks being largely uninsured and their impacts on household wealth/assets, including long-term consequences.

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

individuals from engaging in violent conflict.

Long-term increases in conflict risk following exposure to a locust swarm are consistent with predictions in the model based on a wealth shock decreasing permanent income and productivity. Using spatial data from the Demographic and Health Survey (DHS) AReNA database (IFPRI 2020), I show that NDVI falls in the first year of swarm exposure and that cereal yields decrease by 108kg/ha (6%) on average in years after exposure relative to unaffected areas, indicating a persistent decrease in agricultural productivity. Swarm exposure leads to large increases in the long-term risk of violent conflict involving non-state actors (such as rebel groups, identity militias, and terrorist organizations) and of protests, which would be expected to be affected by changes in individuals' opportunity costs, but has smaller and inconsistent effects on violent conflict only involving state actors (governments), which would not. This evidence supports the argument that long-term impacts of locust swarm exposure on conflict risk are due to a persistent reduction in the opportunity cost of fighting.

Long-term conflict risk does not increase uniformly, with the largest effects on violent conflict risk coming 7-14 years after swarm exposure and a similar pattern for the likelihood of protests. Long-term impacts on violent conflict are driven entirely by cells and periods where there are groups actively engaged in conflict in the surrounding area. The prevalence of violent conflict in the sample countries is relatively low until around 2011 when it begins increasing significantly. The majority of swarm exposure comes from the 2003-2005 upsurge, explaining the lag between exposure and the largest increases in violent conflict in the event studies. Violent conflict is generally an organized group activity, as groups reduce the cost to individuals of engaging in fighting and increase the probability of success. Fighting groups formed following some precipitating event[6] can more easily recruit individuals in areas affected by locusts as their opportunity costs are lower and they will therefore demand less returns to join. Lower agricultural productivity of the levels observed in this study are unlikely to make fighting optimal for affected individuals in most periods absent such recruitment. Locust swarm exposure thus affects conflict incidence over the long-term but does not cause the onset of new conflicts.

Finally, I show that the patterns in impacts on violent conflict over time I observe are not unique to desert locust swarms. Severe droughts also consistently increase long term violent conflict, with the annual risk 1.0 percentage points higher than in unaffected areas on average over the following 12 years. As with locust swarms, impacts of droughts are driven entirely by exposure in agricultural cells and the long-term effects are only significant in years with

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

groups engaged in violent conflict in surrounding cells, indicating the same mechanisms are involved. The long-term increases in conflict risk imply that analyses defining shock exposure as temporary and estimating short-term impacts using fixed effects (the main method in studies of agricultural shocks and conflict) are misspecified. I show that such analyses result in downward-biased estimates of the short-term impacts of both locust swarms and severe drought on violent conflict, affecting the policy implications.

This paper makes several contributions to the literature. First, while a relationship between weather shocks and conflict has been repeatedly demonstrated the mechanisms driving this impact are not fully understood (Mach et al. 2020). Weather shocks affect a variety of economic and social outcomes in addition to reducing agricultural labor productivity and agricultural output (Dell, Jones, and Olken 2012, 2014; Mellon 2022), and some papers cast doubt on the agricultural channel by finding that impacts of rainfall on conflict do not vary by sensitivity or presence of agricultural production (Bollfrass and Shaver 2015; Sarsons 2015). This paper addresses these limitations by testing the impacts on conflict risk of locust swarms, an agricultural shock that does not affect other economic outcomes. I compare impacts by land cover and timing of swarm exposure and show further evidence that impacts of rainfall shocks do not vary by agricultural land cover. The results indicate that the opportunity cost of fighting mechanism alone does not explain impacts of locust swarms and drought on conflict risk and highlight the importance of the predation mechanism and its influence on opportunities for fighting.[7]

Second, I analyze long-term impacts of an economic shock on conflict to further our understanding of the drivers of conflict (Bazzi and Blattman 2014; Blattman and Miguel 2010; Collier and Hoeffler 1998; Dube and Vargas 2013; Grossman 1999; Hodler and Raschky 2014; McGuirk and Burke 2020; Miguel, Satyanath, and Sergenti 2004), and the role of agricultural production in particular (Crost et al. 2018; Harari and La Ferrara 2018; Iyigun, Nunn, and Qian 2017; McGuirk and Nunn 2021; Von Uexkull et al. 2016). Studies of the impacts of agricultural shocks on conflict have focused on the short-term—impacts in the same year and potentially the following year.[8] I consider the possibility of long-term impacts through a permanent income or wealth mechanism, and test for this channel by examining long-term

[7] Little attention is given to the predation mechanism in the climate-conflict literature. Studies showing evidence of opportunity cost and predation mechanisms in agriculture have primarily explored impacts on conflict risk of changes in global prices of agricultural goods (e.g., Dube and Vargas 2013; Fjelde 2015; McGuirk and Burke 2020) rather than shocks to local agricultural production. McGuirk and Nunn (2021) is an exception, analyzing impacts of drought on conflict between pastoralists and farmers.

[8] Crost et al. (2018) and Harari and La Ferrara (2018) estimate effects of weather shocks on conflict 1 and 4 years afterward. Iyigun, Nunn, and Qian (2017) is an exception, considering long-run effects on conflict risk of a *positive and permanent* agricultural productivity shock from the introduction of the potato to the Eastern Hemisphere. To my knowledge, no study has explored long-term impacts on conflict risk of a transient negative shock to agricultural production.

impacts of desert locust swarms on measures of agricultural productivity. Significant increases in long-term conflict risk following locust and drought exposure suggest that studies focusing on short-term impacts of severe economic shocks may be misspecified if they define the shock 'treatment' as temporary.

Third, I add to a broader literature on the impacts of environmental shocks and natural disasters. Many papers have explored how environmental shocks can have persistent effects on poverty and well-being (e.g., Baseler and Hennig 2023; Carter and Barrett 2006; Carter et al. 2007; Lybbert et al. 2004), but these mechanisms have not been related to conflict risk. More generally, the evidence on long-term impacts of disasters such as hurricanes and droughts is limited, inconclusive, and focused on a small number of outcomes (see Botzen, Deschenes, and Sanders (2019) and Klomp and Valckx (2014) for reviews). I study how the impacts of desert locusts swarms—an extreme shock to agricultural production akin to a natural disaster—on conflict risk evolve over time and test whether patterns are consistent with a wealth mechanism.

Finally, this paper also contributes to a small literature studying economic impacts of desert locusts beyond immediate crop destruction and costs of control operations (see e.g., Thomson and Miers 2002), and to a slightly larger literature on the long-term impacts of agricultural pests (Baker, Blanchette, and Eriksson 2020; Banerjee et al. 2010). The range of many agricultural pests is expanding due to climate change and globalization, and though locust outbreaks have become less frequent in recent decades due to increased monitoring desert locusts are ideally situated to benefit from climate change (McCabe 2021; Qiu 2009; Youngblood et al. 2023). Marending and Tripodi (2022) use panel data from the Ethiopia Socioeconomic Survey and find that exposure to desert locust swarms decreases farm profits by 20-48% two harvest seasons after swarm arrival. Several papers use Demographic and Health Survey (DHS) data and variation in swarm exposure across birth cohorts and over space to show negative impacts on school enrollment and educational attainment (De Vreyer, Guilbert, and Mesple-Somps (2015)) and on child height-for-age or stunting (Conte, Tapsoba, and Piemontese 2021; Le and Nguyen 2022; Linnros 2017). These papers illustrate how locust swarm exposure can adversely affect long-term productivity and human capital, but I am not aware of any study considering the impacts of a pest shock on conflict. The impacts of locust swarms on long-term agricultural productivity and conflict risk should be considered in determining policy around desert locust prevention and control.

The remainder of the paper is organized as follows. Section 2 provides background on desert locusts and summarizes the literature on agricultural shocks and conflict. Section 3 presents a model of how agricultural shocks affect occupational choice and the decision to fight over time through income-related mechanisms. Section 4 describes the data used in the analyses and Section 5 outlines the empirical approach. Section 6 shows the results for the impacts of locust swarm exposure on violent conflict. Section 7 discusses the results in light of the model and presents additional analyses testing the mechanisms behind the estimated effects. Section 8 compares impacts of exposure to locust swarms and severe drought and consider implications for analyses of short-term impacts of agricultural shocks. Section 9 concludes.

2 Background

2.1 Desert locusts

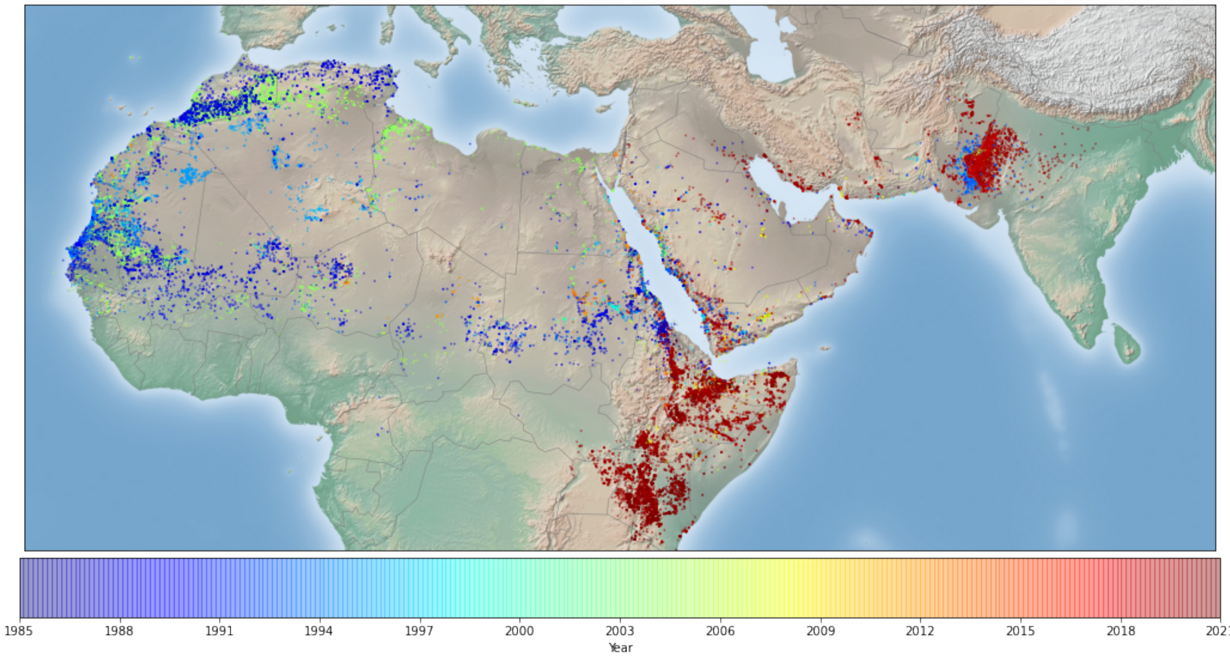
Desert locusts (*Schistocerca gregaria*) are a species of grasshopper always present in small numbers in desert 'recession' areas from Mauritania to India.[9] They usually pose little threat to livelihoods but favorable climate conditions in breeding areas—periods of repeated rainfall and vegetation growth overlapping with the breeding cycle—can lead to exponential population growth. Unique among grasshopper species, after reaching a particular population density locusts undergo a process of 'gregarization' wherein they mature physically and begin to move as a cohesive unit (Symmons and Cressman 2001). In the adult locust stage—lasting 2-4 months—after developing wings, gregarization leads to the formation of 'swarms'. In this paper I focus exclusively on locust swarms, which are much more mobile and destructive than other groupings of desert locusts. Climate change is expected to increase the risk of locust swarm formation, as desert locusts can easily withstand elevated temperatures and the increased frequency of extreme weather events can create conditions conducive to exponential population growth (McCabe 2021; Qiu 2009; Youngblood et al. 2023).

Figure 1 displays the locations of all desert locust swarm observations recorded in the FAO Locust Watch database by year. As illustrated by the figure, locust swarms are not observed with any regularity over time and only in a few countries have locations been exposed to more than one swarm. Which locations are exposed to a locust swarm during an upsurge—a major outbreak of locust swarms from breeding areas which affects multiple countries—depends on which breeding areas fostered initial swarm formation and on wind patterns in the months following swarm formation. The countries affected by the 2003-2005 upsurge (in green in Figure 1), which originated from multiple small outbreaks in Summer 2003 in the Western Sahel, are not the same as those exposed to the 2019-2021 upsurge (in red), which originated in the southern Arabian Peninsula. Conditional on being in the

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

migratory path of a locust swarm, swarm flight patterns create further variation in exposure as some areas in the flight path are flown over and spared any damages.[10]

Figure 1: FAO Locust Watch swarm observations by year



Note: Map created by authors using all recorded locust swarms in the FAO Locust Watch database.

Desert locusts are migratory rather than endemic, moving on after consuming available vegetation without permanently changing local agricultural pest risk. Locust swarm migration follows wind patterns which tend to bring them to breeding areas in time for seasonal breeding. Swarms generally fly downwind and can easily move 100km or more in a day even with minimal wind (FAO and WMO 2016).[11] Locusts live 2-6 months and swarms continue breeding and migrating until dying out from a combination of migration to unfavorable habitats, limited vegetation in breeding areas, and control operations (Symmons and Cressman 2001).

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). Locusts consume any available vegetation without preference for different types of crops (Lecoq 2003). A small swarm covering one square kilometer consumes as much food in one

[10] Figure B3 shows an example of local variation in exposure to the 2003-2005 upsurge in Mali.

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

day as 35,000 people and the median swarm consumes 8 million kg of vegetation per day (Food and Agriculture Organization of the United Nations (FAO) 2023a).

The arrival of a swarm can lead to the total destruction of local agricultural output (Symmons and Cressman 2001; Thomson and Miers 2002). During the 2003-2005 locust upsurge in North and West Africa, 100, 90, and 85% losses on cereals, legumes, and pastures respectively were recorded, affecting more than 8 million people and leading to 13 million hectares being treated with pesticides (Showler 2019). Chatterjee (2022) finds that wheat yields are 12% lower on average in Indian districts typically affected by desert locusts in years of locust outbreaks, suggesting large decreases in the specific areas exposed to locust swarms in those years. Over 25 million people in 23 countries were affected during the most recent 2019-2021 upsurge and damages were estimated to reach \$1.3 billion (Green 2022), with control efforts—including treating over 2 million hectares with pesticides—estimated to have prevented over \$1 billion in damages (Newsom, Koli, and Sebesvari 2021).

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

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, which can take days to have effects as well as being slow and costly to organize and requiring robust locust control infrastructure (Cressman and Ferrand 2021). Knowledge of locust breeding patterns and swarm flight characteristics inform efforts to predict locust swarm formation and movements, but forecasts remain highly imprecise (Latchininsky 2013). Farmers in affected areas report viewing locust swarms as an unpredictable natural disaster that is the government's responsibility to address (Thomson and Miers 2002). Households use a variety of measures to cope with short-term food security and livelihood effects of locust outbreaks. In addition to seeking help from social networks and food aid, households commonly report selling animals and other assets, consuming less food, sending household members away, taking loans and cutting expenses, and consuming seed stocks as coping strategies (Thomson and Miers 2002). A swarm exposure shock therefore represents a shock to income and household wealth as well as a shock to agricultural productivity in the year of exposure.

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

2.2 Agricultural shocks and conflict

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).[12] These results have important implications for conflict risk as climate change increases the frequency and severity of weather shocks.

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

[12] Most studies reporting null effects use country-level data (e.g., Buhaug et al. 2015; Ciccone 2013; Couttenier and Soubeyran 2014; Klomp and Bulte 2013).

mechanism.

Weather affects the economy and society through multiple channels besides agricultural production (Dell, Jones, and Olken 2012, 2014; Mellon 2022), and 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). A few studies have also cast doubt on the importance of the agriculture channel. 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. Bollfrass and Shaver (2015) find that positive temperature deviations in sub-Saharan Africa increase conflict even in areas without significant agricultural production. Reviews of the climate-conflict literature agree that the mechanisms remain unclear and deepening insight into them is highlighted as a priority for future climate-conflict research in Mach et al. (2020). An important advantage of analyzing the effects of locust swarm exposure is that the only active channel should be agricultural destruction, allowing a cleaner identification of the importance of income-related mechanisms.

Income mechanisms have been discussed and tested in the literature on the drivers of conflict more generally 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 (Bazzi and Blattman 2014; Dube and Vargas 2013; Fjelde 2015; McGuirk and Burke 2020; Ubilava, Hastings, and Atalay 2022). A recent literature explores how the onset of harvest season in agricultural areas affects economic incentives to fight (Guardado and Pennings 2021; Hastings and Ubilava 2023). Koren (2018) finds that increased cereal yields in Africa, instrumented by a measure of drought, are associated with an increased risk of conflict.

These studies illustrate different ways in which agricultural shocks affect both the opportunity cost of fighting related to agricultural labor productivity and the returns to predatory capture of agricultural output. In some cases the opportunity cost mechanism appears to dominate (Bazzi and Blattman 2014; Dube and Vargas 2013; Fjelde 2015; Guardado and Pennings 2021), while in others the predation mechanism is decisive (Koren 2018; Ubilava, Hastings, and Atalay 2022), sometimes within the same context (Hastings and Ubilava 2023; McGuirk and Burke 2020). Studies identifying results consistent with predation or banditry emphasize the role of armed groups such as militias or insurgents which coordinate such attacks. It is not clear whether the opportunity cost or predation mechanism would dominate for a shock to agricultural production. Locust swarms can entirely destroy agricultural output, sharply reducing both agricultural labor productivity and the returns to predation over agricultural output.

The majority of studies on agricultural shocks and conflict focus on impacts within the same time period, with a few exceptions. Crost et al. (2018) and Harari and La Ferrara (2018) find that growing season weather shocks have inconsistent effects on conflict in the same year, but consistently increase conflict risk the following year. Harari and La Ferrara (2018) finds some persistence of impacts up to 4 years afterward. Crost et al. (2018) argue that lagged effects on conflict could be due to storage and savings offsetting effects in the same year. This appears inconsistent with effects driven by reduced opportunity costs as the largest impacts on agricultural labor productivity should be realized in the same season as the rainfall shock, unless wealth effects reduce subsequent productivity. To my knowledge, only Iyigun, Nunn, and Qian (2017) consider how a permanent agricultural productivity shock impacts conflict in the long term. They find that introducing potatoes to Europe, the Near East, and North Africa led to a large and persistent reduction in the risk of conflict in subsequent centuries by comparing changes in areas with different suitability for potato cultivation. A paucity of evidence on long-term impacts is a limitation of the literature on natural disasters more generally (Botzen, Deschenes, and Sanders 2019), and particularly in low-income countries (Baseler and Hennig 2023).

3 Model

The standard models discussed in the literature on agricultural shocks and conflict are models of occupational choice (as in Roy 1951; Heckman and Honore 1990; French and Taber 2011) where actors allocate their labor between productive activities and fighting.[13] In particular, Chassang and Padró i Miquel (2009) develop a bargaining model of conflict where groups allocate labor to crop production or fighting over land, and Dal Bó and Dal Bó (2011) model individuals choosing between a labor-intensive sector, a capital-intensive sector, and an 'appropriation' sector fighting over output.

The models illustrate how agricultural shocks affect the risk of conflict through two main, opposing, mechanisms. First, negative shocks such as low prices or drought reduce the returns to agricultural labor. This means the *opportunity cost* of fighting is lower: producers have less to lose by engaging in conflict. At the same time, lower agricultural prices or output reduce the returns to *predation*: bandits or looters have less to gain from fighting. These mechanisms are not unique to agricultural shocks, as they are also discussed in earlier work on the economic drivers of conflict more generally (e.g., Collier and Hoeffler 2004; Grossman

[13] Becker (1968) uses a similar setup to model interpersonal conflict such as theft.

1999). For transient agricultural shocks, the value of output available to capture falls but the value of factors of production—land in particular—is less affected. In line with this, the literature generally finds that the opportunity cost mechanism dominates for shocks that temporarily reduce agricultural returns, increasing conflict risk.

Prior research models transient agricultural shocks as having only temporary effects on conflict. But a transient income shock can also reduce permanent income when consumption smoothing decreases assets. Most agricultural households in developing countries lack insurance and have constrained access to credit. Strategies to smooth consumption following an income shock, such as selling animals and other assets, taking loans, reducing food, health, and education spending, and sending members away reduce household physical and human capital (e.g., de Janvry et al. 2006; Dercon and Hoddinott 2004; Dinkelman 2017). The resulting reductions in wealth mean temporary shocks can have persistent impacts on productivity (Dercon 2004; Hallegatte et al. 2020; Hoddinott 2006; Karim and Noy 2016). In the context of an occupational choice model of conflict, this permanent income or *wealth* effect increases the long-term risk of conflict by reducing the long-term opportunity cost of fighting.

I present a streamlined model of occupational choice as in Chassang and Padró i Miquel (2009) and Dal Bó and Dal Bó (2011) including this long-term wealth mechanism to build intuition and generate hypotheses about the effect of agricultural shocks on conflict. In the model, individuals in each time period allocate one unit of labor L to either agricultural production, non-agricultural work, or violent conflict to maximize total net income I. Returns to all activities are affected by individual and location characteristics X such as land quality, level of education, and fighting ability.

Net returns to agricultural production $F^A(L^A, S, W, X)$ are affected by agricultural shocks S, which may vary across individuals over space and in intensity with a larger S indicating a more severe negative shock. Agricultural production is a concave function of S, with $\frac{\partial F^A}{\partial S} < 0$ and $\frac{\partial^2 F^A}{\partial S^2} < 0$. A larger S therefore reduces agricultural labor productivity—the *opportunity cost mechanism.*

Agricultural production also depends on wealth W with $\frac{\partial F^A}{\partial W} > 0$, where wealth broadly includes human, physical, and financial capital. Wealth in period t is weakly increasing in income I from activities in period $t-1$. As agricultural shocks decrease income, this creates a relationship between past agricultural shocks S_{t-s} and agricultural production in period t, where $s \in [1, \tau]$ for some τ. We can write $F_t^A = F^A(L_t^A, S_t, W_t(\{S_{t-s}\}_{s=1}^{\tau}), X_t))$, with $\frac{\partial F_t^A}{\partial W_t} > 0$ and therefore $\frac{\partial F_t^A}{\partial S_{t-s}} < 0$. This is the permanent income or *wealth mechanism.*[14]

[14]Note that wealth in period t is a function of many factors other than past agricultural shocks, including other types of shocks as well as past conflict, but I focus on the role of past agricultural shocks to build

Net returns to non-agricultural work $F^N(L^N, X, W)$ are based on the most productive activity available outside of own agricultural production. The highest returns available depends on individual and location characteristics X and wealth W. As a simplifying assumption, I suppress the direct dependence of non-agricultural returns on S. Returns to non-agricultural work thus set a lower bound on how far the opportunity cost of fighting may fall following a negative agricultural shock in the short term. F^N will be weakly smaller for individuals primarily engaged in agriculture that experienced a past agricultural shock due to the wealth mechanism.

Individual i can also decide to engage in predatory violent conflict with a set of potential targets J near i that are feasible to attack within the time period. The potential net returns $F^C(L_i^C, X_i, \{I_j, W_j, X_j\}_{j\in J})$ depend on the incomes (production output), wealth (factors of production), and characteristics of the individuals in J. Wealth is valued based on the expected discounted stream of returns. Agricultural shocks S_j for individuals $j \in J$ engaged in agriculture affect i's returns to fighting by decreasing the income available to capture: $\frac{\partial F_t^C}{\partial S_{j,t}} < 0$. This is the *short-term predation mechanism.* Past agricultural shocks to individuals $j \in J$ will reduce both the output and the factors that i can capture through the wealth mechanism, meaning $\frac{\partial F_t^C}{\partial S_{j,t-s}} < 0$. This is the *long-term predation mechanism.*

The probability of success and costs of fighting depend on characteristics $X_{i,t}$ and $X_{j,t}$—some targets will be farther away or have better fighting ability. An important variable in $X_{i,t}$ is whether there are groups engaged in armed conflict nearby, as joining such a group will reduce the costs of fighting for the individual and increase the probability of success. Costs of fighting are incurred with certainty and include economic, social, and emotional costs as well as risk of injury or death. These costs make fighting sub-optimal for most individuals in most time periods.

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

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

intuition with this model.

This yields

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

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

Conflict occurs in the locations of the individuals being attacked. In this paper I analyze conflict at the level of grid cells which contain many individuals. I test the sensitivity of the results to using larger grid cells to capture spillovers of conflict outside the areas affected by agricultural shocks.

3.1 Effects of agricultural shocks on conflict

The effect of an agricultural shock on the decision to fight in the same time period is ambiguous, particularly if there is a strong positive correlation between shocks over space, as in most agricultural shocks. When the shocks are correlated, larger $S_{i,t}$ will decrease i's returns to agricultural production in the same period but also be associated with a decrease in output available to capture from nearby targets for predatory attacks. This makes conflict over output (i.e., banditry) less attractive, but has minimal effect on the returns to conflict over factors of production.[15] We would therefore expect a larger impact of a transient agricultural shock on conflict over factors of production in the same period than on conflict over output. Overall impacts on violent conflict depend on whether outputs or factors make up a greater share of the returns fighting.

Reductions in agricultural output available to capture are particularly severe for desert locust swarm shocks. Swarms consume all types of vegetation and there are no effective methods for farmers to limit damage to their output, meaning levels of agricultural destruction will therefore be similar across individuals with different characteristics in the affected area. Shocks to agricultural production from weather deviations (lower rainfall, higher temperatures) may have more heterogeneous and less severe effects on production depend on the extent of the deviation.

The long-term effects of past agricultural shocks $S_{i,t-s}$ on the decision to engage in conflict

[15] I focus on transient agricultural shocks which do not have a permanent direct effect on local agricultural productivity. Transient shocks may have some effect on the returns to fighting over factors if they affect individuals' ability to productively utilize factors or if they affect expectations about future productivity. Shocks that have direct permanent productivity effects, for example through soil erosion or other land degradation, would have larger effects on the returns to capturing factors of production.

in period t also involve offsetting mechanisms. Because of impacts on wealth as a result of consumption smoothing, the returns to both agricultural production and to fighting will be lower than before the shock in affected areas relative to unaffected areas, though higher than in the period of the shock. As with short-term impacts of an agricultural shock, long-term impacts should be smaller for conflict over output than over factors of production. Land is likely to be the main factor of production available to capture and its value should not be much affected by a transient agricultural shock, though increased conflict risk following the shock could reduce land values.

The wealth effect is likely to be particularly strong following desert locust swarm exposure due to the severity of the income shock relative to small decreases in rainfall or increases in temperature from local averages. If the wealth mechanism is important, this should be observable in long-term impacts on measures of assets and agricultural productivity.

Whether a long-term productivity reduction increases the risk of violent conflict depends on the relative magnitudes of the reductions in productivity and in returns to fighting, but also on the absolute returns to fighting. Decreases in agricultural productivity will not be expected to increase violent conflict if the returns to fighting are very low (or negative). Since violent conflict is not the norm in most locations and periods, it implies the returns are generally low. A persistent decrease in agricultural productivity would therefore be expected to increase conflict risk primarily in locations or periods where the returns to fighting are higher.

One factor affecting these returns is the possibility of forming or joining an armed group, as this this reduces the costs of fighting and increases the probability of success. In practice, individuals are unlikely to engage in violent conflict alone, as such fighting generally involves organized armed groups which recruit members and pay them a wage or share of the returns from victory (Collier and Hoeffler 2004; Grossman 1999).

While there is evidence that agricultural shocks motivate the formation of fighting groups and cause the onset of new violent conflict immediately following the shock (Harari and La Ferrara 2018; McGuirk and Burke 2020), it is not clear whether lower productivity in the long term after a shock would lead fighting groups to form in the absence of some precipitating event. One proxy for the possibility of joining an armed group in a particular location and period could be the activity of groups engaged in violent conflict nearby. Given some proximate cause for groups to form and engage in violent conflict, individuals with persistently lower agricultural productivity should be easier to recruit as their opportunity cost is lower.

While the model focuses on violent conflict with the objective of capturing outputs or factors of production, agricultural shocks could also affect non-violent forms of conflict such as protests (Hastings and Ubilava 2023). Such activity does not target the capture of agricultural output or wealth and thus will not be affected by the predation mechanism, but would still be affected by a decrease in agricultural production as the opportunity cost of participating falls. Individuals may also derive value from expressing their grievances or motivating increased attention and relief. Effects of an agricultural shock should be larger for protests than for violent conflict, since there is no offsetting effect through the predation mechanism.

To summarize, the model informs a set of testable predictions for the impacts of a transient agricultural shock on conflict risk:

1. The impact on the likelihood of violent conflict in the year of the shock is ambiguous, but if the predation mechanism offsets the opportunity cost mechanism, a shock should increase the short-term likelihood of factor conflict and protests by more than the likelihood of output conflict.
2. If a transient but severe shock has long-term effects through a wealth mechanism, this should be observable through long-term reductions in measures of productivity.
3. The impact of a shock on the long-term likelihood of violent conflict is ambiguous, but if opportunity costs of fighting fall and the returns to predation are an important mechanism we should observe different impacts across types of conflicts. Impacts on the likelihood of protests should be larger than on the likelihood of violent conflict, and larger for conflict over factors of production than for conflict over output.
4. If there are long-term effects of a severe shock on opportunity costs of fighting through the wealth mechanism and the returns to predation are an important mechanism, the long-term risk of violent conflict should increase by more in periods when fighting groups are active.

4 Data

The Locust Watch database (FAO 2022) reports observations of desert locust swarms as well as smaller concentrations of locusts from 1985 to the present. I consider only data on locust swarms which pose the greatest threat to agriculture and whose flight patterns create local variation in exposure. The Locust Watch data include latitude, longitude, and date of swarm observations. Locust observations are recorded by national locust control and monitoring officers on the ground, but incorporate reports from agricultural extension agents, government officials, and other sources. Local farmer scouts are also often trained in locust monitoring and reporting (Thomson and Miers 2002).

A concern might be that locust reporting is correlated with violent conflict. Showler and Lecoq (2021) review how insecurity has affected national and international desert locust control operations from 1985-2020 across countries where locusts are active. They mention Chad, Mali, Somalia, Sudan, Western Sahara, and Yemen as countries with areas where insecurity has constrained locust control operations in certain periods since 1997. This concern is the focus of Torngren Wartin (2018)'s analysis of the impact of locusts on conflict, which uses similar data but focuses on the short-term, modeling locusts as temporary shocks.

Insecurity is likely less of a constraint for locust monitoring than for control operations. FAO locust monitoring guidelines discuss conducting aerial surveys and using reports from local scouts, agricultural extension agents, security forces, and other sources (Cressman 2001, which would allow reporting even in insecure areas. The Locust Watch data includes observations of locust swarms even in countries and periods where Showler and Lecoq (2021) indicate control operations have not been possible. 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. None of the monthly FAO locust swarm bulletins published during the 2003-2005 upsurge—the major locust event in the sample period—mention issues related to insecurity affecting locust monitoring efforts. The share of cells within 50km of a locust swarm observation in a given year that have reports of both violent conflict and a locust swarm in the cell is 27% in the set of countries Showler and Lecoq (2021) indicate pose challenges for locust control, similar but below the 34% in all other countries. I test the sensitivity of the results to excluding the countries listed in the report as potential locations of locust swarm under-reporting, and to imputing 'missing' locust swarms near the locations of reported swarms.

Data on conflict events come from the Armed Conflict Location & Event Data Project (ACLED) database (Raleigh et al. 2010). The database records the location, date, actors, and nature of conflict events globally starting from 1997 by compiling and validating reports from traditional media at different levels, from institutions and organizations, from local partners in each country, and from verified new media sources. The analysis focuses on events categorized by ACLED as "violent conflict," which includes battles, explosions, and violence against civilians. I also test impacts on protest and riot events recorded by ACLED and on larger-scale violent conflicts from the Uppsala Conflict Data Program (UCDP; Sundberg and Melander 2013) and distinguish between conflict that does and does not involve a non-state actor, as these types of conflict will involve different mechanisms. The UCDP database is similar to the ACLED database but goes back to 1989 and only records conflicts involving at least one "organized actor" and resulting in at least 25 battle-related deaths in a calendar year.

The ACLED database has no organized actor or minimum death threshold requirements. McGuirk and Burke (2020) characterize UCDP events as more likely to represent conflict over territory and factors of production, and I follow them in constructing a measure of output conflict (i.e., banditry) using ACLED records of violence against civilians, rioting, and looting.

I collapse the data to a raster grid with annual observations for cells with a 0.25° resolution (15 arcminutes, approximately 28×28km). Analyzing impacts at this spatial level reduces potential measurement error about the specific areas affected by swarm and conflict events and allows me to leverage local variation in swarm presence created by their flight patterns. Nearly all swarms will be contained within 0.25° cells (~784km^2), except those near cell boundaries. I test for robustness to analyzing data at the level of 0.5° and 1° cells, which will also capture potential spillovers from swarm exposure (McGuirk and Nunn 2021). In each cell and year I measure whether any locust swarm and conflict event was recorded.

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

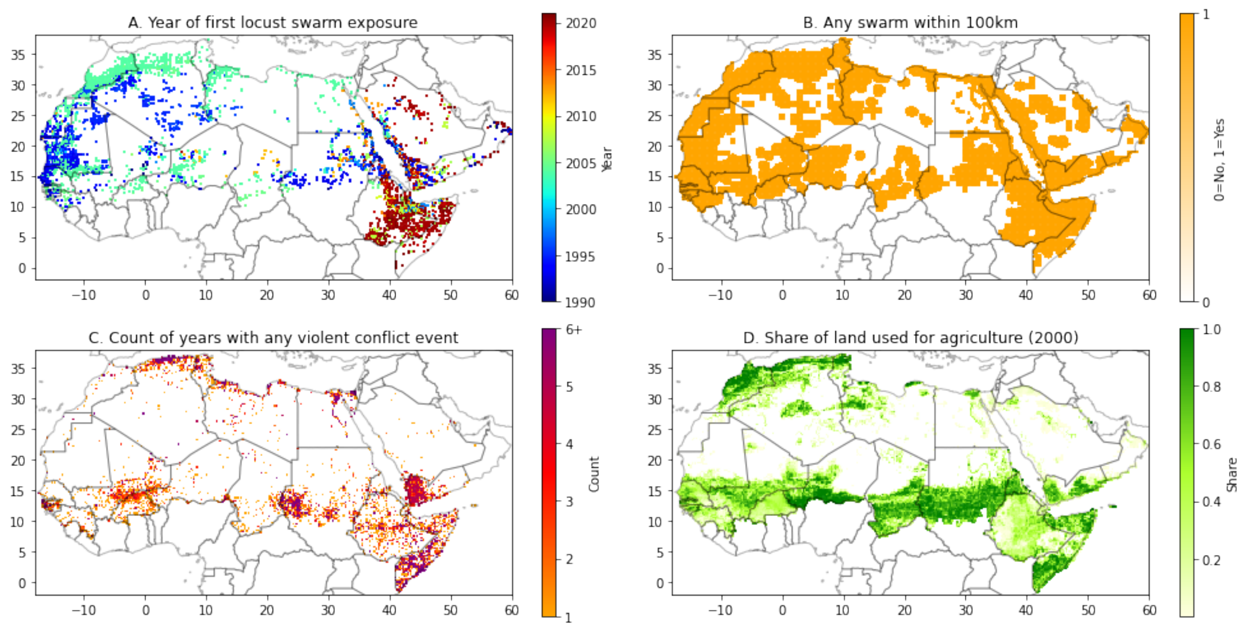
Given the role of weather in desert locust biology, its importance in determining agricultural production, and the well-documented relationship between weather variations and conflict, all analyses control for local weather to isolate the impact of locust swarm exposure. I measure total annual precipitation (in mm) and maximum temperature (in °C) using high-resolution monthly data from WorldClim available through 2018.[16] 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 in each cell that is cropland and pasture (Ramankutty et al. 2010). I include additional cell characteristics from the PRIO-GRID dataset (Tollefsen, Strand, and Buhaug 2012), assigning all 0.25° cells the values for the 0.5° cell in which they are located.

Since ACLED records conflicts beginning in 1997 and the weather data are available until 2018, the analysis sample includes observations 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 West Africa, and the Horn of Africa. The resulting analysis sample covers 22 years across 24,460 cells, for a total of

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

538,086 observations. Figure 2 visualizes swarm exposure, violent conflict incidence, and agricultural land cover for the sample countries. Summary stats are included in Table A1.

Figure 2: Swarm exposure, violent conflict incidence, and land cover in sample countries



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

A locust swarm is recorded in the Locust Watch database between 1985-2021 for 18% of cells, and 63% of cells are within 100km of a locust swarm report (Figure 2 Panel B). For each cell, I identify the first year after 1989 in which a locust swarm is recorded (Figure 2 Panel A), and define a cell as exposed to a locust swarm in each following year and not exposed in all other years or if no locust swarm is ever observed.[17] Locations where locust swarms are observed in more than one year (12.6% of exposed cells) are not distinguished from those where they are observed only once. Cells exposed to a swarm before 1997 (in dark blue in Figure 2 Panel A) are treated during the entire sample period and are therefore dropped from the analyses, while cells exposed to a swarm after 2018 (in red) are considered not treated during the sample period. 7.5% of cells are exposed to a swarm during the sample period, including 5.4% exposed during the 2003-2005 upsurge (in teal).

Fourteen percent of cells experienced at least one violent conflict event, in 3.4 different years on average (Figure 2 Panel C). Protests and riot events and large-scale violent conflict events as defined in the UCDP are both recorded at least once in 8% of cells. About half

[17] A major locust upsurge occurred from 1985-1989. 1,195 cells where a locust swarm was recorded between 1985 and 1989 but in no year afterward are treated as not exposed to locust swarms during the 1997-2018 sample period. Treatment timing for another 997 cells where a locust swarm was recorded between 1985-1989 is based on the first year after this period that a locust swarm was recorded. The results are robust to basing treatment timing on the first year any swarm is recorded in a cell in the Locust Watch database.

the cells (54%) in the sample include some agricultural land: 53% have pasture land while 29% have crop land. Across all cells, the mean share of land allocated to agriculture is 24% (Figure 2 Panel D), with 19% pasture land and 5% crop land.

5 Empirical approach

I estimate the causal impacts of locust swarms on conflict using a difference-in-differences approach allowing for long-term effects of this transient agricultural shock. Cells are defined exposed to (or affected by) a locust swarm in all years starting from the first year a swarm is observed in a cell, and not exposed before or if no locust swarm is ever observed.

I estimate both static average impacts of locust swarm exposure using two-way fixed effects (TWFE) models and dynamic impacts over time using event study approaches. The TWFE linear probability models take the form:

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

where i indexes cells, c countries, and t years. $Conflict$ is a dummy variable for observing any conflict event and $Exposed$ is a dummy variable for having been exposed to a locust swarm. The primary specifications focus on impacts on violent conflict using the ACLED data. I consider effects on other measures of conflict in tests of the impact mechanisms. Analyzing conflict as a binary variable at an annual level reduces potential measurement error and is the main approach in the literature. γ_{ct} are country-by-year fixed effects, and μ_i are cell fixed effects. X_{ict} is a vector of time-varying controls at the cell level. Standard errors (SEs) are clustered at the sub-national region level (170 clusters) to allow for correlation in the errors within nearby areas over time.[18]

I estimate event study models considering the 14 years before and after locust swarm exposure using the staggered treatment difference-in-differences methods developed in Borusyak, Jaravel, and Spiess (2021)—which I will refer to as BJS—and Callaway and Sant'Anna (2021)—which I will refer to as CS.[19] I include the same fixed effects and clustering as in Equation 1. These two event study approaches deal with concerns with TWFE estimators when there is heterogeneity in treatment effects by time since treatment or across treatment

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

[19] Specifically, I use the Stata packages *did_imputation* (Borusyak, Jaravel, and Spiess 2021) and *csdid* (Callaway and Sant'Anna 2021), and generate event study plots using Stata's *event_plot* package (Borusyak, Jaravel, and Spiess 2021).

cohorts, which can lead to 'forbidden' comparisons between late- and early-treated groups and negative weighting of effects for certain treatment groups or periods (Goodman-Bacon 2021). Both methods effectively estimate an average treatment effect on the treated in each time period separately for groups exposed in different years g. Event study estimates are then calculated by taking weighted averages of these treatment effects. The main difference between the two approaches is that the CS method takes as a base value the year prior to treatment while the BJS imputation estimator makes comparisons against the average over all pre-treatment periods (Roth et al. 2023). The methods imply different assumptions about parallel trends but generally give quite similar results. I primarily present results using the BJS method.

In addition to the analyses considering all swarm exposure events I also specifically estimate impacts of exposure to the 2003-2005 major desert locust upsurge, dropping cells exposed to swarms in other years. This is the only major locust upsurge in the sample period (1997-2018), and accounts for 72% of first cell locust swarm exposure. 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 treat 2004 as the year of first exposure as the small number of swarms in 2003 at the beginning of the upsurge arrived in the last months of the year. Trends for violent conflict events and locust swarms prior to the upsurge are similar across cells that were and were not affected by the 2003-2005 upsurge supporting the parallel trends assumption, and locust swarm presence is similar following the upsurge (Figure A1).

To test for heterogeneity in the impacts of swarms, I estimate Equation 1 fully interacting the right-hand side variables with another variable of interest. I test robustness of the results to different controls and fixed effects, restrictions of the analysis sample, cell sizes, and clustering of SEs. Results of robustness tests are included in Appendix C.

The key identifying assumption of this design is that trends in conflict risk would be parallel over time in affected and unaffected areas within the same country in the absence of locust swarm exposure, after controlling for effects of weather, population. I find no significant differences in the probability of violent conflict by swarm exposure in the pre-exposure periods, indicating no differential conflict risk pre-trends (Figure 3). Though this does not preclude the possibility that trends would differ in the years after swarm exposure for reasons unrelated to agricultural destruction, it is an encouraging sign that the parallel trends assumption may be likely to hold.

Cells exposed to a locust swarm during the sample period have different baseline characteristics than unexposed cells which are largely consistent with desert locusts rarely being observed in the interior of the Sahara desert (as shown in Figure 2); among cells with agricultural land only mean annual rainfall and the share of crop land differ with swarm exposure status (Table A2). Differences are similar when comparing cells exposed to the 2003-2005 locust upsurge to unexposed cells.

Baseline differences are not a concern if they only affect levels of civil conflict and not trends. Cell fixed effects control for time invariant cell characteristics that might affect the risk of conflict such as distance to major cities or country boundaries, topography, and agricultural suitability, as well as factors affecting risk of locust exposure such as distance from locust breeding areas and typical seasonal wind patterns. Country-by-year fixed effects flexibly control for factors varying over time at the country level that might affect conflict risk and the impact of agricultural shocks, such as food price shocks, weather patterns, the policy environment and national economic and social conditions. Importantly, they also control for trends in violent conflict incidence, which increases over the sample period. To isolate impacts of locust swarm exposure from other potentially time-varying factors affecting conflict risk, I include controls for characteristics that differ between exposed and unexposed cells. In particular, my preferred specification includes total annual precipitation (in mm), the maximum annual temperature (in °C), and annual population.[20]

I test the robustness of the results to efforts to increase the plausibility of the parallel trends assumption by imposing different constraints on the areas included in the comparison sample and to using inverse propensity weights based on the estimated probability of locust swarm exposure (Stuart et al. 2014).[21] Exposed and non-exposed cells are well-balanced on baseline characteristics after include these inverse propensity weights (Table C1), suggesting the parallel trends assumption may be more likely to hold.

Another identification assumption relevant to event study designs with staggered treatment timing is the no anticipation assumption: knowledge of future treatment timing does not affect current outcomes (Roth et al. 2023). Populations may expect a higher probability of swarm exposure in years of major upsurges but cannot perfectly anticipate timing of exposure. For example, the FAO Desert Locust Watch publishes monthly forecasts of areas predicted to be at risk of locust swarm exposure but the predictions include a great deal of uncertainty due to unpredictable variation in swarm flight patterns. Consequently,

[20] Results are robust to including squared temperature and rainfall terms or used logged versions and to including 1 year weather lags. I do not have time-varying data on land cover, but results are not sensitive to accounting for changes in crop land over time as documented in Xiong et al. (2017).

[21] I calculate propensity scores using a logit regression with a dummy for being exposed to a locust swarm on baseline cell characteristics and mean weather and country fixed effects. I calculate inverse propensity weights as $\frac{1}{p}$ for cells that were exposed and $\frac{1}{1-p}$ for cells that were not, where p is the estimated probability of swarm exposure. I assign cells with estimated probabilities outside the range of common support a weight of 0. I separately calculate inverse propensity weights for any swarm exposure and for exposure during the 2003-2005 upsurge.

areas forecast to be at risk are generally quite large, the majority of which end up not being affected by locusts.[22] Anticipation may also have limited effects as there are no effective methods of defending vegetation against locust swarms, and farmers in at-risk areas typically describe locust prevention and control as out of their hands and the responsibility of governments (Thomson and Miers 2002).

6 Results

6.1 Dynamic impacts of swarm exposure on violent conflict

Figure 3 Panel A presents event study estimates of the impacts of swarm exposure on the risk of violent conflict over time using the staggered treatment timing difference-in-differences approach developed in Borusyak, Jaravel, and Spiess (2021). The pattern of results is similar using the Callaway and Sant'Anna (2021) method (Figure C1). There is no significant difference in conflict risk between cells that are and are not exposed to locusts in the years prior to exposure, supporting the parallel trends assumption.[23]

The point estimate for the effect on violent conflict risk in the year locusts arrive is -0.002 but not statistically significant. All other estimated treatment effects are positive and statistically significant. Impacts in years 1-6 post-exposure are relatively smaller—the average effect is a 1.2 percentage point increase in conflict risk—and for 3 of years the effects are only marginally statistically significant. The impacts are larger in years 7-14 post-exposure and are highly significant after year 7 even as the standard errors are larger with more time since exposure. Swarm exposure causes an average increase in violent conflict risk in a given year of 2.8 percentage points over these periods.

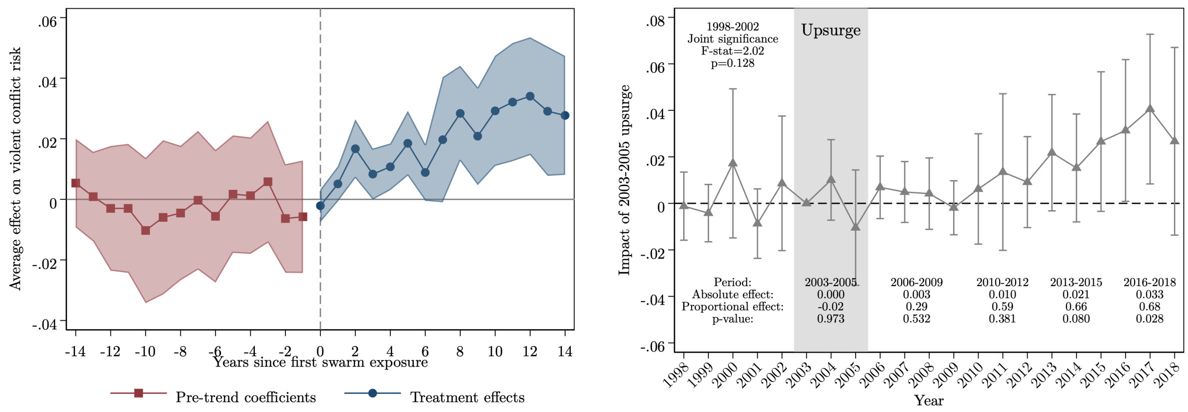
Figure 3 Panel B shows the results of an event study analysis of the 2003-2005 upsurge. I include inverse propensity weights to account for differences in which countries in the sample were affected by this upsurge. Patterns are similar but estimated effects are larger and more frequently statistically significant when not including inverse propensity weights (Figure C4). Effects are all estimated relative to 2003, when a few locust swarms were observed near the end of the year. There are no significant differences in the risk of violent conflict between areas exposed to locust swarms during this upsurge and areas that were not in the years preceding the upsurge, and I cannot reject the joint hypothesis that the pre-trend coefficients

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

[23]The average difference in the pre-exposure period is -0.005. None of the 14 pre-exposure period differences are significantly different from 0 and I fail to reject that pre-period differences are jointly equal to 0 (p=0.236).

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

A) Exposure to any swarm B) Exposure to a 2003-2005 upsurge swarm



Note: The dependent variable is a dummy for any violent conflict event observed.
Panel A shows event study results for impacts of exposure to any locust swarm on violent conflict risk over time using the Borusyak, Jaravel, and Spiess (2021) approach. Estimated impacts in each time period are weighted averages across effects for swarm exposure in particular years. Time period 0 is the year of swarm exposure. A joint test that the pre-exposure coefficients equal 0 gives $p = 0.236$.
Panel B shows coefficients for the interaction of a dummy for being exposed to a 2003-2005 upsurge swarm with year using 2003 as the reference period. In the top left is the result from a joint test of the hypothesis that all pre-upsurge coefficients equal 0. 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.
Shading and bars represent 95% confidence intervals using SEs clustered at the sub-national region level. All regressions include country-by-year and cell fixed effects. The analyses in Panel B also includes controls for rainfall, temperature, and population and inverse propensity weights. Observations are grid cells approximately 28×28km by year. Locust swarm exposure is based on the first year a locust swarm is observed in a cell. Cells with locust swarms observed before the start of the sample period are not included in the analyses, and cells exposed outside of 2003-2005 are not included in Panel B.

are equal to 0 (p=0.128). This again supports the assumption of parallel trends between these areas if not for the locust swarm exposure.

There is no significant impact of locust exposure on the risk of conflict in the main years of the upsurge, 2004 and 2005, as in the exposure year estimates in Figure 3 Panel A. Estimated impacts of the 2003-2005 upsurge on conflict in the following years are almost all positive (the coefficient for 2009 is slightly negative), and generally become larger in magnitude over time starting after 2009. The estimated effects for individual years are noisier and only statistically significant at a 90% confidence level or greater for 2013 and 2015-2017.

Average estimates over bins of years are shown at the bottom of the figure and are more precise. Being exposed to a 2003-2005 upsurge swarm does not significantly affect violent conflict risk from 2006-2012, but increases the annual risk by 2.1 percentage points on average between 2013-2015 and by 3.3 percentage points between 2016-2018, and these effects are statistically significant. An advantage of the upsurge event study is the ability to compare effects against violent conflict incidence in control areas at different points in time. The effect of the upsurge represents a 67% increase in violent conflict risk relative to the mean in unaffected areas from 2013-2018, as violent conflict in the sample countries increased over time due to a variety of factors (Figure A1 Panel A).

In summary, after null effects on violent conflict risk in the short-term immediately following swarm exposure, the annual probability of any violent conflict event is significantly higher than in unaffected cells in the years post-exposure. The largest impacts are realized around 7-14 years after swarm exposure. Patterns are similar when considering impacts of the exposure to the 2003-2005 locust upsurge in particular, though treatment effects are not significant for the first several years after exposure. The large and statistically significant increases in violent conflict risk in areas affected by the upsurge from 2013-2018 (8-14 years after exposure) align with the periods of highest estimated effects in the main event study and also with the timing of a general increase in violent conflict in the study sample. This suggests heterogeneity in impacts by the activity of fighting groups discussed in the model, which I return to in Section 7.

6.2 Average impacts of swarm exposure on violent conflict

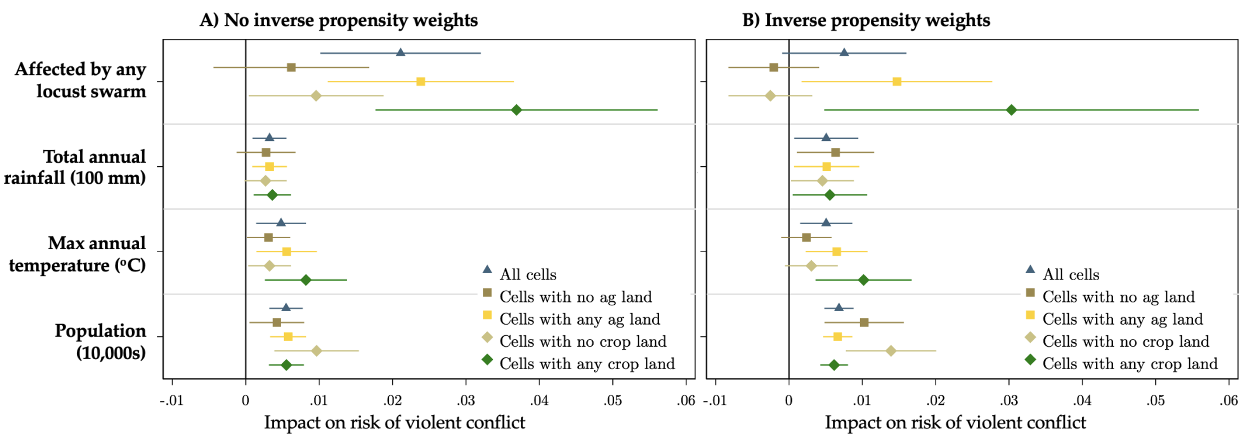
I now estimate average long-term impacts of swarm exposure on the annual risk of violent conflict to compare estimated effects against those of annual weather deviations and test heterogeneity by land cover. Figure 4 Panel A shows that on average cells exposed to locust swarms are 2.1 percentage points (pp) more likely to experience any violent conflict in a given year in the period after swarm exposure than cells not exposed. This estimate is very close to the average of the treatment effects in Figure 3—a 1.9pp increase—indicating limited bias in the TWFE estimates from staggered timing of swarm exposure. A 2.1pp increase on the probability of any violent conflict in a year represents an 88% increase over the mean for cells not exposed to locusts.

This effect is large compared to the effects of weather deviations. An increase in annual precipitation of 100mm relative to the average in the cell during the sample period increases the probability of violent conflict in the same year by 0.3pp (13%), while an increase in the maximum annual temperature of 1°C relative to the cell average increases conflict risk in the same year by 0.5pp (21%). These effects fall in the upper middle range of estimates reported in Burke, Hsiang, and Miguel (2015)'s meta-analysis of the impacts of weather deviations on conflict. Cell population is also positively associated with conflict risk, with an increase of 10,000 people associated with a 0.5pp (21%) increase in the probability of any violent conflict event in a year.

The average impact of locust exposure remains statistically significant at the 99% confidence level under other forms of standard error clustering, including two-way clustering at the region and year level and using Conley (1999) SEs allowing for spatial correlation within

100 and 500km and serial correlation over 0 or 10 years (Figure C5). Associations between weather deviations and population and violent conflict risk are also statistically significant at the 95% confidence level or greater under all clustering choices. Clustering at the sub-national region level consistently leads to SEs at least as large as Conley SEs allowing for spatial correlation within 500km and serial correlation over 10 years, implying the main SEs I report with region clustering are conservative and may understate statistical significance of certain estimates.

Figure 4: Average impacts of exposure to locust swarms on violent conflict risk by land cover



Note: The dependent variable is a dummy for any violent conflict event observed. Coefficients and 95% confidence intervals are from three separate regressions in each panel: one with no land cover interactions and the other two interacting all right-hand side variables with cell land cover dummies. The coefficients and standard errors for cells with any agricultural (pasture or crop) land and with any crop land are calculated using Stata's *xlincom* command based on the sums of the coefficients for the baseline effect and the interaction term. Inverse propensity weights included in the regressions in Panel B are calculated based on the estimated propensity for cells to have been exposed to a swarm. Cells are regarded as 'affected' by locust swarms for all years starting from the first year in which a swarm is recorded in the cell. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses. Results from the regressions are reported in Table A3.

I test for differences in the impacts of swarm exposure and weather by whether a cell has any agricultural (crop or pasture) land or any crop land using measures of land cover from 2000 (Ramankutty et al. 2010).[24] Locust swarm exposure in non-agricultural cells (46% of the sample) has no significant effect while in agricultural cells annual violent conflict risk increases by 2.4pp. Locust swarms increase annual violent conflict risk by 3.7pp in crop cells (29% of the sample) compared to 1.0pp in non-crop cells (35% of which have pasture land), indicating that impacts on crop production drive most of the effect on conflict risk but impacts on pasture also explain part of the total effect. This aligns with desert locusts

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

consuming all forms of vegetation.

There is no significant difference in the effects of higher rainfall by land cover, echoing previous work questioning whether agricultural mechanisms explain the relationship between rainfall and conflict (Bollfrass and Shaver 2015; Sarsons 2015). Impacts of higher temperatures are larger in by cells with crop land, where a 1°C hotter year increases annual violent conflict risk by 0.8pp. But higher temperatures also increase conflict in non-agricultural cells. The association between population and conflict risk does not vary significantly with land cover.

Panel B of Figure 4 shows the results from the same regressions weighting observations by the inverse of the estimated propensity to have been exposed to a locust swarm during the study period. Estimated magnitudes for the impacts of swarm exposure are smaller than in Panel A with no weights, suggesting part of those estimated effects are due to comparisons between cells affected by locust swarms and dissimilar unaffected cells with different trends in violent conflict risk. But the patterns and qualitative conclusions are the same. On average, locust swarm exposure increases annual violent conflict risk by 0.8pp in subsequent years. This is significant at the 90% confidence level and represents a 43% increase relative to the mean in unaffected cells. Estimated effects in cells without pasture or crop land are close to zero and not statistically significant. Impacts are driven particularly by cells with any crop land where the annual risk of violent conflict increases by 3pp, compared to an increase of 1.5pp in cells with either crop or pasture land.

The pattern of swarm exposure impacts is very similar when specifically analyzing the 2003-2005 locust upsurge with upsurge-specific inverse propensity weights (Table A3). This is not surprising since the 2003-2005 upsurge was the main swarm exposure event in the sample period. Upsurge exposure is associated with a 1.1pp (60%) increase in violent conflict risk over the following years on average. This is again driven exclusively by cells with crop or pasture land.

The heterogeneity in TWFE results by land cover is consistent with locust swarms representing shocks that affect the economy and society solely through their impacts on agricultural production, and particularly through damages to crop land. Effects also vary by timing of swarm exposure relative to the local crop calendar in ways consistent with this channel (Table A4). 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 from The United States Department of Agriculture (USDA) (2022).[25] The off season—between harvesting and planting—lasts between 3 and 6 months in most of the

[25] 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.

sample countries, with an average of slightly over 4 months.[26] Focusing on the 2003-2005 upsurge I find that impacts are driven by exposure to upsurge swarms that arrived in crop cells during the country's crop growing season when damages to agriculture would be greatest. Exposure to upsurge swarms during the off-season or in cells with no crop land does not significantly affect conflict risk, though point estimates for impacts of off season swarms in crop and non-crop cells are relatively large, indicating effects through damages to pasture land and other vegetation. The finding relates to studies showing that the impact of weather shocks on conflict risk varies depending on whether the timing of the shock is such that it is likely to decrease agricultural productivity (Caruso, Petrarca, and Ricciuti 2016; Crost et al. 2018; Harari and La Ferrara 2018).

6.3 Robustness

I test the sensitivity of the results to various alternative specifications and estimate similar impacts of locust swarm exposure on violent conflict risk. The results are included in Appendix C. In this section I summarize the main sensitivity checks and discuss any differences.

Estimated impacts are largely unchanged when varying the set of control variables included. Dropping weather and population controls leads to slightly larger magnitude effects on violent conflict risk and greater statistical significance in the main event study but do not affect the upsurge event study. Dynamic effects of upsurge exposure are also very similar when interacting the weather and population controls with year. TWFE estimates with and without inverse propensity weights are similar without controls and when including 1 year lags of rainfall and maximum temperature as additional controls.

Across all analyses the estimated treatments effect sizes are slightly larger and standard errors are smaller when using sub-national region-by-year fixed effects instead of country-by-year fixed effects. More local time fixed effects control for the possibility that swarm migratory paths may overlap with parts of countries with greater future risk of violent conflict. The similarity of the results increases confidence that the estimates reflect true long-term causal effects of swarm exposure. Using year fixed effects results in a similar pattern of treatment effects as in Figure 3, with slightly larger estimated magnitudes. TWFE estimates are smaller with year fixed effects and lose significance when also including inverse propensity

[26] Figure A3 shows the share of sample cells at different stages of agricultural cycle by month and the counts of locust swarms during the sample period observed by season and region. I do not distinguish between planting, growing, and harvest season swarms in the analysis as the months assigned to these periods are approximate and effects should largely be similar. Most 2003-2005 upsurge swarms were recorded during months of the main growing season, which covers a greater share of the year, and the majority of swarms were in the 71% of cells with no crop land. A small number of cells were exposed to both off-season and growing season swarms.

weights, though impacts in crop cells remain significant. These differences across fixed effects indicate that impacts of swarm exposure are most notable when comparing exposed cells to nearby unexposed cells.

Results are similar when restricting the sample of control cells to those within 100km of any locust swarm exposure (shown in Figure 2). This ensures that the results are not driven by comparisons between exposed cells and unexposed desert cells with low risk of either swarm exposure or violent conflict, though the inverse propensity weights serve a similar function. I also obtain similar results when systematically omitting countries from certain regions (North, West, and East African and the Arabian Peninsula). This addresses concerns that the long-term impacts on violent conflict may be spurious and due to swarm exposure during the sample period being correlated with factors driving later conflict emergence. For example, dropping North Africa ensures that results are not driven by the Arab Spring and dropping Arabia ensures results are not driven by the civil war in Yemen.[27]

Estimated impacts on violent conflict risk of locust swarm exposure events are slightly smaller when dropping countries listed in Showler and Lecoq (2021) as areas where insecurity limited desert locust control operations during the sample period to addresses concerns about possible unreported locust swarms correlated with conflict risk.[28] This could indicate that some swarms were not reported in insecure areas and the cells are classified as not exposed to a swarm, biasing the estimated effect of exposure downward. In general, unreported swarms would bias the estimates downward if they also increase violent conflict risk on average, but they would bias estimates upward if swarms are more likely to be unreported in areas with persistently low risk of violent conflict. Both types of bias may exists and partially offset. The similarity of the results when excluding the most insecure countries from the sample and robustness to including inverse propensity weights (which exclude cells with low estimated probability of any locust swarm being reported) increase confidence that bias from unreported swarms is unlikely to be driving the estimated impacts of exposure on violent conflict risk.

Finally, I consider differences in estimates at the 0.5° and 1° cell levels. Using larger grid cells addresses several potential measurement issues. First, it minimizes the possibility that

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

[28]This is true when considering all locust swarm exposure events. Estimated impacts of the 2003-2005 upsurge are slightly larger when dropping these countries. The difference is likely because two of these countries, Yemen and Somalia, are already excluded from the upsurge analysis as the 2003-2005 upsurge did not affect these countries.

the area exposed to a locust swarm recorded in a cell exceeds the boundaries of the cell. Second, it reduces concerns about nearby areas that might have been affected by unreported swarms since the entire cell is considered exposed if any swarm is reported within it. Third, it limits the potential for conflict spillovers outside the cell. Downsides to analyzing impacts in a more coarse grid are dilution of treatment intensity (as the share of the cell affected by swarms weakly decreases with cell size) and the loss of local variation in swarm exposure, which the previous robustness checks show is important for estimating the impacts on violent conflict risk.

The pattern of dynamic swarm exposure effects over time is similar at different levels. Estimated magnitudes increase with cell size (though not in proportion to mean conflict risk) but the standard errors do as well. In the full event study, the negative effect in the year of exposure becomes statistically significant while some of the later treatment effects lose significance. Average impacts increase from a 2.1 percentage point rise in annual violent conflict risk at the 0.25° cell level to a 2.4pp increase at the 0.5° level and 4.1pp at the 1° levels, with the largest impacts concentrated in years 7-10 post-exposure. With inverse propensity weights, impacts of swarm are not significant at the 0.5 or 1° levels on average but are significant and larger for cells with crop land. Changes are similar for average impacts of the 2003-2005 locust upsurge at different scales. Larger estimated magnitudes when using larger grid cells despite dilution of treatment intensity suggest violent conflict spills over outside exposed areas. The consistent negative point estimate in the year of swarm exposure indicate this is not driven by spillover conflict outside affected cells. Nearby cells not exposed to locust swarms could be targets for predatory attacks as they are likely to have greater wealth in the long-term, having been spared the major income shock. Focusing on 0.25° cells may therefore understate the full effect of swarm exposure on violent conflict around affected areas.

7 Mechanisms

7.1 Short-term

The small and non-significant impacts of locust swarms in the year of exposure provide evidence that negative agricultural production shocks need not increase the risk of conflict in the same year. This contrasts with much of the literature on climate and conflict. One explanation for the difference is that the effect of weather shocks on violent conflict may primarily go through channels other than agricultural production. I find no significant difference in the effects of rainfall deviations by land cover while higher temperatures significantly increase conflict risk in both agricultural and non-agricultural areas (Figure 4), echoing previous work finding impacts of rainfall on conflict that cannot be explained by agricultural mechanisms (Bollfrass and Shaver 2015; Sarsons 2015). But some studies also find that growing season weather shocks have null or inconsistent effects on conflict in the same year, notably Crost et al. (2018) and Harari and La Ferrara (2018). These studies emphasize increases in conflict risk the year after a shock, which I also find for locust swarms, and suggest a general mechanism suppressing immediate impacts of a shock on violent conflict.

A non-significant short-term effect of a negative agricultural shock on conflict risk is not surprising in the context of the model, as the decrease in opportunity cost of fighting is offset by a decrease in the returns to predation when the value of output and wealth available to capture is smaller. Studies of shocks to agricultural prices have shown instances where the predation mechanism outweighs the opportunity cost mechanism: McGuirk and Burke (2020) and Ubilava, Hastings, and Atalay (2022) both document increases in violent conflict in cells producing agricultural goods following increases in the global price of these goods.

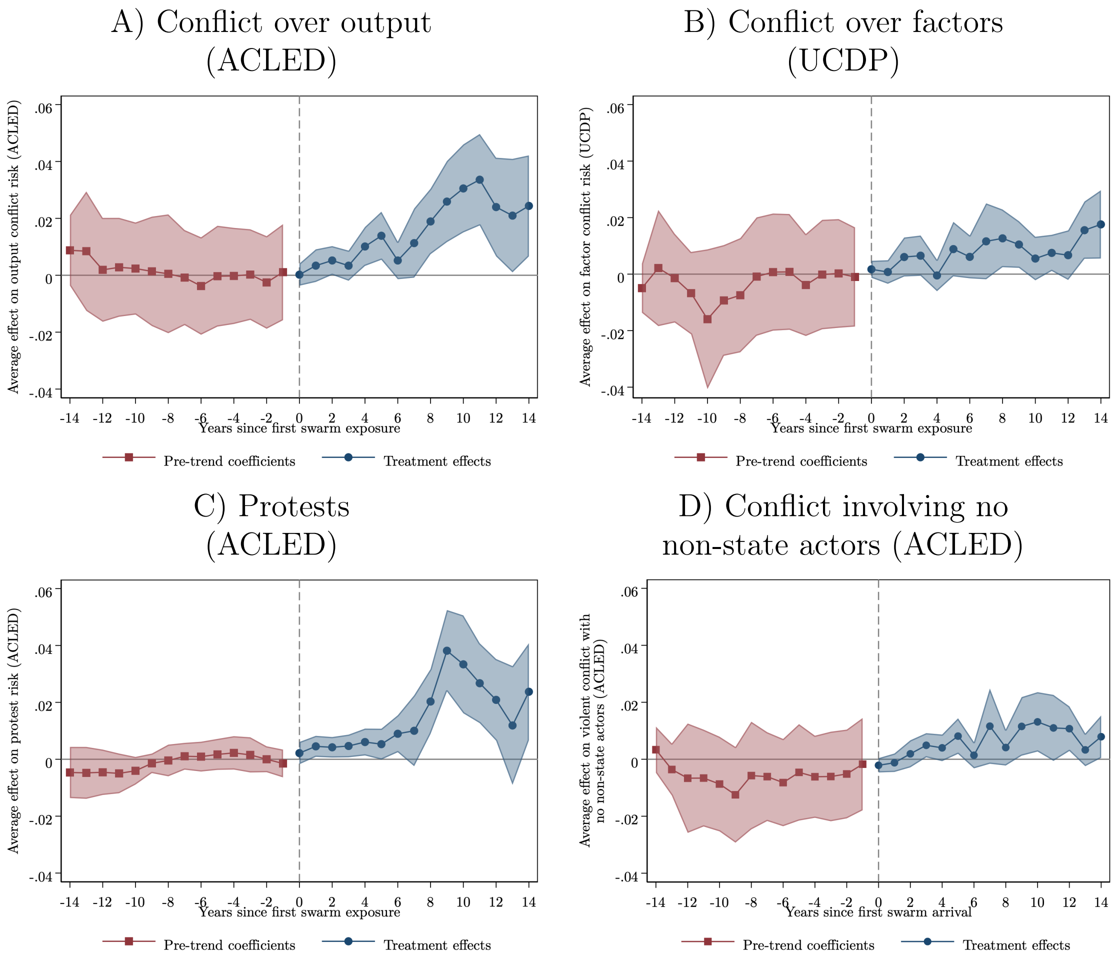
If the null effect in the year of exposure results from these offsetting mechanism, we should observe larger short-term impacts on conflict over factors and on protests—whose returns are less affected by agricultural destruction—than on conflict over output. Figure 5 shows results from event studies of the impact of swarm exposure on alternative measures of conflict. I follow McGuirk and Burke (2020) in using reports of violence against civilians, riots, and looting from ACLED as representing conflict over output (Panel A) and violent conflict events reported in the UCDP database, which must include at least one "organized actor" and result in at least 25 battle-related deaths in a calendar year, as more likely to represent conflict over factors of production (Panel B). I compare these to reports of protests from ACLED (Panel C). Effects in the year of exposure are all close to 0 and not statistically significant and I cannot reject that impacts in the year of swarm exposure are the same across all types of conflict.[29]

Null effects on factor conflict and protests in the year of swarm exposure indicate mechanisms other than reductions in the returns to predation explain the null effect on violent conflict. There are several possible factors that could suppress violent conflict in the short term but not the long term.

Psychological mechanisms may contribute the null short-term impact of locust swarms on violent conflict. The dominant religion in the sample countries is Islam, where locusts are mentioned as both a punishment from Allah and as a sign of Judgment Day. If locust

[29] For event studies of the 2003-2005 upsurge, the estimated effect of exposure in 2005 is -0.010 for violent conflict risk compared to +0.011 for protests, the latter of which is statistically significant in line with the model predictions. I can reject that the effects are the same (p=0.007). But I cannot reject that effects in 2004 are the same.

Figure 5: Impacts of swarm exposure on conflict risk over time, by conflict type



Note: The dependent variables are dummies for any conflict event being observed in a cell in a year, with the conflict type specified in the panel title. Each panel replicates Figure 3 Panel A for a different conflict outcome. See the figure note for Figure 3 for more detail. Shading represents 95% confidence intervals using SEs clustered at the sub-national region level.

swarms temporarily increase religiosity this may affect the perceived returns to fighting by increasing social, emotional, and supernatural costs, suppressing immediate violent conflict.

Temporary migration following an agricultural shock may be preferred to fighting. This could decrease the short-term risk of conflict as there are fewer people to potentially engage in fighting, given that cell population is positively and significantly correlated with the risk of violent conflict (Figure 4). Out-migration may be greater for more severe agricultural shocks such as the arrival of a locust swarm. Leaving to search of work is a common response to locust crop destruction (Thomson and Miers 2002) and over 8 million people were displaced across East Africa as a result of the 2019-2021 locust outbreak (The World Bank 2020).[30]

[30]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

Impacts of swarm exposure on violent conflict may then be realized with a delay when displaced populations return and are faced with the effects of the severe income shock.

Another possibility is that temporary relief efforts increase the opportunity cost of fighting by providing another source of livelihood that is presumably not available to fighters and deters individuals from engaging in violent conflict. On the other hand, aid may also increase incidence of violent conflict if it serves as a target for predation or banditry (Nunn and Qian 2014), so the net effect of any increase in aid on violent conflict risk following a shock is unclear. Country-level annual data on international development flows to agriculture (which includes food aid) from FAOSTAT (2023) provide some indication of temporarily increased relief following exposure to desert locust swarms, though with a short delay (Table A5). Agricultural development flows increase by 185 million USD (20%) the year after a country experiences any locust swarm, and by 313 million USD (32%) the year after swarms arrived during the major 2003-2005 locust upsurge which drew significant international attention and support. An increase in international aid with a 1 year delay does not explain null effects on violent conflict in the year of exposure, but more local aid flows may arrive more quickly.

Finally, the null effects on violent conflict in the year of exposure may be due to costs of fighting being too high. Locust swarms are highly destructive and cause severe food insecurity so affected individuals may lack the resources needed to fight. Affected individuals could also have had few opportunities to join fighting groups in years of locust exposure. The majority of locust exposure occurred in 2004 and 2005, when violent conflict incidence in the sample countries was relatively low. On average 4.8% of cells exposed to locust swarms during this upsurge were adjacent to another cells that experienced any violent conflict during the period of exposure, compared to 13.1% in the following years. I return to differences by activity of fighting groups in the following subsection.

In summary, the predation mechanism does not appear to explain null effects of locust swarms on violent conflict risk in the year of exposure. Psychological effects, out-migration, and aid relief may also suppress the short-term likelihood of fighting, and affected households may also have lacked the resources and opportunity to engage in violent conflict.

7.2 Long-term

Locust swarm exposure causes a significant and persistent increase in the long-term risk of violent conflict. In the simple model of occupational choice, the likelihood of conflict increases if either the opportunity cost of fighting falls or if the returns to fighting increase.

the evidence indicates that this is not leading to short-term conflict spillovers as the estimated impact in the year of exposure remains negative when analyzing impacts in 0.5 and 1° cells.

Locust swarms do not have any effect that could lead to long-term increases agricultural production or wealth, which means the impact on violent conflict risk must be driven by decreases in opportunity costs of fighting.

Event study results for different types of conflict in Figure 5 are consistent with such a mechanism. If individuals are deciding to fight when their opportunity cost is low this is most likely to occur in groups such as identity/political militias, rebel groups, and terrorist organizations as opposed to through joining state armed forces. In line with this, impacts on ACLED conflict not involving non-state actors (Panel D) are smaller and less consistently statistically significant. On the other hand, long-term impacts on protests—which should be affected by opportunity costs of participation but not potential resources available to capture—are large. Swarm exposure significantly increases the long-term risk of protests with a similar pattern of smaller impacts in the first 7 years and much larger increases afterward, though the estimates for year 13 is not statistically significant.

Comparing impacts on different conflict types suggests a role of the predation mechanism as well, in line with model predictions. The average treatment effect is a 1.5pp increase in the annual risk of protests, a 138% increase relative to the mean in unaffected cells. The impact on the ACLED-based measure of output conflict is a 1.5pp (92%) average increase, and the impact on the UCDP-based measure of factor conflict is a 0.8% (69%) average increase. A larger impact on protests than output conflict is consistent with predictions of the model based on the predation mechanism offsetting some of the effect of lower opportunity costs on the risk of violent conflict. A smaller impact on factor conflict does not align with predictions, as the value of land in particular should not be affected by locust exposure. But land values may have fallen for other reasons, and another possibility is that factor conflict is more costly to engage in than output conflict and therefore increases by less in response to a decrease in opportunity costs.

If long-term impacts on conflict risk are due to persistent decreases in agricultural productivity reducing the opportunity cost of fighting, this should be observable in effects on productivity in affected areas. Marending and Tripodi (2022) find that agricultural profits of households in parts of Ethiopia exposed to locust swarms in 2014 were 20-48% lower two harvest seasons after swarm arrival. This indicates that impacts on agricultural productivity are not limited to the year of swarm exposure.

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

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

Table 1: Average impacts of locust swarm exposure on measures of productivity

	(1) Max annual NDVI (10,000s)	(2) Max annual NDVI (10,000s)	(3) Cereal yield, kg/ha	(4) Cereal yield, kg/ha	(5) Gross cell product, 1990 USD PPP millions	(6) Gross cell product, 1990 USD PPP millions
Any swarm in cell	-0.011***		12.1		0.59	
	(0.003)		(56.9)		(2.44)	
Any swarm in cell previous year	0.001		-92.3		-6.13**	
	(0.004)		(63.4)		(2.86)	
Affected by any locust swarm		0.000		-108.4*		-5.98*
		(0.002)		(60.0)		(3.10)
Total annual rainfall (100 mm)	-0.000	-0.000	13.1**	17.2**	5.55*	5.76*
	(0.001)	(0.001)	(5.9)	(7.0)	(3.11)	(3.17)
Total annual rainfall previous year (100 mm)	0.002***	0.002***	11.9	7.6	0.59	0.62
	(0.000)	(0.000)	(8.9)	(8.9)	(1.06)	(1.12)
Max annual temperature (deg C)	-0.012***	-0.012***	-61.2	-86.4*	-4.08*	-4.45
	(0.002)	(0.002)	(47.3)	(48.3)	(2.45)	(2.78)
Max annual temperature previous year (deg C)	-0.001	-0.001	41.2	57.6	4.01	4.00
	(0.002)	(0.002)	(45.1)	(43.3)	(2.85)	(2.90)
Population (10,000s)	-0.000***	-0.000***	0.0	0.1	8.17***	8.09***
	(0.000)	(0.000)	(1.2)	(1.4)	(2.00)	(2.06)
Observations	54412	51961	4181	3750	41108	38734
Outcome mean, no swarms	0.537	0.551	1942.5	1987.0	59.93	60.25
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Outcome variables in columns 1-4 are from the DHS AReNA database (IFPRI 2020) at the level of the clusters where DHS surveys are conducted. Maximum NDVI is measured based on satellite data for the location of each survey cluster each month from 2000-2019; I take the maximum value each year. Cereal crop yield in kg/ha is measured based on survey reports and averaged at the cluster level for years in which surveys are conducted in specific clusters. I collapse these data to the level of 28×28km grid cells by year taking means of the outcome variables. Gross cell product in columns 5-6 is from Nordhaus (2006) as included in the PRIO-GRID database. All regressions include country-by-year and location fixed effects. SEs are clustered at the sub-national region level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

While this might suggest no persistent impacts on agricultural labor productivity, Column 4 shows that household reports of cereal yields fall by a statistically significant 108 kg/ha (5.4%) on average in years after locust swarm exposure. This is larger than the effect of a decrease of 100mm of rainfall in the same year or a 1°C increase in maximum temperature. This decrease emerges from the first year after locust swarm exposure (though it is not statistically significant), but is not observed in the year of exposure where there is no significant effect on yield (Column 3). No effect on yield in the year of exposure may be a result of two factors. First, in some countries and years survey timing will involve asking about cereal yields over a season that ended before swarms arrived. Second, yield is typically reported as output over area harvested, and consequently will not capture damages on plots where crops are completely destroyed so there is no harvest.

Columns 5 and 6 show how locust swarm destruction affects income using measures of gross cell product—estimates of total income at the cell level based on population and output in agricultural and non-agricultural activities—from Nordhaus (2006) as included in the PRIO-GRID database. These estimates are only available for 2000 and 2005 in the sample period, allowing an analysis of the immediate impact of exposure to the 2003-2005 locust upsurge. Total income falls by 6 million USD (in 1990 PPP terms)—nearly 10%—in cells affected by locust swarms, in the year after swarm is exposure, consistent with when yields are affected.

A significant immediate decrease in average incomes in areas exposed to locust swarms and a persistent decrease in cereal yields in the following years relative to unexposed areas are consistent with the wealth mechanism described in the model. Locust swarms do not affect local agricultural productivity fundamentals, but damages to agriculture from locust exposure result in a permanent income and wealth shock. Adoption of agricultural insurance is very low in the sample countries, access to credit is constrained, and local risk sharing networks may be insufficient to help affected households recover from the extent of damage caused by locust swarms. Household coping strategies involve drawing down wealth to deal with the income and food security shock. The severity of this shock has been demonstrated by studies showing long-term negative impacts of locust swarm exposure on children's education (De Vreyer, Guilbert, and Mesple-Somps 2015) and health (Conte, Tapsoba, and Piemontese 2021; Le and Nguyen 2022; Linnros 2017). Reduced household wealth would decrease access to productive inputs in subsequent years, which would explain a persistent decrease in cereal yields. This implies lower agricultural productivity and therefore a lower opportunity cost of fighting in areas exposed to locust swarms, which would increase the probability of violent conflict.

The wealth mechanism alone would suggest that impacts of swarm exposure on conflict risk should fall over time if households gradually recover or should be fairly stable if households reach a new productivity equilibrium. The fact that long-term impacts of swarm exposure on conflict are not consistent over time and are largest in a period starting around 8 years after exposure suggests some heterogeneity in impacts by time-varying conditions affecting either opportunity costs or returns to fighting.

The largest effects of upsurge swarm exposure coincide with the years when the general risk of conflict increased across the sample countries (Figure A1), indicating heterogeneity by local conflict activity. Proximate causes for the increase in conflict include food price shocks, the Arab Spring, the spread of Islamic militant groups, and multiple civil wars. Recruitment of fighters to armed groups following the onset of conflict will be easier in areas where opportunity costs of fighting are lower (Collier and Hoeffler 2004). But individuals in those areas may otherwise not find switching to fighting optimal as violent conflict is generally a collective activity. Without a group, the social, emotional, and monetary costs of fighting are likely to be high and the probability of victory low, as discussed in Section 3.

Table 2 shows the estimates from testing whether long-term impacts swarm exposure vary by the presence of groups active in violent conflict the previous year or in the surrounding cells. Results are similar when considering any swarm exposure and when focusing on the 2003-2005 upsurge. Impacts of swarm exposure on violent conflict risk are driven entirely by effects in areas and periods with groups engaging in violent conflict, as predicted. This is consistent with Figure 3 showing significant impacts of upsurge exposure are delayed until years when violent conflict incidence was greatest in the sample countries, and similarly explains the delay in the largest effects on protests in Figure 5.

Table 2: Average impacts of exposure to locust swarms on violent conflict risk, by presence of groups active in civil conflict

Outcome: Any violent conflict event	(1) Any exposure	(2) 2003-2005 exposure	(3) Any exposure	(4) 2003-2005 exposure
Exposed to locust swarm	0.002 (0.003)	0.003 (0.004)	0.001 (0.003)	0.002 (0.004)
Any violent conflict in cell previous year	0.299 (0.218)	0.275 (0.274)		
Exposed to locust swarm × Any violent conflict in cell previous year	0.081*** (0.028)	0.160*** (0.031)		
Any violent conflict elsewhere in 1 degree cell			0.132 (0.092)	0.210** (0.105)
Exposed to locust swarm × Any violent conflict elsewhere in 1 degree cell			0.049*** (0.014)	0.056*** (0.017)
Observations	452218	400668	452218	400668
Outcome mean post-2005, no swarm exposure	0.018	0.019	0.018	0.019
p-value: coefficients shown all =0	0.031	<0.001	0.007	0.016
Country-Year FE	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
IPW	Yes	Yes	Yes	Yes

Note: The dependent variable is a dummy for any violent conflict event observed. Cells are regarded as 'affected' by locust swarms for all years starting from the first year in which a swarm is recorded in the cell. Analyses of the 2003-2005 upsurge exclude cells exposed in other years from the sample. Inverse propensity weights are applied in all regressions and are calculated separately based on estimates of the propensities of cells to have been exposed to any swarm and to the 2003-2005 upsurge. Controls include annual total rainfall, maximum temperature, and population, and their interactions with the conflict activity variables. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Swarm exposure magnifies the correlations in violent conflict activity over time and space. Cells exposed to any swarm (the 2003-2005 upsurge) are 8.1 percentage points (16.0pp) more likely to have any violent conflict if there was violent conflict in the cell the previous year, relative to unexposed cells, and 4.9pp (5.6pp) more likely if there is violent conflict in any of the cells in the surrounding 1° cell.[31] Being exposed to a swarm thus makes cells significantly more likely to engage in violent conflict when it emerges, even years after exposure, but not otherwise.

In summary, long-term impacts of locust swarm exposure on conflict risk can be explained by persistent decreases in opportunity costs of fighting. These decreases are observed in a cereal yields, a measure of agricultural productivity, and are consistent with an initial wealth shock affecting long-term access to productive resources. The decrease in opportunity cost does not cause outbreaks of new violent conflicts but rather affects the locations and duration of violent conflicts after these emerge due to other proximate causes, when net returns to fighting are high enough to make a switch to fighting optimal.

8 Comparing locust swarms and severe drought

Locust swarms are a unique and catastrophic agricultural shock, but the model described in Section 3 is general and predicts similar patterns of impacts on the risk of violent conflict for other severe shocks to agricultural production. In this section I compare the impacts of locust swarm exposure to the impacts of exposure to a severe drought. Following Harari and La Ferrara (2018) and others I use the Standardized Precipitation and Evapotranspiration Index (SPEI) which combines both rainfall and the ability of the soil to retain water. Grid cell SPEI data from 1996-2014 are included in the PRIO-GRID database (Begueria et al. 2014). The units for the measure of SPEI are standard deviations from the cell's historical average. I define a cell as experiencing a severe drought shock in a particular year if there are at least 4 consecutive months where the SPEI is below -1.5 (deviations within 1 indicate near normal conditions). As with locust swarm exposure I identify the first year in which a cell experiences such a drought and consider cells to be 'affected' in all subsequent years.

Figure 6 Panel A shows the results from an event study of drought exposure using the BJS method. Pre-exposure coefficients are small in magnitude and not statistically significant, with the exception of the period 8 years before exposure to a drought. Conflict risk increases

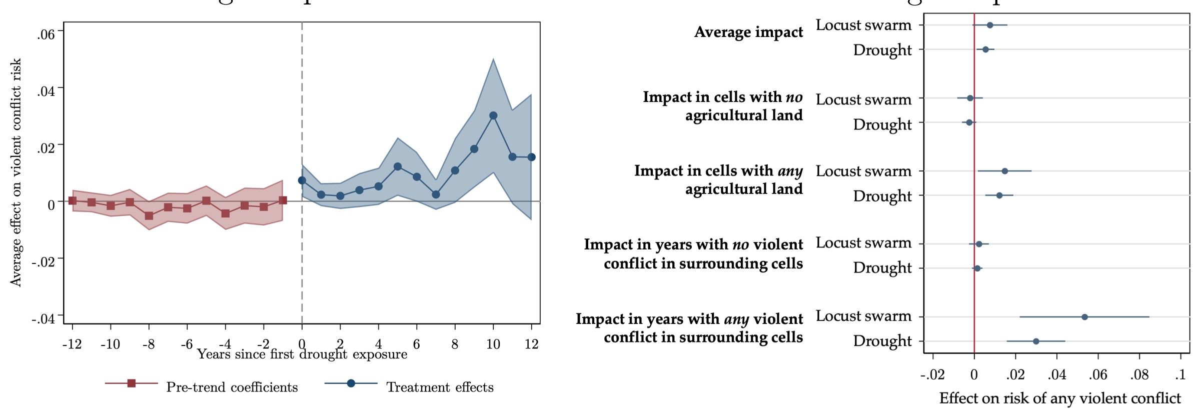
[31] Because swarm exposure affects long-term conflict risk it is not orthogonal to conflict in the previous year nor likely to surrounding conflict in the same year, though I reject that the interacted terms are jointly equal to 0 with a high level of confidence. These results should therefore be considered as illustrative of differences in upsurge impacts by the broader conflict environment rather than accurately estimating differences in the causal impacts.

by a statistically significant 0.9 percentage points in the year of exposure. Treatment effect estimates are positive and statistically significant for years 5-6 and 8-11 post-exposure, with the largest effects in years 9-11. The average effect over the 12 years post-exposure is a 1.0pp increase in the annual risk of violent conflict.

Figure 6: Long-term impacts of drought and locust swarm exposure on violent conflict risk

A) Dynamic impacts of drought exposure

B) Average long-term impacts of swarm and drought exposure



Note: The dependent variable is a dummy for any violent conflict event observed. Panel A shows the event study results for impacts of exposure to any drought (4 consecutive months with SPEI<-1.5) on violent conflict risk over time using the Borusyak, Jaravel, and Spiess (2021) approach. Estimated impacts in each time period are weighted averages across effects for drought exposure in particular years. The time period 0 is the year of drought exposure. The shaded areas represent 95% confidence intervals. Treatment effects are based on comparisons against the pre-exposure period.
Panel B shows coefficients and 95% confidence intervals are from three separate TWFE regressions for the average impacts of swarm and drought exposure: one with no interactions and the others interacting all right-hand side variables with a dummy for any agricultural (pasture or crop) land and a dummy for any violent conflict in the 15 other cells in the broader 1 degree cell in which the cell is located. Coefficients and standard errors are calculated using Stata's *xlincom* command based on the sums of the coefficients for the baseline effect and the interaction term. Inverse propensity weights are included in the regressions of swarm exposure.
In both panels, cells are regarded as 'affected' by locust swarms or drought for all years starting from the first year in which the shock is recorded in the cell. All regressions include country-by-year and cell fixed effects. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses. Regression results are shown in Table A6.

Panel B shows TWFE estimates of the average long-term impacts of swarm and drought exposure by cell land cover and activity of armed groups in the surrounding cells. Impacts of locust swarms are the same as those reported previously including inverse propensity weights. The TWFE estimate of the average impact of drought is a significant 0.5pp increase in the annual risk of violent conflict. slightly smaller than the average of the event study treatment period effects.

The patterns in the impacts of swarm and drought exposure are very similar with slightly larger effects of swarm exposure, consistent with both of these transient agricultural shocks affecting the risk of violent conflict through the same mechanisms. Impacts of both shocks are concentrated in cells with any agricultural land, and in years where there is any violent conflict in surrounding cells. The impact of past swarm exposure in years where there is conflict activity near a cell is particularly large for locust swarms—a 5.3pp increase in the risk of violent conflict in the cell compared to 2.9pp for drought—likely because the sample for the analysis of swarm exposure includes more high-conflict years from 2015-2018 that are not included in the drought analysis sample.

The results show that exposure to two different severe but transient agriculture shocks cause large and persistent long-term increases in violent conflict risk. The patterns indicate that the mechanism for both shocks is a persistent decrease in the opportunity cost of fighting making affected areas more likely to engage in future conflict when they emerge.

This finding has implications for previous research on the short-term impacts of economic shocks on conflict which also use grid cell panel data.[32] This literature has overwhelmingly focused on the short-term and assumes effects of shocks are temporary. A common empirical approach is a distributed lag two-way fixed effects model which takes the form:

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

This follows the persistent effects model in Equation 1 with the exception that instead of the *Shock* variable representing a permanent treatment status over subsequent years, in this temporary effects model the years following a shock are regarded as unaffected except as captured by the one year lag. This lag allows for limited delays or persistence in impacts of the shock (Burke, Hsiang, and Miguel 2015).

With cell fixed effects the short-term impacts in the temporary effects model are estimated relative to conflict risk in other years in the same cell where a shock is not observed, including years after exposure to a shock. For shocks that cause persistent increases in conflict, this implies that the temporary effects estimate will be biased downward as a result of comparing conflict risk in the year a shock is observed against later years with no shock but higher conflict risk *caused* by the shock. I show that this is the case for locust swarms and severe drought, comparing estimates from the temporary effects approach to the event study estimates treating shock effects as permanent Table A7.

In the case of the locust swarms, the temporary effects model estimates a highly significant 1.5pp *decrease* in the probability of any violent conflict in the year of exposure relative to unaffected cells. I can reject that this is the same as the event study estimate of -0.2pp with high confidence (p=0.009), consistent with downward bias of the temporary effects estimate. In the case of severe drought, the temporary effects estimate is a non-significant 0.4pp increase in violent conflict risk the year of a drought, compared to a highly significant 0.9pp increase in the event study estimate. While I cannot reject that the estimates for

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

impact of drought on violent conflict risk in the year of exposure are the same (p=0.198), the two approaches would yield very different conclusions with different policy implications.

The temporary effects estimate for locust swarms—a 1.5pp decrease in violent conflict the year locusts are observed—is very close to Torngren Wartin (2018)'s estimate of a 1.3pp decrease using a similar method.[33] He interprets the result as suggesting endogenous underreporting of locust swarm presence correlated with violent conflict, and does not consider potential bias from ignoring long-term impacts of swarm exposure on conflict risk. The much larger event study estimate for the impact of swarms on conflict in the same year suggests the large share negative estimate in the temporary effects regression can instead be attributed to downward bias from ignoring long-term impacts.

These results provides some evidence of a potential misspecification of studies analyzing short-term impacts on conflict of transient economic shocks that are severe enough to decrease permanent income and reduce wealth and future productivity. Studies of such shocks using specifications similar to Equation 2 and ignoring possible long-term effects will generate downward-biased short-term impact estimates to the extent the shocks increase long-term conflict risk.

9 Conclusion

Violent conflict and environmental shocks can have devastating consequences for economic and human development which are the subject of significant study even beyond the economics literature. This paper shows that exposure to a severe agricultural shock—both desert locust swarms and drought—significantly increases long-term conflict risk. The mechanism is a persistent reduction in the opportunity cost of fighting, as shown in a long-term decrease in cereal yields following locust swarm exposure. This effect implies that short-term efforts to provide food aid and other support to populations affected by severe agricultural shocks are insufficient to facilitate full recovery, in line with many studies showing natural disasters have long-term impacts on poverty and well-being.

Locust swarms have no significant effect on violent conflict in the year of exposure. I show evidence that relief efforts may also play a role, as international agricultural aid increases in the year after countries are affected by locust swarms. Geographically-disaggregated data on relief could be useful to test whether such support deters short-term conflict and limits

[33] Torngren Wartin (2018) uses a similar sample and the analysis is at the level of 0.5° and 0.1° cells with somewhat different controls for lagged locust presence and weather but employs the same general distributed lag specification with cell and country-by-year fixed effects. 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.

the extent of the wealth shock and long-term increase in conflict risk, though prior studies suggest aid may increase conflict risk (Crost, Felter, and Johnston 2014; Nunn and Qian 2014). More generally, additional research could explore whether policies that can promote resilience to agricultural shocks, such as cash transfers (Crost, Felter, and Johnston 2016; de Janvry et al. 2006; Garg, McCord, and Montfort 2020), livelihood graduation programs (Hirvonen et al. 2023), improved infrastructure (Gatti, Baylis, and Crost 2021), and work programs (Fetzer 2020) also reduce conflict risk.

The lack of immediate impacts of swarm exposure on violent conflict and the long-term decrease in the opportunity costs of fighting mean locust swarms do not increase conflict onset but rather make affected areas more likely to become involved in periods of elevated civil conflict. This contrasts with prior studies finding price (McGuirk and Burke 2020) and drought (Harari and La Ferrara 2018) shocks cause the onset of new conflict, but is consistent with Bazzi and Blattman (2014), who find that commodity price shocks primarily affect conflict incidence and not conflict onset. Many factors have contributed to the increased onset and incidence of violent conflict in the sample countries in this period, including the Arab Spring, several civil wars, insurgencies, and the spread of terrorist organizations. The results illustrate how failing to support communities affected by disasters to fully recover can increase the incidence of future conflict and influence which areas become involved.

The long-run results are consistent with a wealth mechanism where the initial shock to agricultural production income and coping strategies lead to persistently lower wealth and productivity. Further research on impacts of economic shocks on household measures of productivity (as in Marending and Tripodi 2022), labor supply, food security, and wealth would help further explore how temporary shocks to productivity can have persistent effects on the opportunity cost of fighting by reducing household productive assets (including human capital).

The findings suggest future avenues of research in the literature on climate and conflict. I show that the methods typically used in this literature, which treat shocks as only affecting conflict risk in the short-term, can result in downward-biased estimates of short-term effects when the shocks have long-term impacts. Event study analyses of severe weather shocks such as droughts could show the extent and patterns of long-term impacts on conflict risk and how this affects estimates of short-term effects. Although not a focus of this paper, the lack of variation in the impacts of rainfall and temperature deviations on violent conflict risk by land cover cast further doubt on whether effects on agricultural production are the primary mechanism. The association between climate and conflict has been demonstrated in a wide variety of settings but the mechanisms remain unclear (Mach et al. 2020). A better understanding of the different mechanisms is essential to determining the appropriate policy responses.

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

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

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

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Appendix A: Additional Figures and Tables

Table A1: Summary statistics

Panel A: Yearly variables

	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 protest or riot event - ACLED	0.01	0.10	0.0	0.0	0.0	0.0	1.0	538086
Any violent conflict event - UCDP	0.01	0.10	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
Population (10,000s)	1.70	9.10	0.0	0.0	0.2	1.0	749.8	538083
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

Panel B: Fixed variables

	Mean	SD	Min	25^{th}	50^{th}	75^{th}	Max	N
Any ACLED violent conflict event in cell in any year	0.14	0.35	0.0	0.0	0.0	0.0	1.0	24460
Any protest/riot event in cell in any year	0.08	0.27	0.0	0.0	0.0	0.0	1.0	24460
Any UCDP violent conflict event in cell in any year	0.08	0.27	0.0	0.0	0.0	0.0	1.0	24460
Any locust swarm reported, 1985-2021	0.18	0.38	0.0	0.0	0.0	0.0	1.0	24460
Any swarms within 100 km in any year	0.63	0.48	0.0	0.0	1.0	1.0	1.0	24460
First exposed to locust swarm in sample period (1997-2018)	0.07	0.26	0.0	0.0	0.0	0.0	1.0	24460
First exposed to locust swarm in 2003-2005 upsurge	0.05	0.23	0.0	0.0	0.0	0.0	1.0	24460
Any cropland or pasture in cell	0.54	0.50	0.0	0.0	1.0	1.0	1.0	23923
Share of crop and pasture land in cell	0.24	0.32	0.0	0.0	0.0	0.5	1.0	23923
Any pasture in cell	0.53	0.50	0.0	0.0	1.0	1.0	1.0	23923
Share of pasture in cell	0.19	0.27	0.0	0.0	0.0	0.3	1.0	23923
Any cropland in cell	0.29	0.45	0.0	0.0	0.0	1.0	1.0	23923
Share of cropland in cell	0.05	0.13	0.0	0.0	0.0	0.0	1.0	23923

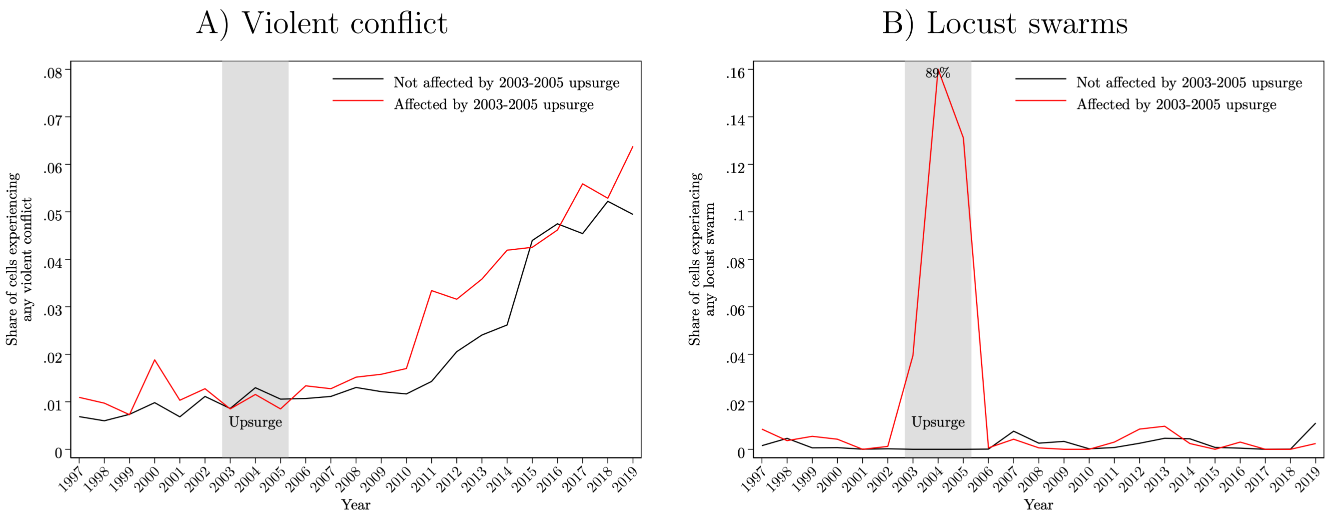
Note: Observations are grid cells approximately 28×28km by year.

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

	N	No sample period exposure Mean (SD)	Any sample period exposure Difference (SE)	N	No sample period exposure Mean (SD)	2003-2005 swarm exposure Difference (SE)
Panel A: All cells						
Population in 2000	23242	1.30	1.22**	22748	1.30	1.07
(10,000s)		(6.39)	(0.61)		(6.39)	(0.86)
Gross cell product	21931	0.25	0.13	21513	0.25	0.16
in 2005 (USD PPP)		(0.95)	(0.09)		(0.95)	(0.11)
Mean of cell	22982	0.05	0.01*	22490	0.05	0.01
nightlights 1996-2012 (0-1)		(0.04)	(0.00)		(0.04)	(0.01)
First month rainy	22982	6.29	0.40	22490	6.29	0.43
season		(3.33)	(0.26)		(3.33)	(0.35)
Percent of cell	22714	4.80	0.90	22225	4.80	1.41
covered by crop land in 2000		(13.33)	(0.79)		(13.33)	(0.99)
Percent of cell	22714	17.95	10.68***	22225	17.95	11.66***
covered by pasture land in 2000		(27.26)	(2.62)		(27.26)	(2.98)
Mean annual rainfall	22988	2.50	0.08	22494	2.50	0.06
1997-2018 (dm)		(3.83)	(0.29)		(3.83)	(0.36)
Mean annual max	22988	37.60	-1.41***	22494	37.60	-1.21**
temperature 1997-2018 (deg C)		(5.19)	(0.47)		(5.19)	(0.60)
Joint significance			$F = 8.01$ $p < 0.001$			$F = 3.29$ $p < 0.001$
Panel B: Cells with agricultural land						
Population in 2000	12093	2.30	0.83	11729	2.30	0.62
(10,000s)		(8.39)	(0.73)		(8.39)	(1.05)
Gross cell product	11170	0.32	0.10	10878	0.32	0.13
in 2005 (USD PPP)		(1.09)	(0.09)		(1.09)	(0.12)
Mean of cell	12077	0.05	0.01	11713	0.05	0.01
nightlights 1996-2012 (0-1)		(0.04)	(0.00)		(0.04)	(0.01)
First month rainy	12077	6.34	0.08	11713	6.34	0.13
season		(2.96)	(0.28)		(2.96)	(0.38)
Percent of cell	12093	9.35	-1.88*	11729	9.35	-1.28
covered by crop land in 2000		(17.43)	(1.08)		(17.43)	(1.31)
Percent of cell	12093	35.02	2.55	11729	35.02	3.49
covered by pasture land in 2000		(29.18)	(2.18)		(29.18)	(2.47)
Mean annual rainfall	12093	4.35	-1.21***	11729	4.35	-1.28***
1997-2018 (dm)		(4.55)	(0.34)		(4.55)	(0.44)
Mean annual max	12093	34.89	0.65	11729	34.89	1.15*
temperature 1997-2018 (deg C)		(5.06)	(0.42)		(5.06)	(0.61)
Joint significance			$F = 3.99$ $p < 0.001$			$F = 2.25$ $p = 0.026$

Note: The table shows results from separate bivariate regressions of baseline or mean cell outcomes on locust swarm exposure. The rows indicate which dependent variable is used. The first set of columns compares cells where a swarm was first observed between 1998-2018 ('Any sample period exposure') to cells where no swarm was observed from 1990-2018. The second set of columns compares cells where a swarm was first observed during the major 2003-2005 locust upsurge ('2003-2005 swarm exposure') to the same control cells. Panel A includes all cells while Panel B includes only cells with agricultural land. I include results of joint tests that there is no relationship between any of the characteristics and swam exposure. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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



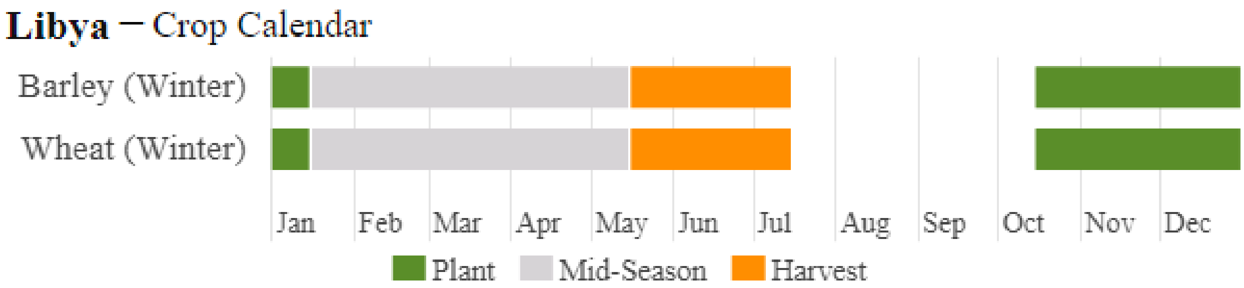
Note: The figures shows the share of cells experiencing any locust swarm or violent conflict event by year, separately for cells that did and did not experience any locust swarms during the 2003-2005 upsurge. Observations are grid cells approximately 28×28km by year.

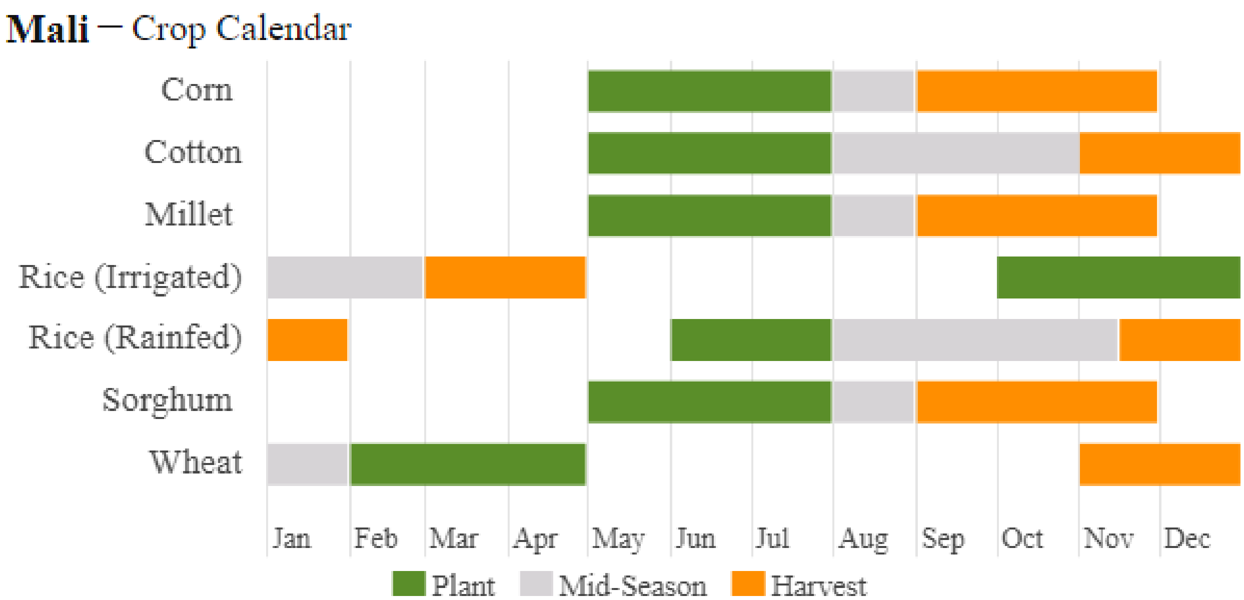
Table A3: Average impacts of exposure to locust swarms on violent conflict risk by land cover and specification

Outcome: Any violent conflict event	All land			Land = Any crop/pasture land			Land = Any crop land		
Swarm exposure	(1) Any	(2) Any	(3) Upsurge	(4) Any	(5) Any	(6) Upsurge	(7) Any	(8) Any	(9) Upsurge
Affected by any locust swarm	0.021***	0.008*	0.011*	0.006	-0.002	0.002	0.010**	-0.003	-0.001
	(0.006)	(0.004)	(0.006)	(0.005)	(0.003)	(0.007)	(0.005)	(0.003)	(0.005)
Total annual rainfall (100 mm)	0.003***	0.005**	0.004*	0.003	0.006**	0.006	0.003*	0.005**	0.004
	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.006)	(0.001)	(0.002)	(0.003)
Max annual temperature (deg C)	0.005***	0.005***	0.007***	0.003**	0.002	0.006**	0.003**	0.003*	0.006**
	(0.002)	(0.002)	(0.003)	(0.001)	(0.002)	(0.003)	(0.001)	(0.002)	(0.003)
Population (10,000s)	0.005***	0.007***	0.007***	0.004**	0.010***	0.001	0.010***	0.014***	0.004
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)
Affected by any locust swarm × Land==1				0.018**	0.017**	0.014*	0.027***	0.033**	0.032**
				(0.007)	(0.007)	(0.008)	(0.009)	(0.014)	(0.013)
Total annual rainfall (100 mm) × Land==1				0.000	-0.001	-0.003	0.001	0.001	-0.001
				(0.002)	(0.003)	(0.006)	(0.002)	(0.004)	(0.003)
Max annual temperature (deg C) × Land==1				0.002	0.004**	0.002	0.005**	0.007**	0.003
				(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.004)
Population (10,000s) × Land==1				0.002	-0.004	0.006**	-0.004	-0.008***	0.003
				(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Observations	505679	473754	419748	499651	473754	419748	499651	473754	419748
Outcome mean, no swarms & Land=1	0.024	0.018	0.019	0.042	0.033	0.033	0.056	0.046	0.046
Proportional impact of exposure, Land=1	0.893	0.430	0.597	0.561	0.451	0.479	0.654	0.653	0.683
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inverse propensity weights	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes

Note: The dependent variable is a dummy for any violent conflict event observed. Cells are regarded as 'affected' by locust swarms for all years starting from the first year in which a swarm is recorded in the cell. In columns labeled 'Upsurge' only cells exposed during the 2003-2005 locust upsurge are included as treated; other exposed cells are excluded from the sample. The 'Land=1' rows show the coefficients for the interaction of right-hand side variables with cell land cover dummies indicated in the column heading. Inverse propensity weights are calculated separately based on estimates of the propensities of cells to have been exposed to any swarm and to the 2003-2005 upsurge. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

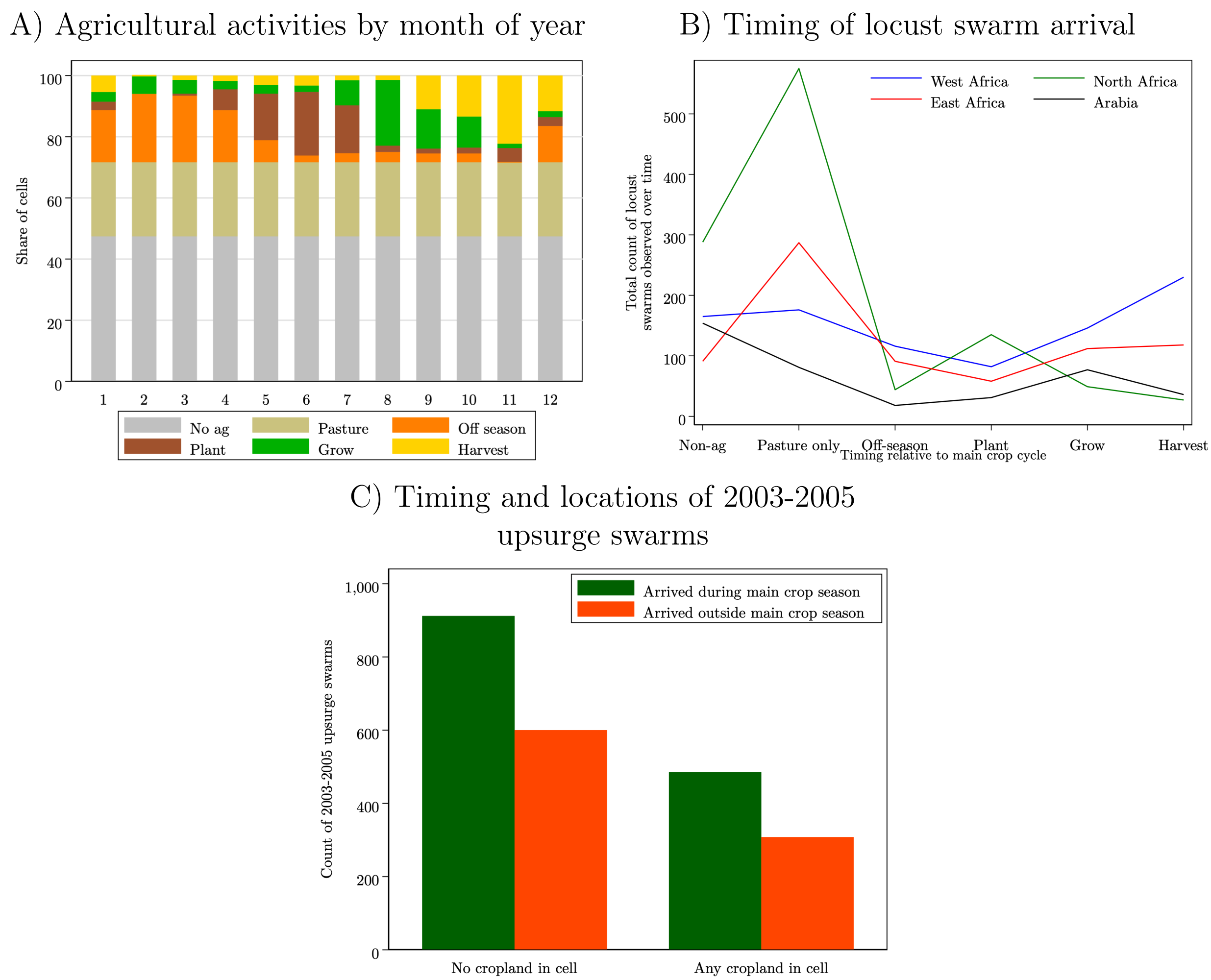
Figure A2: Example crop calendars





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



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 A4: Average impacts of exposure to 2003-2005 upsurge swarms on conflict risk, by timing of upsurge swarms and land cover

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

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

Table A5: Correlations between locust swarm exposure and international development flows to agriculture

Outcome: Development flows to agriculture (2021 USD millions)	(1)	(2)
Any swarm in year	93.4	
	(145.8)	
Any swarm previous year	185.0*	
	(92.7)	
Any swarm in year during upsurge		159.7
		(171.5)
Any swarm previous year during upsurge		312.9**
		(141.8)
Observations	936	936
Outcome mean, no swarms	932.8	965.8
Country FE	Yes	Yes
Year FE	Yes	Yes

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

Table A6: Average impacts of exposure to agricultural shocks on violent conflict risk

Outcome: Any violent conflict event	(1) Swarm	(2) Swarm	(3) Swarm	(4) Drought	(5) Drought	(6) Drought
Exposed to shock	0.008*	-0.002	0.002	0.005**	-0.003	0.001
	(0.004)	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)
Exposed to shock × Any cropland or pasture in cell		0.017**			0.015***	
		(0.007)			(0.004)	
Any violent conflict elsewhere in 1 degree cell			0.140			0.053*
			(0.095)			(0.031)
Exposed to shock × Any violent conflict elsewhere in 1 degree cell=1			0.051***			0.028***
			(0.015)			(0.007)
Observations	473754	473754	473754	432843	429524	432843
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather and population controls FE	Yes	Yes	Yes	Yes	Yes	Yes
Inverse propensity weights FE	Yes	Yes	Yes	No	No	No

Note: The dependent variable is a dummy for any violent conflict event observed. The columns indicate which agricultural shock is analyzed. Cells are regarded as 'affected' by a shock for all years starting from the first year in which the shock is recorded in the cell. Inverse propensity weights for swarm exposure are calculated based on estimates of the propensities of cells to have been exposed to any swarm. Columns with interactions also include interactions with other right-hand side variables. Observations are grid cells approximately 28×28km by year for 1997-2018 for swarms and 1997-2014 for drought. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A7: Impacts of agricultural shocks on the conflict risk, treating shocks as temporary vs. persistent

	(1)	(2)	(3)	(4)
	Locust swarms		Drought	
	Temporary effects	Persistent effects	Temporary effects	Persistent effects
Any swarm in cell	-0.015***			
	(0.004)			
Any swarm in cell previous year	-0.006			
	(0.004)			
Affected by any locust swarm		0.021***		
		(0.005)		
Any drought in year			0.004	
			(0.003)	
Any drought previous year			0.002	
			(0.002)	
Affected by any drought				0.005**
				(0.002)
Year 0 event study estimate	-0.002		0.009***	
	(0.003)		(0.003)	
p-value, equality of estimates	0.009		0.198	
Observations	508269	482691	408744	408752
Country-Year FE	Yes	Yes	Yes	Yes
Cell FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes

Note: The dependent variable is a dummy for any violent conflict event observed. Locust swarm and drought exposure in columns (1) and (3) is based only on whether the shock was observed in a particular year. Cells are considered 'affected' by any locust swarm or any drought in columns (2) and (4) for all years after these shocks are first observed in the cell. At the bottom of columns (1) and (3) I show coefficients for the treatment effect in the year of exposure from a persistent effects event study specification along with the p-value for the test of equality of the coefficients. Controls in all regressions include total cell population and current and prior year measures of total rainfall and maximum annual temperature. Observations are grid cells approximately 28×28km by year. SEs clustered at the sub-national region level are in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

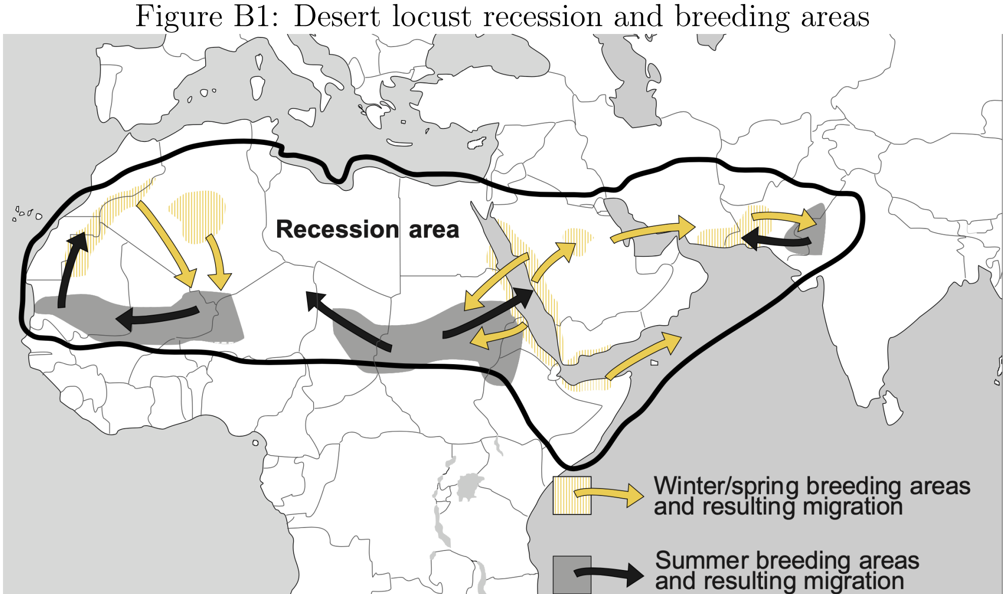
Appendix B: Desert locusts background

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

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

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

Figure B1: Desert locust recession and breeding areas



Source: Symmons and Cressman (2001).

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

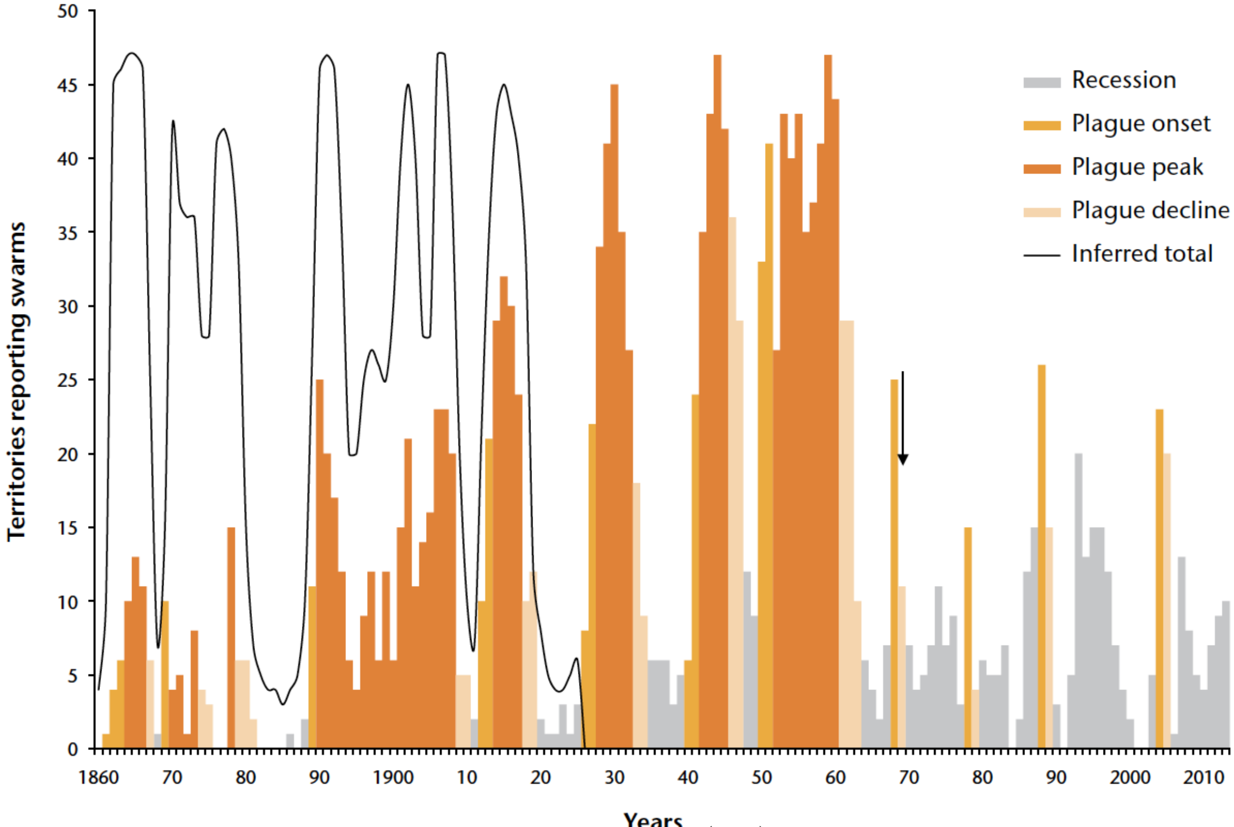
As illustrated by Figure 1, locust swarms are not observed with any regularity over time or space. Desert locusts are migratory, moving on after consuming all available vegetation, and outside of outbreak periods are ultimately restricted to desert 'recession' areas. Unlike many other insect species, therefore, the arrival of a desert locust swarm does not signal a permanent change in local agricultual pest risk. Instead, the arrival of a swarm can be considered a locally and temporally concentrated natural disaster where all crops and pastureland are at risk (Hardeweg 2001).

The frequency of large-scale outbreaks has fallen since around the 1980s (Figure B2), in large part due to increases in coordinated preventive operations (Cressman and Stefanski 2016), as shown by the figure below. Given their tolerance for extreme heat and responsiveness to periods of heavy precipitation, however, climate change might create conditions conducive to more frequent desert locust outbreaks.

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

Desert locust control is most effective before locust populations surge, and the FAO manages an international network of early monitoring, warning, and prevention systems in support of this goal (Zhang et al. 2019). While improvements in desert locust management have been largely effective in reducing the frequency of outbreaks (as seen in Figure B2), many challenges remain. Desert locust breeding areas are widespread and often in remote or

Figure B2: Desert locust observations by year



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

insecure areas. Small breeding groups are easy to miss by monitors, and swarms can migrate quickly. In addition, control operations are slow and costly, resources for monitoring and control are limited outside of upsurges, and the cross-country nature of the thread creates coordination issues. Insecurity may also limit locust control activities (Showler and Lecoq 2021).

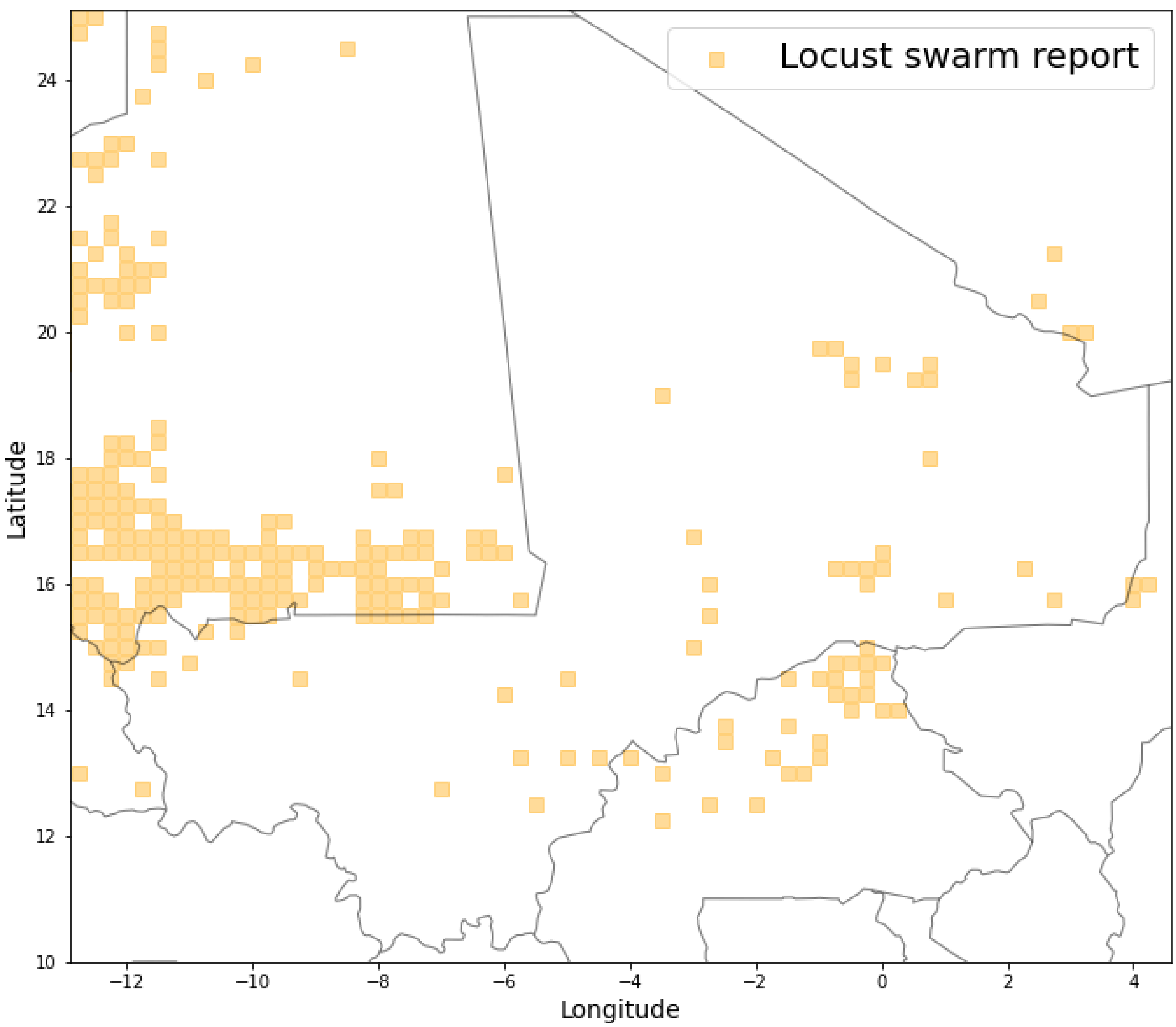
Locust swarms vary in their density and extent (Symmons and Cressman 2001). The average swarm includes around 50 locusts per m^2 with a range from 20-150, and can cover under 1 square kilometers to several hundred (Symmons and Cressman 2001). About half of swarms exceed 50km^2 in size (FAO and WMO 2016),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

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

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

Figure B3 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 B3: Reports of locust swarms and violent conflict around Mali, selected years



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

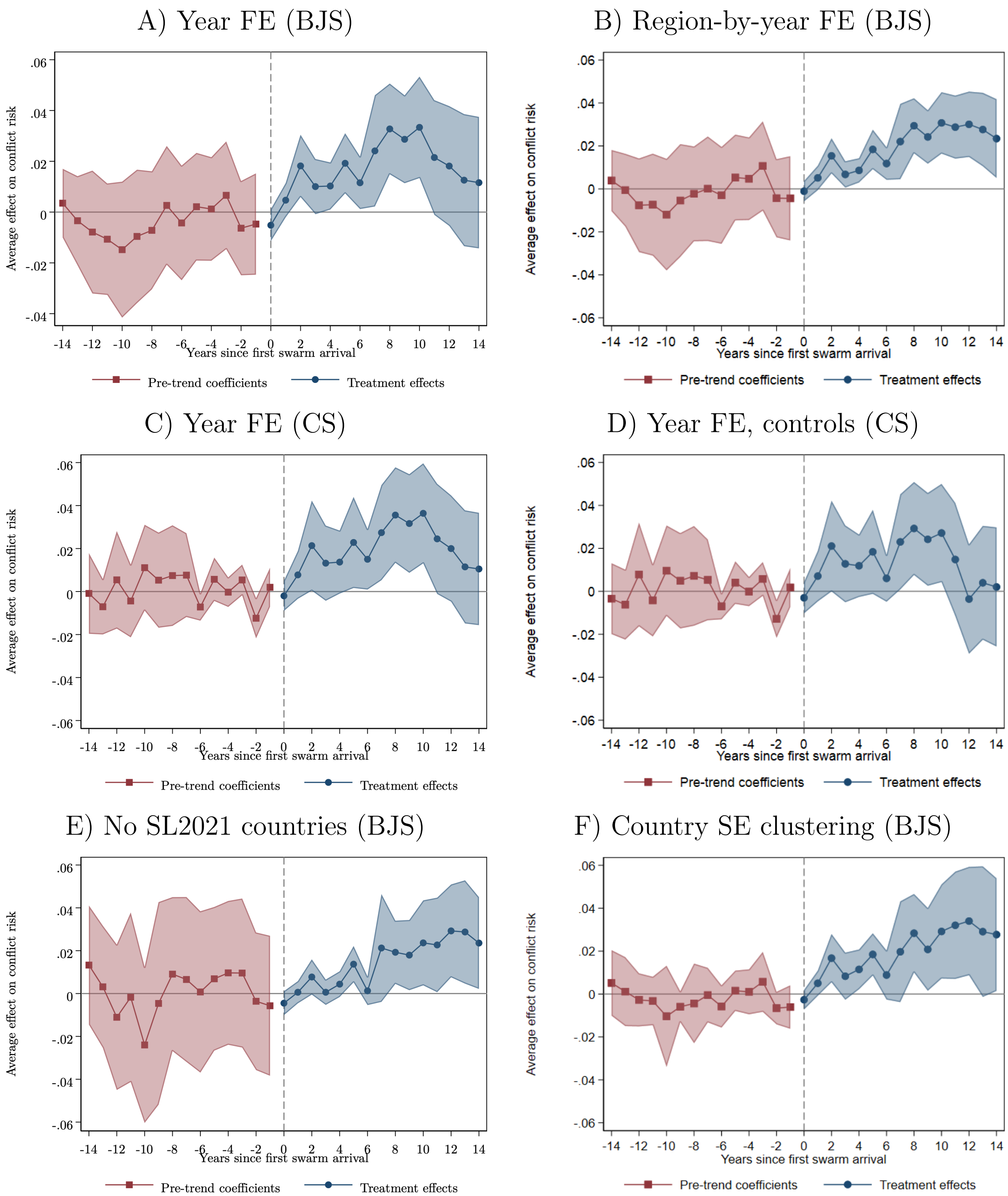
Appendix C: Robustness

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

	N	Never swarm Mean (SD)	Any swarm treatment diff (SE)	N	Never swarm Mean (SD)	2003-2005 swarm treatment diff (SE)
Population in 2000	21536	1.26	0.27	21147	1.26	-0.36
(10,000s)		(6.16)	(0.35)		(6.15)	(0.35)
Gross cell product	21536	0.24	-0.00	21147	0.24	-0.07
in 2005 (USD PPP)		(0.92)	(0.07)		(0.92)	(0.07)
Mean of cell	21536	0.05	0.00	21147	0.05	-0.00
nightlights 1996-2012 (0-1)		(0.04)	(0.00)		(0.04)	(0.00)
First month rainy	21536	6.21	0.13	21147	6.22	0.16
season		(3.34)	(0.21)		(3.35)	(0.28)
Percent of cell	21536	4.97	-0.32	21147	4.97	-1.56
covered by crop land in 2000		(13.63)	(1.04)		(13.62)	(1.31)
Percent of cell	21536	16.42	-2.46	21147	16.40	-6.56*
covered by pasture land in 2000		(25.95)	(2.37)		(25.94)	(3.52)
Mean annual rainfall	21536	2.50	0.06	21147	2.50	-0.65
1997-2018 (dm)		(3.90)	(0.45)		(3.90)	(0.56)
Mean annual max	21536	37.88	-0.27	21147	37.89	0.52
temperature 1997-2018 (deg C)		(5.12)	(0.61)		(5.13)	(0.79)
Joint significance			$F = 0.99$ $p = 0.450$			$F = 0.95$ $p = 0.477$

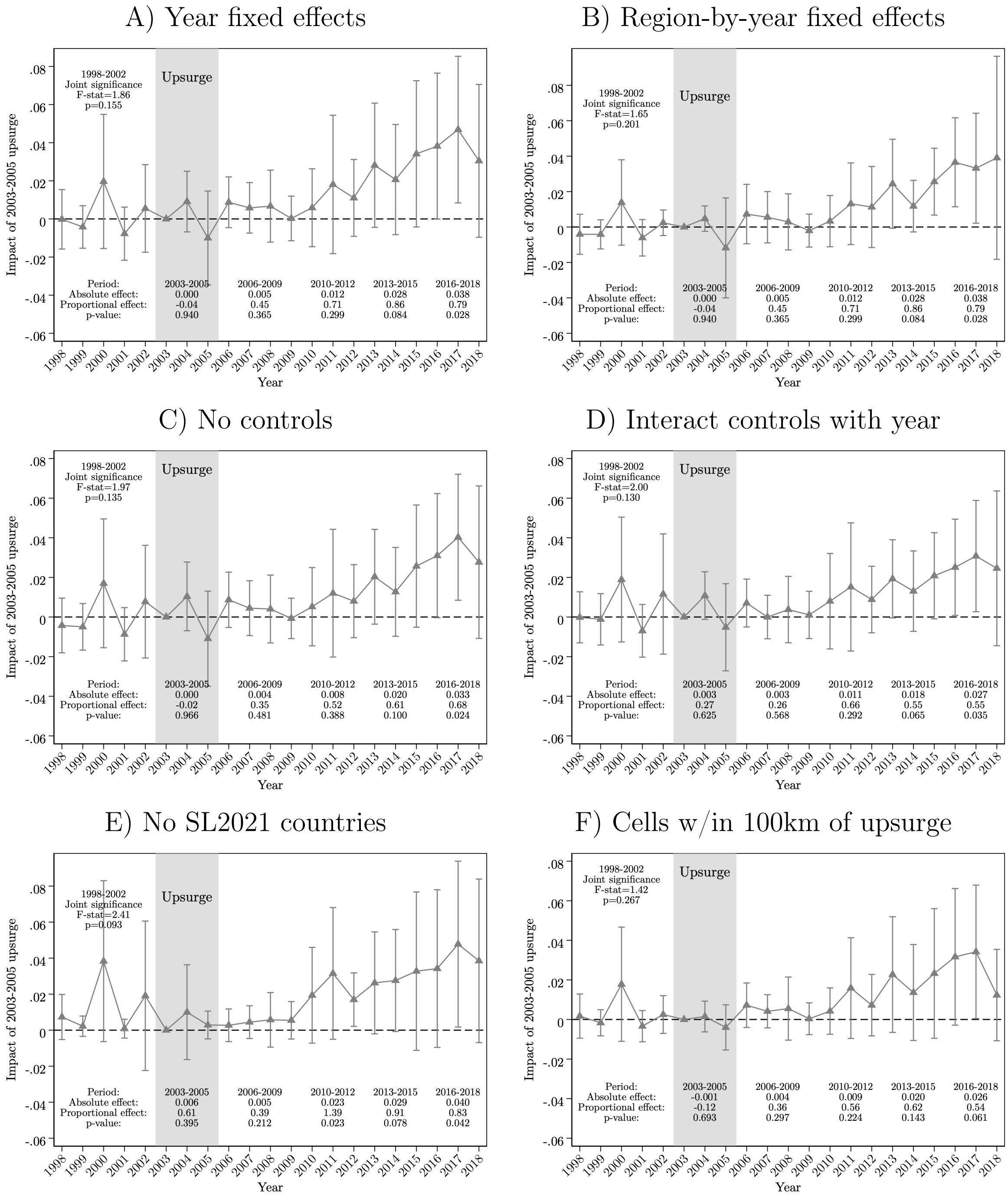
Note: The table shows results from separate bivariate regressions of baseline or mean cell outcomes on locust swarm exposure, including inverse propensity weights. The rows indicate which dependent variable is used. Inverse propensity weights are calculated based on estimates of the propensities of cells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

Figure C1: Sensitivity of locust swarm exposure event study results



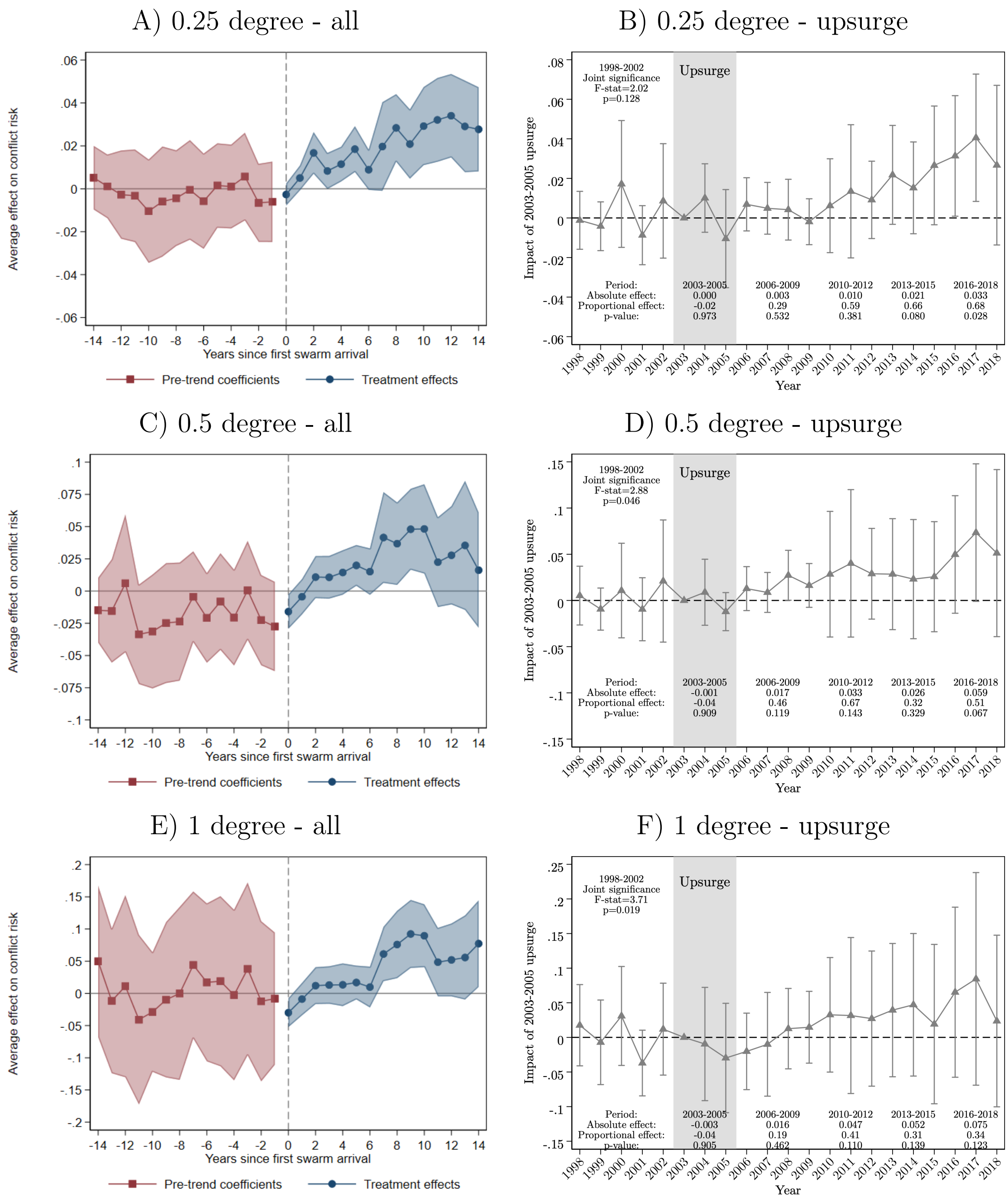
Each panel replicates Figure 3 Panel A but changes some aspect of the specification as indicated in the panel title. 'BJS' refers to the Borusyak, Jaravel, and Spiess (2021) method. 'CS' refers to the Callaway and Sant'Anna (2021) method. The BJS method calculates all effects relative to the full pre-exposure period. The CS method calculates pre-trend effects using adjacent years and treatment effects relative to the year prior to exposure. The CS *csdid* package did not converge with country-by-year FE and the BJS *did_impute* did not converge when including weather and population controls, so a more complete comparison of estimates was not possible. 'SL2021' countries in panel E refers to the countries listed in Showler and Lecoq (2021) as areas where insecurity has limited desert locust control operations during the sample period. See the figure note for Figure 3 for more detail.

Figure C2: Sensitivity of upsurge swarm exposure event study results



Note: Each panel replicates Figure 3 Panel B but changes some aspect of the specification as indicated in the panel title. 'SL2021' countries in panel E refers to the countries listed in Showler and Lecoq (2021) as areas where insecurity has limited desert locust control operations during the sample period. See the figure note for Figure 3 for more detail.

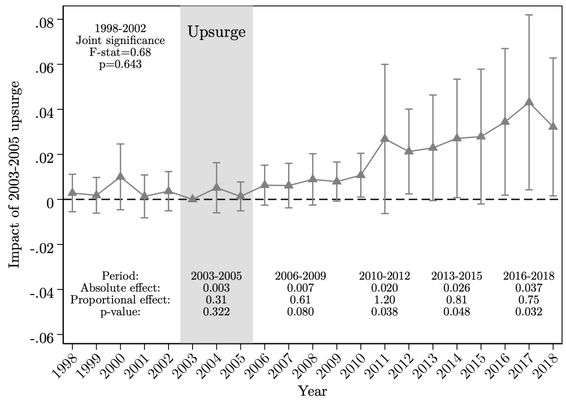
Figure C3: Locust swarm exposure event study results by cell size



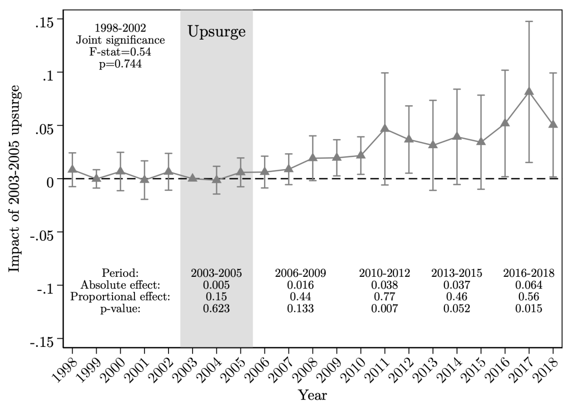
Note: Panels A, C, and E replicate Figure 3 Panel A with different cell sizes. Panels B, D, and F replicate Figure 3 Panel B with different cell sizes. See the figure notes for Figure 3 for more detail. When collapsing to larger cells I take the maximum of the swarm exposure and violent conflict variables and the mean of control variables across smaller cells within the aggregate cell. Shading and bars represent 95% confidence intervals using SEs clustered at the sub-national region level. In panels B, D, and F, estimates from the same specification with binned years are reported at the bottom of the figure. Proportional effects are relative to the probability of observing any of the particular type of conflict during the particular time period. p-values are for tests of the null of 0 impact of the upsurge in each period. In the top left are the results from a joint test of the hypothesis that all pre-upsurge coefficients equal 0.

Figure C4: Upsurge swarm exposure event study by cell size, no inverse propensity weights

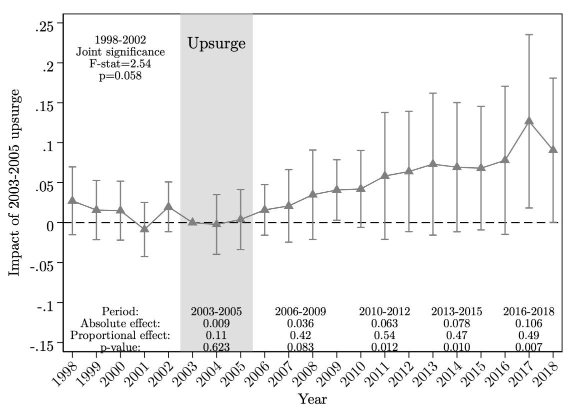
A) 0.25 degree



B) 0.5 degree

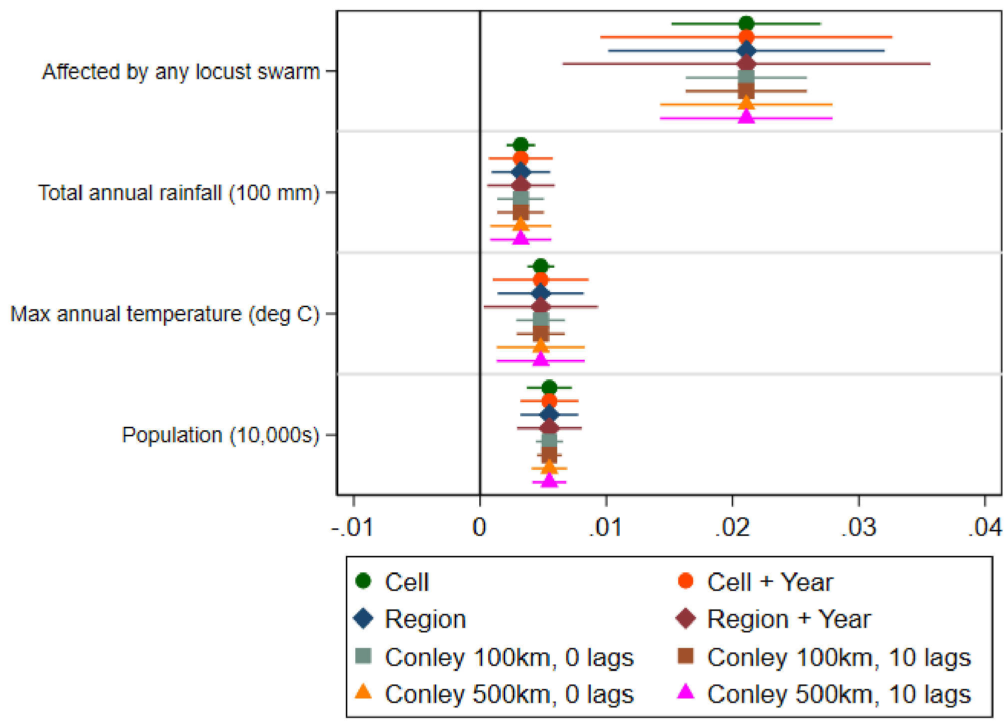


C) 1 degree



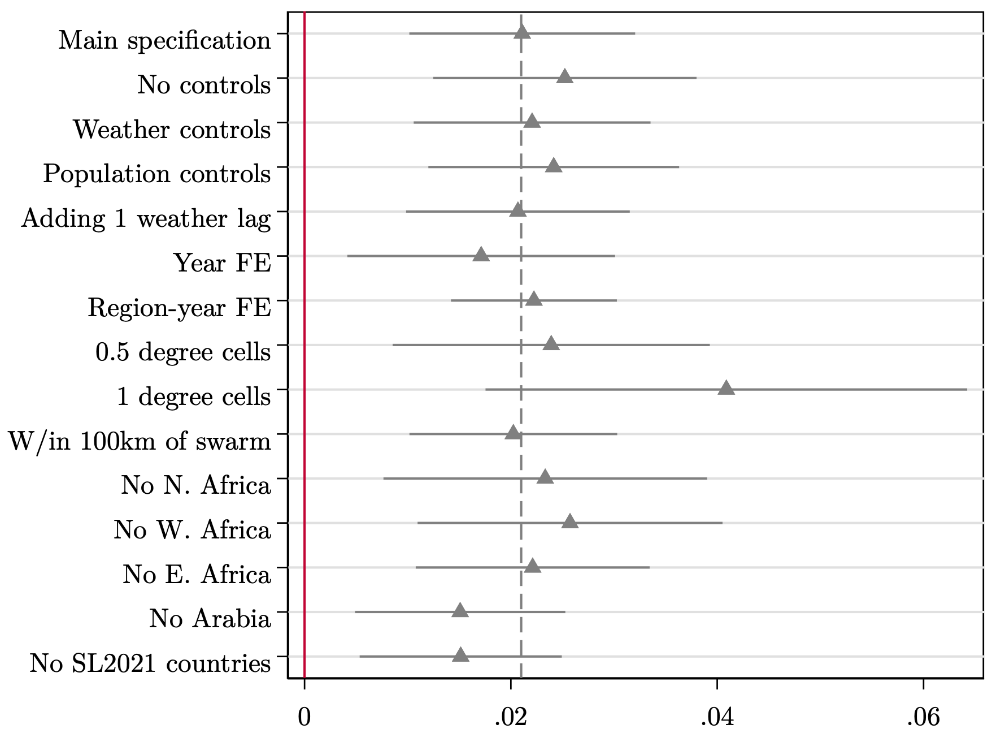
Note: The figure replicates Figure 3 Panel B but without inverse propensity weights and with different cell sizes. See the figure note for Figure 3 for more detail. When collapsing to larger cells I take the maximum of the swarm exposure and violent conflict variables and the mean of control variables across smaller cells within the aggregate cell.

Figure C5: Estimated coefficients from Equation 1 with different SEs



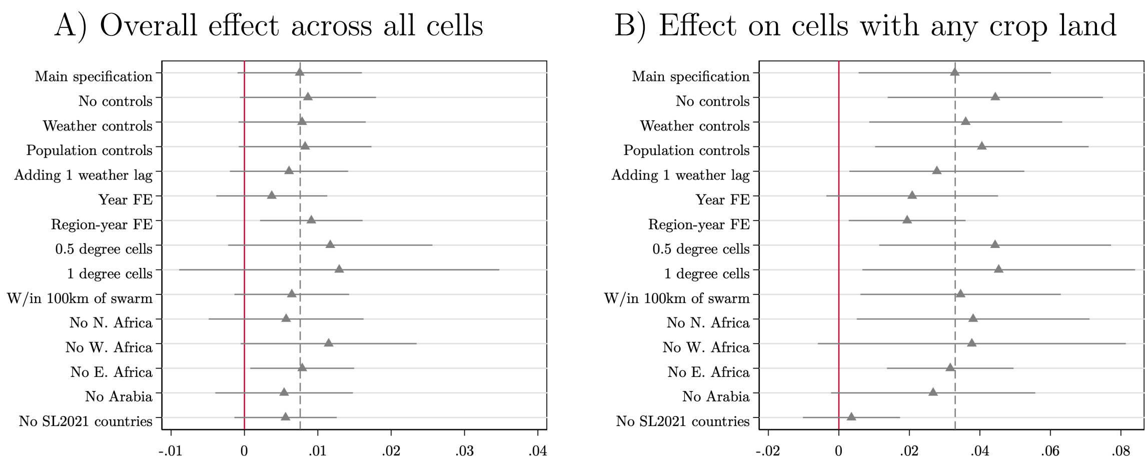
Note: The outcome variable is a dummy for any violent conflict observed. The figure shows 95% confidence intervals for estimates from Table A3 column (1) applying different clustering for the SEs. Observations are grid cells approximately 28×28km by year. Regressions also include country-by-year and cell FE.

Figure C6: Average impacts of locust swarm exposure on violent conflict risk, varying specifications and samples



Note: The outcome variable is a dummy for any violent conflict observed. The figure shows 95% confidence intervals for estimates from Table A3 column (1) varying controls, fixed effects, cell size, and countries included in the sample. 'SL2021' countries are those listed in Showler and Lecoq (2021) as having areas where insecurity limited desert locust control operations during the sample period, and include Chad, Mali, Somalia, Sudan, Western Sahara, and Yemen. Observations are grid cells approximately 28×28km by year. Regressions all include cell FE as well as country-by-year FE unless otherwise stated. SEs are clustered at the sub-national region level.

Figure C7: Average impacts of locust swarm exposure on violent conflict risk with inverse propensity weights, varying specifications and samples



Note: The outcome variable is a dummy for any violent conflict observed. Panel A shows 95% confidence intervals for estimates from Table A3 column (2) varying controls, fixed effects, cell size, and countries included in the sample. Panel B shows the same for the total effect in crop cells from Table A3 column (9). 'SL2021' countries are those listed in Showler and Lecoq (2021) as having areas where insecurity limited desert locust control operations during the sample period, and include Chad, Mali, Somalia, Sudan, Western Sahara, and Yemen. Inverse propensity weights are applied in all regressions and are calculated separately based on estimates of the propensities of cells to have been exposed to any swarm and to the 2003-2005 upsurge. Observations are grid cells approximately 28×28km by year. Regressions all include cell FE as well as country-by-year FE unless otherwise stated. SEs are clustered at the sub-national region level. All estimates in Panel B except 'No SL2021 countries' are significant at a 10% confidence level or less.