Economic Complementarities and Conflict: Evidence from Herders, Farmers and Fertilizer in Africa

Oeindrila Dube[‡]
University of Chicago, NBER and *BREAD*

Eoin McGuirk[*]
Tufts University, NBER and *BREAD*

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Abstract: Scholars have long debated the potential role of economic complementarities as a pacifying force. If groups benefit from each other's economic activities, then the opportunity cost of inter-group conflict ought to rise. We examine this theory in the context of neighboring agricultural and pastoral ethnic groups in Africa, who share complementarities in production. We focus on the availability of synthetic fertilizer in agricultural parts of the continent. In the absence of complementarities, synthetic fertilizer is expected to alleviate conflict within farmland areas, since increased agricultural productivity is known to reduce incentives to engage in armed conflict. In the presence of complementarities, however, we expect the opposite effect on conflict, as synthetic fertilizer is a substitute for the organic fertilizer that is a byproduct of pastoral production. We test for these differences by separating agricultural grid-cells into those close to pastoral areas, where complementarities are present ("mixed farmland"), and those farther from pastoral areas, where they are not ("pure farmland"). Using panel data, we exploit two sources of variation to estimate the effect of fertilizer availability on conflict outcomes. First, in pure farmland, we find that World Bank fertilizer projects tend to reduce the likelihood and intensity of conflict. However, in mixed farmland, fertilizer projects tend to *increase* the likelihood and intensity of conflict. We do not observe a similar pattern for other (i.e., non-fertilizer) agriculture projects, which are unlikely to disrupt the system of shared complementarities. Second, we find that an increase in the world price of fertilizer input chemicals significantly reduces conflict in mixed farmland relative to pure farmland. Taken together, these findings indicate that undermining production complementarities between groups can result in more inter-group conflict. From a policy perspective, measures that foster economic complementarities between groups may be an effective tool for conflict prevention.

[‡]Harris School of Public Policy, University of Chicago, 1307 E 60th St, Chicago, IL, 60637, USA (e-mail: dube@uchicago.edu; website: http://odube.net/).

[*]Department of Economics, Tufts University, 177 College Avenue, Medford, MA, 02155, USA. (e-mail: eoin.mcguirk@tufts.edu; website: https://eoinmcguirk.com).

1. Introduction

Armed conflict undermines economic development by reducing trade and investment and destroying physical and human capital. Policies that alleviate conflict are thus likely to exhibit large social returns. Scholars have long debated the potential role of economic exchange between groups as a pacifying force (Montesquieu, 1748, Rohner, Thoenig and Zilibotti, 2013). As the degree of economic reliance between groups increases, so too does the opportunity cost of engaging in conflict. This observation is at the heart of a large literature on international trade and conflict, which suggests that bilateral trade between nations is associated with peace, while multilateral trade is not (Polachek 1980; Martin, Mayer and Thoenig 2008).

We extend this tradition by examining the effect of economic interdependence on conflict between agricultural and pastoral ethnic groups in Africa. In farmland areas that are proximate to pastoral territories, these groups share production complementarities that are facilitated by the seasonal migration of herders, who typically arrive after crops are harvested to occupy fallow land. This land-use arrangement benefits both groups. For farmers, the animals provide organic fertilizer that increases the productivity of crop agriculture in future seasons. In turn, herders benefit from access to dry-season grazing resources that are not available in semi-arid pastoral territories.

Despite this mutually beneficial system, conflict between herders and farmers is increasingly prevalent. In this paper, we study how changes in the degree of economic reliance between these groups affect armed conflict. In the first exercise, we focus on the role of synthetic fertilizer distribution projects administered by the World Bank. In the absence of this traditional land-sharing system, fertilizer projects in agricultural areas would be expected to lower conflict, since rising productivity in labor-intensive sectors such as agriculture is widely understood to reduce incentives to fight (Dal Bo and Dal Bo, 2011, Dube and Vargas, 2013, Berman and Couttenier, 2015, McGuirk and Burke, 2020). However, in the presence of this system, conflict may be generated through a countervailing mechanism. By distributing synthetic fertilizer to farmers, these projects could reduce the demand for organic fertilizer that is traditionally provided by herders, undermining the production complementarities that sustain peace and thus broadening the scope for conflict over resources.

To test for this differential effect of fertilizer on conflict, we assemble a panel dataset of 0.5 degree cells (around 55km $\times$ 55km at the equator) covering the continent of Africa. We combine (i) geocoded data on conflict from Acled and UCDP; (ii) geocoded data on World Bank development projects from AidData; and (iii) ethnographic data on the spatial distribution of ethnic groups and their traditional modes of subsistence (Murdock, 1959, 1967, Nunn, 2008, Kincaide, McGuirk and Nunn, 2020).

We aim to estimate the effect of synthetic fertilizer distribution on conflict within traditionally agricultural areas, focusing on heterogeneity between "mixed" farmland that is proximate to neighboring pastoral territories (and thus likely to host seasonal herders) versus "pure" farmland that is distant from any pastoral areas. To do this, we first drop all cells in traditionally pastoral territories, leaving only agricultural cells. We then generate measures of proximity to pastoral

territories within this agricultural subsample. We regress measures of conflict on a cell-year measure of cumulative projects of different types within a cell, controlling for both cell fixed effects and country-by-year fixed effects.

We find that, in pure farmland cells that are farther from pastoral territories, synthetic fertilizer projects either have no effect (using Acled data) or a significant negative effect (using UCDP data) on conflict. This is consistent with a large empirical literature on agricultural productivity and the opportunity costs of conflict. However, in mixed farmland areas, where inter-group complementarities are present, we see a different pattern: conflict incidence and intensity is greater following the introduction of synthetic fertilizer projects. For a mixed farmland cell that is proximate to the median pastoral territory, the total effect of a synthetic fertilizer project is to significantly raise conflict incidence by almost 9.9 p.p. (118% of the dependent mean), conflict events by 41%, and conflict fatalities by 40%, using Acled data. Using UCDP data, the interaction effects are positive but insignificant.

Importantly, we can benchmark these estimates against the effects of other, i.e., non-fertilizer, agricultural projects. These interventions ought to be similarly productive for farmers, but they likely do not generate the same substitution effect away from organic fertilizer that undermines the complementarity with neighboring pastoral communities. Accordingly—and in contrast to the effect of fertilizer projects—we find that other agriculture projects weakly decrease conflict in mixed farmland areas relative to pure farmland areas. Estimating the differential interaction effect between the two project types in mixed areas, fertilizer projects are significantly and substantially more likely to generate conflict relative to other agriculture projects across various specifications.

For robustness, we add controls for ethnic-territory-by-year fixed effects, a highly demanding specification that absorbs all variation at the level of a group and year, such as average weather realizations for each ethnicity (McGuirk and Nunn, 2025). We also use a more precise measure of mixed use farmland that takes into account the distance of every neighboring pastoral group from a given cell. The estimates are similarly large and significant in these specifications.

In addition to studying variation in fertilizer availability via development projects, we also study variation in international prices of the three input chemicals: nitrogen (N), phosphorus (P), and potassium (K). Higher international NPK prices would imply greater scarcity in agricultural parts of Africa. In pure farmland cells, this is expected to lead to more conflict, since it lowers the labor productivity of agricultural production. However, in the mixed cells, higher prices would force farmers to deepen economic exchange with neighboring pastoralists, strengthening the system of shared complementarities. Consistent with this viewpoint, we find that higher fertilizer prices lead to a significant reduction of conflict in mixed farmland cells relative to pure farmland cells.

Taken together, we interpret our findings across both exercises as evidence in favor of economic complementarities being a force for peace.

2. Background and Conceptual Framework

Le Contrat de Fumure Transhumant pastoralism is an important subsistence mode in Africa. It directly supports around 50 million people and indirectly supports around 200 million, roughly 20% of the continent's agricultural population (FAO, 2018). Pastoralism is practiced on around 43% of Africa's land mass, most of which is semi-arid rangeland that is considered unsuitable for other modes of production.

One critical characteristic in the transhumant pastoral production function is cooperation with nearby crop agricultural communities. In the growing (wet) season, herders graze their animals in pastoral rangelands while farmers cultivate crops in agricultural farmlands. At the end of the growing season, pastoralists and their herds migrate from the semi-arid pastoral regions to the more humid agricultural regions in order to occupy farmlands while they lie fallow. This arrangement allows pastoralists to access pasture and water, sustaining their herds for the duration of the dry season. In exchange, agricultural communities benefit from the organic fertilizer left behind by grazing animals in the form of manure, which increases the productivity of crop production in the ensuing growing season.

This mutually beneficial arrangement is known as *le contrat de fumure* in Sahelian ethnography and is understood as an example of a symbiotic relationship in ecology more generally.

Farmer-Herder Conflict Despite these inter-group complementarities, conflict between farmers and herders has become more prevalent in recent decades. In Figure 1 below, we show that countries containing pastoral regions are the principal source of armed conflict growth in Africa since around 2010. Most of this is understood to be driven by farmer-herder conflicts.

Understanding the origins of this change is the subject of a nascent but rapidly growing literature. McGuirk and Nunn (2025) provide evidence for one mechanism through which climate change is playing an important role: adverse rainfall in pastoral areas induces herders to migrate earlier than is typical. If they arrive with their herds before the harvest, the previously cooperative relationship becomes rivalrous, as livestock animals destroy crops and consume water, leading to conflict. Consistent with this mechanism, they find that low rainfall in pastoral regions leads to more conflict in neighboring agricultural areas, but only during the growing season. Gehring and Schaudt (2026) find evidence of a policy that mitigates this channel in Kenya: index-based livestock insurance eases the migratory pressure and reduces conflict in adjacent agricultural areas as a result. Eberle, Rohner and Thoenig (2025) also uncover an important role for climatic factors, finding that high temperatures lead to more conflict in border areas between nomadic and sedentary ethnicities.

Economic Complementarities and Fertilizer We propose an additional mechanism that is contributing to the spread of farmer-herder conflict in Africa. Access to synthetic fertilizer potentially undermines the complementarities that existed between farmers and herders. Once farmers adopt synthetic fertilizer, they no longer require transhumant pastoralists to occupy their land for the

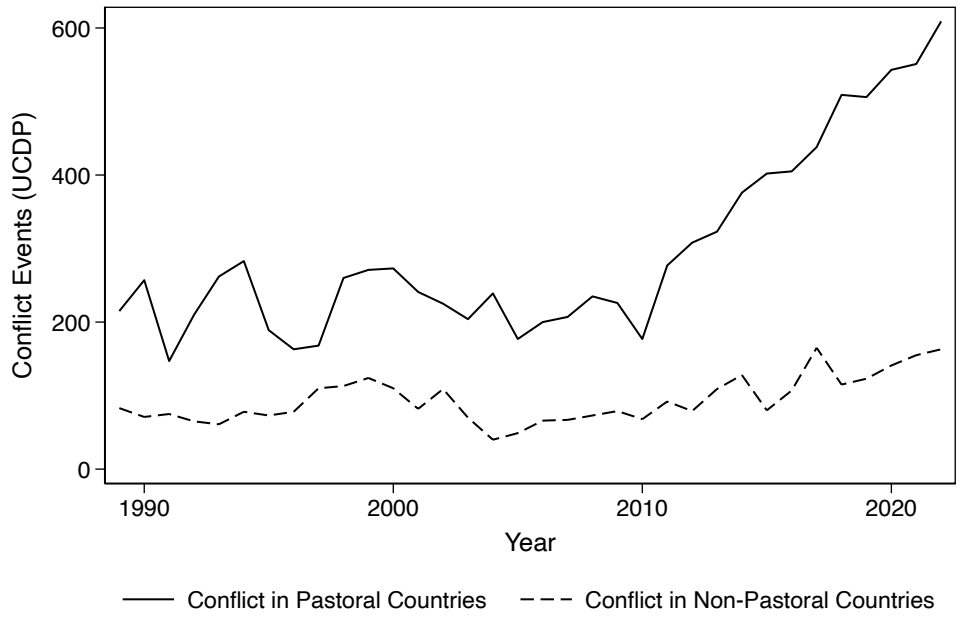


Figure 1: Conflict Events in Africa, 1989–2023. Source: UCDP.
Notes: Pastoral countries are countries in which our index measuring transhumant pastoralism is greater than zero. Conflict events are the sum of conflict events in the UCDP dataset for each year.

dry season. This reduces the opportunity cost of conflict, narrowing the bargaining range for a transfer that keeps peace (Fearon, 1995).

Whether or not this leads to conflict may depend on the nature of the new arrangement. In the ecological literature, the nature of interactions between species is said to shift along a continuum in response to changing environmental conditions (Bronstein, 1994). The introduction of fertilizer may represent a shift from *mutualism* (win-win) in the traditional exchange to either *commensalism* (win-unaffected), whereby herders gain from accessing pasture while farmers are largely unaffected, or *parasitism* (win-lose), whereby herders gain at farmers' expense. It is this latter shift that we expect is more likely to generate conflict.

Thus, much will depend on whether farmers have reason to resist the seasonal in-migration of herders once they have access to synthetic fertilizer. Farmers typically bear some risk of crop damage from passing livestock, but this cost was traditionally offset by the manure that animals left on their fields. Case study accounts suggest that synthetic fertilizer erodes this benefit, leaving farmers with the costs alone:

> "With the ... advent of artificial fertilizers, fewer farmers now depend on passing livestock to fertilize their fields. Younger generations of farmers may see passing pastoral livestock as pests that destroy their fields instead of a productive complement to their livelihood" (Jobbins and McDonnell, 2021, p. 17).

The implication is that access to synthetic fertilizer will increase tensions between neighboring farmers and herders. This insight yields two predictions to take to the data:

1. In "pure" farmland areas that are not proximate to transhumant pastoralists, access to synthetic fertilizer will reduce conflict, since fertilizer raises agricultural productivity and thus the opportunity cost of participating in conflict (Dal Bo and Dal Bo, 2011, Dube and Vargas, 2013, Berman and Couttenier, 2015, McGuirk and Burke, 2020).

2. In "mixed" farmland areas that are proximate to transhumant pastoralists, the effect of synthetic fertilizer on conflict will be significantly more positive than in pure farmland areas, since fertilizer also undermines economic complementarities between farmers and herders.

3. Estimation Strategy and Data

We consider two empirical approaches to test these predictions. In the first, we use World Bank development projects as a measure of fertilizer abundance. In the second, we use international fertilizer prices as a measure of fertilizer scarcity. In both approaches, we discard data from pastoral regions of Africa. We hypothesize that, within agricultural regions (i) fertilizer projects will increase conflict in cells with pastoral neighbors (relative to cells without pastoral neighbors) and (ii) fertilizer prices will decrease conflict in cells with pastoral neighbors (relative to cells without pastoral neighbors).

A. Data

Structure We begin with a panel dataset of 9,691 0.5 degree cells (approx. 55km x 55km at the equator) covering the continent of Africa for each year in the series. The hypothesis that we examine requires variation in proximity to pastoral regions within agricultural Africa. We therefore drop cells that are located in areas traditionally inhabited by transhumant pastoral ethnic groups (using data from McGuirk and Nunn (2025), described below), leaving an estimation sample of 5,461 cells once uninhabited areas are discarded. Cells are denoted by i and are nested within polygons representing precolonial ethnic societies, denoted by e, taken from the digitized version of George Peter Murdock's ethnolinguistic map of Africa (Murdock, 1959, Nunn, 2008).

Conflict Outcomes We use two data sources on geocoded conflict events. The first is the *Armed Conflict Location and Event Data* (Acled) series (Raleigh, Linke, Hegre and Karlsen, 2010), which begins coverage in 1997. The second is the *Uppsala Conflict Data Program* (UCDP) Georeferenced Event Data series, which begins coverage in 1989.

The Acled dataset covers a broad range of violent events, protests/demonstrations, and non-violent conflict-related events. We retain only violent armed conflict events, which correspond to the union of two-sided ('battles') and one-sided ('violence against civilians') events.

The UCDP dataset covers fewer events, due to inclusion criteria such as (i) at least one fatality per included event and (ii) at least 25 fatalities in any year of the series per included dyad.

While the UCDP data tracks large-scale conflict events between organized civil conflict actors, the Acled data additionally covers smaller-scale events between communal actors. For each, we

use as our main outcome a measure of conflict incidence, equal to one for cells and years in which at least one event occurs and equal to zero otherwise. We denote this by $I(Conflict)_{it}$, for cell i and year t. We also examine intensive margin effects.

Proximity To Pastoral Regions We use data on proximity to pastoral regions from McGuirk and Nunn (2025), who assign an index score measuring the importance of transhumant pastoralism for each ethnic territory e, which we denote by THP_e. The index is an interaction between the following component variables: an indicator for whether the ethnic group was traditionally mobile (versus sedentary); an indicator for whether the ethnic group has large animals (versus small or no animals); and a 0-1 index estimating the share of caloric intake that is derived from animal husbandry (versus crop cultivation, fishing, hunting, and gathering).

Our first proximity variable is $THP_i^{Neighbor}$, which is the THP index score of the ethnic territory that is closest to the centroid of cell i, among all territories that are contiguous neighbors of group e.

$$THP_i^{Neighbor} \;=\; THP_{j^*(i)}, \qquad j^*(i) \;=\; \underset{j \in \mathcal{N}(e(i))}{\arg\min}\; d_{ij}, \tag{1}$$

where $\mathcal{N}(e(i))$ denotes the set of ethnic territories that share a border with territory $e(i)$, and d_{ij} is the shortest distance (in km) between the centroid of cell i and the boundary of territory j. Higher values of $THP_i^{Neighbor}$ indicate greater reliance on transhumant pastoralism in the ethnic society that is cell i's nearest neighbor. A value of zero indicates that cell i's nearest neighbor does not practice transhumant pastoralism. This is the proximity variable used in McGuirk and Nunn (2025).

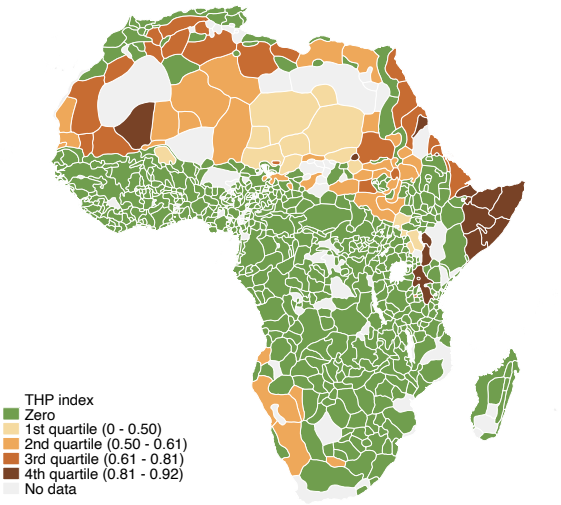
Our second proximity variable, $THP_i^{Neighbors\text{-}IDW}$, is the inverse-distance weighted average of *THP* index scores across all territories contiguous to the ethnic territory in which cell i is located:

$$THP_i^{Neighbors\text{-}IDW} \;=\; \sum_{j \in \mathcal{N}(e(i))} \omega_{ij}\, THP_j, \qquad \omega_{ij} \;=\; \frac{1/d_{ij}}{\sum_{k \in \mathcal{N}(e(i))} 1/d_{ik}}, \tag{2}$$

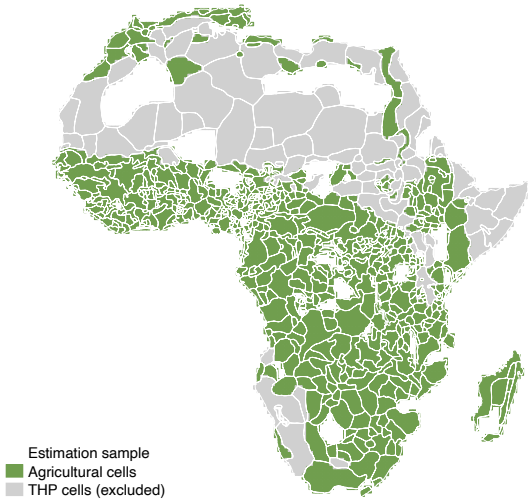
with $\mathcal{N}(e(i))$ and d_{ij} as defined above. Because the weights sum to one, the variable lies in the same [0,1] range as the *THP* index itself and can be interpreted as the *THP* score of a typical neighbor, with closer territories weighted more heavily. This proximity variable captures more information on the intensity of transhumant pastoralism in the neighborhood of a cell than the nearest neighbor variable in equation (1), while ensuring that its scale is not driven by territories located very close to cell i.

For both measures, we report effects evaluated at a value of 0.605, the median *THP* score among transhumant pastoral territories.

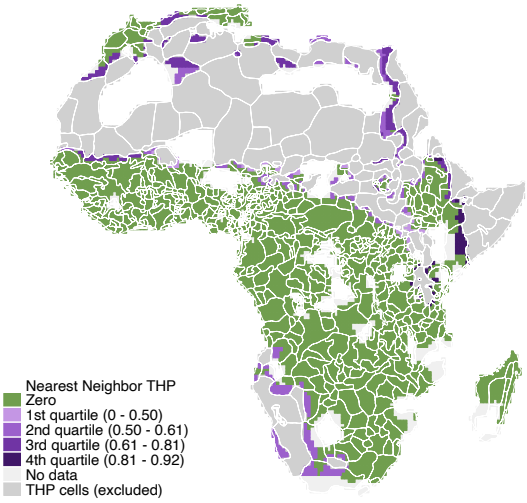
In Figure 2, panel (a), we map the THP_e variable across ethnic territories in Africa. Values of zero are in green, which we interpret to be agricultural societies. Among territories with positive values of THP_e, quartiles are represented in shades of brown. In panel (b), we highlight the estimation sample, i.e., cells for which $THP_e = 0$. In panel (c), we layer on the cell-level $THP_i^{Neighbor}$ proximity variable. In panel (d), we substitute this for the broader $THP_i^{Neighbors\text{-}IDW}$ proximity variable.



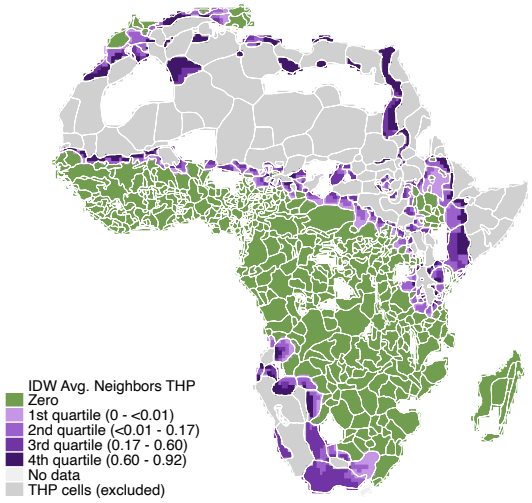
(a) THP index, Murdock ethnic homelands



(b) Estimation sample: agricultural cells



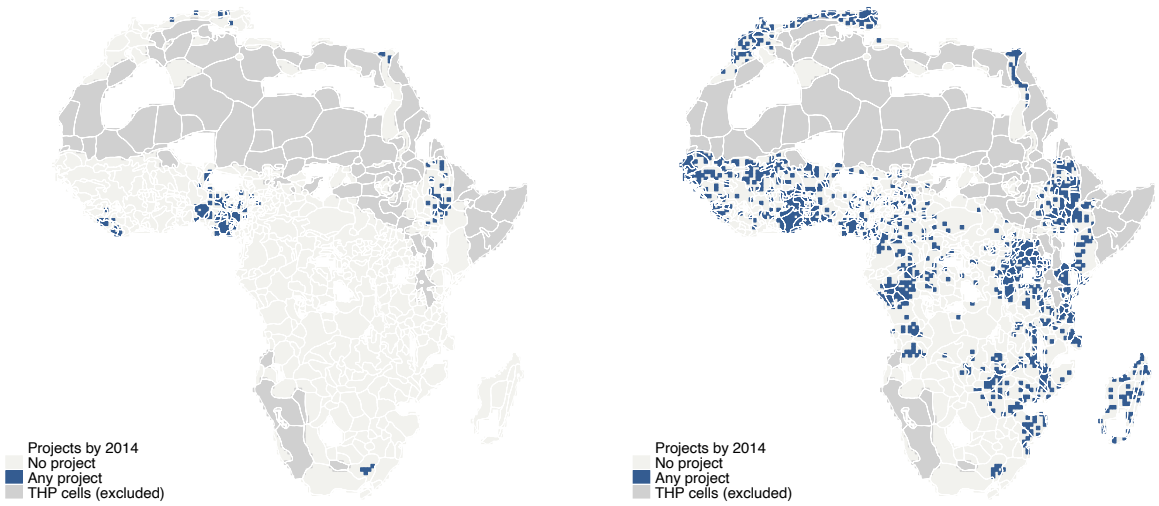
(c) Nearest Neighbor THP



(d) IDW Avg. Neighbors THP

Figure 2: Transhumant pastoralism and the agricultural estimation sample

Notes: Panel (a) shades Murdock ethnic homelands by the THP index; zero indicates agricultural groups. Panels (b)–(d) show $0.5^\circ \times 0.5^\circ$ grid cells; THP cells (grey) are excluded from the estimation sample. In panels (c) and (d), classes are zero and quartiles of the positive values among agricultural cells.



(a) Fertilizer projects

(b) Other agricultural projects

Figure 3: Fertilizer and other agricultural projects

Notes: Both panels show $0.5° \times 0.5°$ grid cells. Blue cells are those that ever receive at least one project of the given type during the sample period. Panel (a) shows fertilizer projects; panel (b) shows agricultural projects without a fertilizer component. THP cells (grey) are excluded from the estimation sample.

Fertilizer Projects Our main measure of synthetic fertilizer abundance comes from the geocoded dataset of World Bank development projects (AidData, 2020), which covers projects assigned from 1995-2014. There are 1,907 projects located in 16,591 project sites in Africa during this period. We define fertilizer projects as those within the 'Agricultural, Forestry and Fishing' category that contain the word "fertilizer" in any of the project description variables.[1] There are 318 geocoded fertilizer project sites.

We also measure other (i.e., non-fertilizer) agricultural project sites, of which there are 3,633, and non-agricultural project sites. We assign all of these projects to the cell in which they are located, which allows us to measure the cumulative number of projects of each type assigned to each cell in a given year.

In panel (a) of Figure 3, we highlight cells that received at least one fertilizer project during the 1995-2014 sample period. In panel (b), we highlight cells that received at least one other agricultural project during that period.

Fertilizer Prices To measure international fertilizer prices, we use the *Mixed Fertilizers (WPU0651)* index variable from the U.S. Bureau of Labor Statistics via the Federal Reserve Bank of St. Louis website. We use the annual mean, where the 1982 observation is set to equal 100. The data series runs to 2024.

In Table 1, we present summary statistics for the key variables in the fertilizer project sample, which covers agricultural cells from 1995 to 2014. In Table 2, we present summary statistics for the key variables in the fertilizer price sample, which covers agricultural cells from 1989 to 2024.

[1] These include sector, project name, project title, short description, long description, and AidData activity names.

Table 1: Summary Statistics for Project Sample (1995-2014)

	Cell-Year Level Variables					
	Mean	SD	Count	Min	Median	Max
ACLED: I(Any Conflict)	0.08	0.27	98,298	0.00	0.00	1.00
ACLED: IHS (Events)	0.19	0.65	98,298	0.00	0.00	7.51
ACLED: IHS (Fatalities)	0.17	0.78	98,298	0.00	0.00	11.77
UCDP: I(Any Conflict)	0.04	0.19	109,220	0.00	0.00	1.00
UCDP: IHS (Events)	0.06	0.35	109,220	0.00	0.00	5.51
UCDP: IHS (Fatalities)	0.12	0.69	109,220	0.00	0.00	11.50
Neighbor THP	0.07	0.21	97,980	0.00	0.00	0.92
IDW Avg. Neighbors THP	0.08	0.21	109,100	0.00	0.00	0.92
Fertilizer Projects	0.02	0.24	109,220	0.00	0.00	12.00
Other Ag. Projects	0.25	1.03	109,220	0.00	0.00	29.00
Other Non Ag. Projects	0.79	2.98	109,220	0.00	0.00	96.00

Table 2: Summary Statistics for Price Sample (1989-2024)

	Cell-Year Level Variables					
	Mean	SD	Count	Min	Median	Max
ACLED: I(Any Conflict)	0.12	0.33	152,908	0.00	0.00	1.00
ACLED: IHS (Events)	0.36	0.91	152,908	0.00	0.00	8.38
ACLED: IHS (Fatalities)	0.27	0.95	152,908	0.00	0.00	11.77
UCDP: I(Any Conflict)	0.05	0.22	191,135	0.00	0.00	1.00
UCDP: IHS (Events)	0.08	0.41	191,135	0.00	0.00	7.57
UCDP: IHS (Fatalities)	0.15	0.76	191,135	0.00	0.00	13.04
Neighbor THP	0.07	0.21	176,364	0.00	0.00	0.92
IDW Avg. Neighbors THP	0.08	0.21	196,380	0.00	0.00	0.92
ln Fertilizer Prices (wpu0651)	5.02	0.31	196,596	4.59	5.03	5.61

4. Estimation: Fertilizer Projects

A. Estimating Equation

To examine the differential impact of fertilizer projects on conflict for cells with pastoral neighbors, we estimate the following specification:

$$\begin{aligned} y_{it} \;=\; & \beta_1 \, THP_i^{Neighbor} \times FertilizerProjects_{it} + \beta_2 \, FertilizerProjects_{it} \\ & + \beta_3 \, THP_i^{Neighbor} \times OtherAgProjects_{it} + \beta_4 \, OtherAgProjects_{it} \\ & + \alpha_i + \alpha_{c(i)t} + \eta_{it} \end{aligned} \tag{3}$$

where y_{it} is the conflict outcome for cell i and year t; $THP_i^{Neighbor}$ is the THP proximity index for cell i; $FertilizerProjects_{it}$ is the cumulative number of fertilizer projects assigned to cell i by year t; $OtherAgProjects_{it}$ is the cumulative number of other (non-fertilizer) agricultural projects assigned to cell i by year t; α_i represents cell fixed effects; and $\alpha_{c(i)t}$ represents country-by-year fixed effects. We cluster standard errors along two dimensions: by cell to account for serial dependence within cells and by country-year to account for spatial dependence across cells within countries.

The parameter β_2 captures the difference-in-differences effect of fertilizer projects on conflict in *pure* farmland cells that do not have pastoral neighbors. It allows for time-invariant differences

across cells, which are absorbed by α_i, as well as shocks/trends that are common across cells within countries, which are absorbed by $\alpha_{c(i)t}$.

The parameter β_1 captures the additional effect of a project when it is assigned to *mixed* farmland cells with a pastoral neighbor. Since this is similar in spirit to a triple-difference estimator, we require weaker identification assumptions relative to β_2. We can allow for time-varying sources of selection bias provided they are common across cells with varying degrees of pastoral proximity.

The conceptual framework predicts that β_1 is positive, implying that access to synthetic fertilizer increases conflict in mixed farmland cells relative to pure farmland cells, and, if anything, β_2 is negative, implying that access to synthetic fertilizer reduces conflict in pure farmland cells.

We allow other agricultural projects to enter the specification in the same manner as fertilizer projects. These are important control variables, as cells receiving agricultural projects in general may differ from those that do not for reasons that correlate with potential conflict over time. Including these also allows us to estimate $\beta_1 - \beta_3$, which is the differential effect of fertilizer projects in mixed farmland relative to the differential effect of other agricultural projects in mixed farmland. This separates the effect that is due to the fertilizer-specific component of agricultural projects, which is predicted by theory to increase conflict, from the effect that is due to a more general increase in productivity.

B. Estimates

We present estimates for equation 3 in Table 3. For each conflict data source (Acled and UCDP), we first present effects on our main extensive margin outcome $I(Conflict)_{it}$ in columns 1 and 4. We also report intensive margin effects on the number of events and fatalities respectively, using the inverse hyperbolic sine transformation. In addition to controlling for other agricultural projects, which are reported for comparison, we also control for the cumulative number of all non-agricultural projects and its interaction with pastoral proximity.

Beginning with column (1), we see that fertilizer projects have no significant impact on Acled conflict incidence in pure farmland areas (row [2]). By contrast, fertilizer projects have a large, positive and significant impact on conflict in mixed farmland areas: the $\hat{\beta}_1$ estimate is 0.159 ($p < 0.05$) and the total predicted effect of an additional fertilizer project in a cell for which the nearest neighbor has the median THP index score is 9.9 percentage points ($p = 0.01$), which is 118% of the dependent variable sample mean.

Crucially, we see no equivalent effect for other agricultural projects, such as irrigation, extension, seed distribution or credit provision projects. The interaction effects are not significant, and the estimated differential effect $\beta_1 - \beta_3$ is positive and highly significant for all three outcomes, suggesting that fertilizer has a distinct effect on conflict in mixed farmland areas relative to other agricultural interventions.

While we see a different pattern for the UCDP data, it is qualitatively consistent with the Acled results. The estimates for β_1 remain positive but are smaller in magnitude and not significant. Interestingly, the estimates for β_2 are negative for all three outcomes and significant for the intensive margin effects, implying that while fertilizer projects reduce the intensity of large-scale conflict in pure farmland areas, they do not in mixed farmland areas. Moreover, the effect of other

Table 3: Fertilizer Projects, Pastoral Proximity, and Conflict in Agricultural Africa

	ACLED Conflict			UCDP Conflict		
	(1) Any	(2) IHS (Events)	(3) IHS (Fatalities)	(4) Any	(5) IHS (Events)	(6) IHS (Fatalities)
[1] Neighbor THP × Fertilizer Projects	0.1591**	0.6256**	0.7199***	0.0176	0.0554	0.2495
	(0.0620)	(0.2545)	(0.2306)	(0.0566)	(0.0952)	(0.1673)
[2] Fertilizer Projects	0.0025	0.0301	-0.0370	-0.0146	-0.0376**	-0.0963***
	(0.0123)	(0.0245)	(0.0331)	(0.0089)	(0.0162)	(0.0316)
[3] Neighbor THP × Other Ag. Projects	-0.0077	0.0097	-0.0883	-0.0244**	-0.0477**	-0.1270***
	(0.0175)	(0.0541)	(0.0739)	(0.0100)	(0.0203)	(0.0423)
[4] Other Ag. Projects	-0.0010	0.0042	-0.0076	0.0007	-0.0019	-0.0012
	(0.0032)	(0.0081)	(0.0103)	(0.0022)	(0.0050)	(0.0085)
Total Effect in Neighbor of Median THP						
$THP_{med} \times [1] + [2]$	0.0987	0.4086	0.3985	-0.0040	-0.0041	0.0546
p-value	[0.01]	[0.01]	[0.00]	[0.91]	[0.94]	[0.58]
Diff. Effect of Fertilizer vs. Other Ag.						
$[1] - [3]$	0.1667	0.6159	0.8082	0.0420	0.1031	0.3765
p-value	[0.01]	[0.01]	[0.00]	[0.46]	[0.29]	[0.02]
Dep. Var. Mean	0.0837	0.2010	0.1713	0.0404	0.0635	0.1188
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cells	4899	4899	4899	4899	4899	4899
Country-Years	864	864	864	960	960	960
Observations	88,182	88,182	88,182	97,980	97,980	97,980

Note: "I(Any)" is an indicator variable that equals one if at least one violent conflict occurs in a cell and year. "IHS(Events)" is the inverse hyperbolic sine of the number of conflict events that are recorded in a cell and year; "IHS(Fatalities)" is the inverse hyperbolic sine of the number of conflict-related fatalities that are recorded in a cell and year. Standard errors are adjusted for clustering at the level of a cell and a country-year. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 4: Fertilizer Projects, Pastoral Proximity, and Conflict in Agricultural Africa: Ethnicity-by-Year FE

	ACLED Conflict			UCDP Conflict		
	(1) Any	(2) IHS (Events)	(3) IHS (Fatalities)	(4) Any	(5) IHS (Events)	(6) IHS (Fatalities)
[1] Neighbor THP × Fertilizer Projects	0.1588**	0.5901**	0.6189***	0.0171	0.0590	0.2794
	(0.0618)	(0.2476)	(0.2249)	(0.0546)	(0.0886)	(0.1934)
[2] Fertilizer Projects	-0.0150	0.0094	-0.0164	-0.0020	-0.0117	-0.0485
	(0.0126)	(0.0232)	(0.0323)	(0.0123)	(0.0202)	(0.0517)
[3] Neighbor THP × Other Ag. Projects	-0.0119	0.0007	-0.1021	-0.0230**	-0.0358*	-0.1078**
	(0.0181)	(0.0546)	(0.0870)	(0.0100)	(0.0208)	(0.0424)
[4] Other Ag. Projects	-0.0012	0.0023	-0.0056	0.0016	-0.0041	-0.0020
	(0.0027)	(0.0069)	(0.0086)	(0.0023)	(0.0047)	(0.0076)
Total Effect in Neighbor of Median THP						
$THP_{med} \times [1] + [2]$	0.0810	0.3664	0.3580	0.0083	0.0239	0.1206
p-value	[0.02]	[0.01]	[0.01]	[0.79]	[0.64]	[0.26]
Diff. Effect of Fertilizer vs. Other Ag.						
$[1] - [3]$	0.1707	0.5894	0.7210	0.0400	0.0948	0.3873
p-value	[0.01]	[0.01]	[0.00]	[0.46]	[0.29]	[0.05]
Dep. Var. Mean	0.0827	0.1988	0.1688	0.0401	0.0631	0.1177
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Ethnicity × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cells	4799	4799	4799	4799	4799	4799
Country-Years	864	864	864	960	960	960
Observations	86,382	86,382	86,382	95,980	95,980	95,980

Note: "I(Any)" is an indicator variable that equals one if at least one violent conflict occurs in a cell and year. "IHS(Events)" is the inverse hyperbolic sine of the number of conflict events that are recorded in a cell and year; "IHS(Fatalities)" is the inverse hyperbolic sine of the number of conflict-related fatalities that are recorded in a cell and year. Standard errors are adjusted for clustering at the level of a cell and a country-year. * p < 0.1, ** p < 0.05, *** p < 0.01.

agricultural projects in mixed farmland areas is negative and significant, suggesting that general productivity gains are conducive to more peace. Thus, the differential effect of fertilizer projects relative to other projects is positive across all three outcomes and is significant for the fatalities outcome.

In Table 4, we present equivalent estimates for specifications that now include ethnic territory × year fixed effects. This absorbs all factors that vary over time between ethnicities, such as weather conditions and political power, for example. Our estimates are similar in magnitude and statistical significance, which implies that our findings are robust to the inclusion of a highly granular battery of fixed effects.

In Table 5, we replace the nearest neighbor pastoral proximity variable $THP_i^{Neighbor}$ with $THP_i^{Neighbors\text{-}IDW}$, the inverse-distance weighted average of *THP* scores of all contiguous neighbors of group e. This measure introduces more variation in the interaction term of interest. While this index is measured in the same [0,1] range as the nearest neighbor index, higher values are farther up in the distribution. Accordingly, we find slightly greater and more precisely estimated coefficients for the Acled regressions in row [1]. In Table 6, we add ethnic-group × year fixed effects, again finding a similar pattern.

Table 5: Fertilizer Projects, Pastoral Proximity, and Conflict in Agricultural Africa: All Neighbors (Distance-Weighted)

	ACLED Conflict			UCDP Conflict		
	(1) Any	(2) IHS (Events)	(3) IHS (Fatalities)	(4) Any	(5) IHS (Events)	(6) IHS (Fatalities)
[1] IDW Avg. Neighbors THP × Fertilizer Projects	0.1673***	0.6561**	0.7283***	0.0174	0.0514	0.2477
	(0.0630)	(0.2656)	(0.2357)	(0.0563)	(0.0946)	(0.1674)
[2] Fertilizer Projects	0.0026	0.0313	-0.0406	-0.0166*	-0.0402**	-0.1007***
	(0.0120)	(0.0258)	(0.0342)	(0.0091)	(0.0166)	(0.0313)
[3] IDW Avg. Neighbors THP × Other Ag. Projects	-0.0053	0.0153	-0.0814	-0.0241**	-0.0500**	-0.1317***
	(0.0174)	(0.0558)	(0.0715)	(0.0104)	(0.0210)	(0.0412)
[4] Other Ag. Projects	-0.0006	0.0073	-0.0078	0.0004	-0.0016	-0.0008
	(0.0033)	(0.0081)	(0.0108)	(0.0022)	(0.0048)	(0.0083)
Total Effect in Neighbor of Median THP						
$THP_{med} \times [1] + [2]$	0.1038	0.4283	0.4000	-0.0061	-0.0091	0.0492
p-value	[0.00]	[0.01]	[0.00]	[0.85]	[0.87]	[0.62]
Diff. Effect of Fertilizer vs. Other Ag.						
$[1] - [3]$	0.1725	0.6408	0.8097	0.0415	0.1013	0.3794
p-value	[0.01]	[0.01]	[0.00]	[0.46]	[0.30]	[0.02]
Dep. Var. Mean	0.0818	0.1942	0.1670	0.0393	0.0616	0.1162
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cells	5,455	5,455	5,455	5,455	5,455	5,455
Country-Years	864	864	864	960	960	960
Observations	98,190	98,190	98,190	109,100	109,100	109,100

Note: "I(Any)" is an indicator variable that equals one if at least one violent conflict occurs in a cell and year. "IHS(Events)" is the inverse hyperbolic sine of the number of conflict events that are recorded in a cell and year; "IHS(Fatalities)" is the inverse hyperbolic sine of the number of conflict-related fatalities that are recorded in a cell and year. Standard errors are adjusted for clustering at the level of a cell and a country-year. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 6: Fertilizer Projects, Pastoral Proximity, and Conflict in Agricultural Africa: All Neighbors (Distance-Weighted) and Ethnicity-by-Year FEs

	ACLED Conflict			UCDP Conflict		
	(1) Any	(2) IHS (Events)	(3) IHS (Fatalities)	(4) Any	(5) IHS (Events)	(6) IHS (Fatalities)
[1] IDW Avg. Neighbors THP × Fertilizer Projects	0.1595**	0.6216**	0.6188***	0.0125	0.0512	0.2694
	(0.0620)	(0.2548)	(0.2285)	(0.0535)	(0.0863)	(0.1902)
[2] Fertilizer Projects	-0.0105	0.0120	-0.0077	-0.0010	-0.0107	-0.0461
	(0.0130)	(0.0233)	(0.0330)	(0.0112)	(0.0188)	(0.0478)
[3] IDW Avg. Neighbors THP × Other Ag. Projects	-0.0100	0.0111	-0.0962	-0.0238**	-0.0399**	-0.1153***
	(0.0176)	(0.0557)	(0.0834)	(0.0097)	(0.0203)	(0.0406)
[4] Other Ag. Projects	-0.0014	0.0024	-0.0078	0.0016	-0.0030	-0.0007
	(0.0028)	(0.0070)	(0.0090)	(0.0022)	(0.0045)	(0.0073)
Total Effect in Neighbor of Median THP						
$THP_{med} \times [1] + [2]$	0.0860	0.3880	0.3666	0.0066	0.0203	0.1168
p-value	[0.02]	[0.01]	[0.01]	[0.83]	[0.69]	[0.28]
Diff. Effect of Fertilizer vs. Other Ag.						
$[1] - [3]$	0.1695	0.6105	0.7149	0.0363	0.0911	0.3847
p-value	[0.01]	[0.01]	[0.00]	[0.50]	[0.31]	[0.05]
Dep. Var. Mean	0.0811	0.1926	0.1649	0.0390	0.0610	0.1149
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Ethnicity × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cells	5,367	5,367	5,367	5,367	5,367	5,367
Country-Years	864	864	864	960	960	960
Observations	96,606	96,606	96,606	107,340	107,340	107,340

Note: "I(Any)" is an indicator variable that equals one if at least one violent conflict occurs in a cell and year. "IHS(Events)" is the inverse hyperbolic sine of the number of conflict events that are recorded in a cell and year; "IHS(Fatalities)" is the inverse hyperbolic sine of the number of conflict-related fatalities that are recorded in a cell and year. Standard errors are adjusted for clustering at the level of a cell and a country-year. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 7: Fertilizer Prices, Pastoral Proximity, and Conflict in Agricultural Africa

	ACLED Conflict			UCDP Conflict		
	(1) Any	(2) IHS (Events)	(3) IHS (Fatalities)	(4) Any	(5) IHS (Events)	(6) IHS (Fatalities)
[1] Neighbor THP × ln Fertilizer Prices	-0.0396	-0.2047	-0.0615	0.0287	0.0896	0.1329
	(0.0707)	(0.1886)	(0.2253)	(0.0524)	(0.1103)	(0.1673)
[2] Neighbor THP × L.ln Fertilizer Prices	-0.0376	-0.2436	0.0060	-0.0176	0.0158	0.0382
	(0.0712)	(0.1916)	(0.2375)	(0.0570)	(0.1285)	(0.1960)
Sum of Coefficients						
[1] + [2]	-0.0772	-0.4484	-0.0554	0.0111	0.1053	0.1711
p-value	[0.05]	[0.00]	[0.70]	[0.72]	[0.16]	[0.14]
Effect in Neighbor of Median THP						
$THP_{med} \times ([1] + [2])$	-0.0467	-0.2713	-0.0335	0.0067	0.0637	0.1035
Dep. Var. Mean	0.1255	0.3707	0.2806	0.0508	0.0841	0.1495
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cells	4,899	4,899	4,899	4,899	4,899	4,899
Country-Years	1,344	1,344	1,344	1,680	1,680	1,680
Observations	137,172	137,172	137,172	171,465	171,465	171,465

Note: "I(Any)" is an indicator variable that equals one if at least one violent conflict occurs in a cell and year. "IHS(Events)" is the inverse hyperbolic sine of the number of conflict events that are recorded in a cell and year; "IHS(Fatalities)" is the inverse hyperbolic sine of the number of conflict-related fatalities that are recorded in a cell and year. Standard errors are adjusted for clustering at the level of a cell and a country-year. * p < 0.1, ** p < 0.05, *** p < 0.01.

5. Estimation: Fertilizer Prices

In equation 4 below, we present a specification to capture the differential effect of fertilizer prices on conflict in mixed farmland relative to pure farmland areas.

$$y_{it} = \sum_{k=0}^{1} \lambda_k \, THP_i^{Neighbor} \times ln(FertilizerPrices)_{t-k} + \alpha_i + \alpha_{c(i)t} + \eta_{it} \tag{4}$$

The parameters on the interaction terms, λ_k, capture this effect. The level effects of each component of the interactions are absorbed by the cell and country × year fixed effects. Our parameter of interest is the cumulative effect $\sum_{k=0}^{1} \lambda_k = \lambda_0 + \lambda_1$, which captures the differential response of conflict to fertilizer price changes in cells with greater pastoral proximity over the current and previous year. Including the lagged term allows for delays in the pass-through of world fertilizer prices to local input prices and planting decisions.

We present the estimates using the $THP_i^{Neighbor}$ and $THP_i^{Neighbors\text{-}IDW}$ proximity variables in Tables 7 and 8, respectively. Strikingly, the estimates mirror our findings using the data on fertilizer projects. In line with the theoretical predictions, higher fertilizer prices significantly reduce the incidence of conflict in mixed farmland areas relative to pure farmland areas. Roughly, a 10% increase in prices leads to a 0.5 p.p. reduction in the risk of conflict for a cell whose neighbor has the median THP score. As before, however, the effect is present only in the Acled data, consistent with the mechanism generating localized violence that often falls below the UCDP fatality threshold for inclusion. On the intensive margin, the estimates for the number of conflict events are significant in both tables, while those for fatalities are not.

Table 8: Fertilizer Prices, Pastoral Proximity, and Conflict in Agricultural Africa: All Neighbors (Distance-Weighted)

	ACLED Conflict			UCDP Conflict		
	(1) Any	(2) IHS (Events)	(3) IHS (Fatalities)	(4) Any	(5) IHS (Events)	(6) IHS (Fatalities)
[1] IDW Avg. Neighbors THP × ln Fertilizer Prices	-0.0497	-0.2985	-0.1133	0.0401	0.0969	0.1386
	(0.0725)	(0.2088)	(0.2296)	(0.0543)	(0.1107)	(0.1673)
[2] IDW Avg. Neighbors THP × L.ln Fertilizer Prices	-0.0373	-0.2449	0.0335	-0.0197	0.0216	0.0466
	(0.0725)	(0.2107)	(0.2397)	(0.0581)	(0.1267)	(0.1925)
Sum of Coefficients						
$[1] + [2]$	-0.0870	-0.5434	-0.0798	0.0205	0.1186	0.1852
p-value	[0.03]	[0.00]	[0.57]	[0.51]	[0.11]	[0.10]
Effect in Neighbor of Median THP						
$THP_{med} \times ([1] + [2])$	-0.0526	-0.3288	-0.0483	0.0124	0.0717	0.1120
Dep. Var. Mean	0.1230	0.3598	0.2742	0.0495	0.0814	0.1452
Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Country × Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cells	5,455	5,455	5,455	5,455	5,455	5,455
Country-Years	1,344	1,344	1,344	1,680	1,680	1,680
Observations	152,740	152,740	152,740	190,925	190,925	190,925

Note: "I(Any)" is an indicator variable that equals one if at least one violent conflict occurs in a cell and year. "IHS(Events)" is the inverse hyperbolic sine of the number of conflict events that are recorded in a cell and year; "IHS(Fatalities)" is the inverse hyperbolic sine of the number of conflict-related fatalities that are recorded in a cell and year. Standard errors are adjusted for clustering at the level of a cell and a country-year. * p < 0.1, ** p < 0.05, *** p < 0.01.

6. Discussion and Conclusion

We examine the longstanding hypothesis that economic complementarities are conducive to peace between groups. We study the case of neighboring agricultural and pastoral ethnic groups in Africa, who share complementarities in production characterized by the exchange of grazing rights in the dry season for organic fertilizer in return. We hypothesize that this mutually beneficial arrangement is undermined when farmers gain access to synthetic fertilizer, which removes their reliance on herders and broadens the scope for armed conflict.

We find a robust pattern of evidence in support of this hypothesis. First, using data on World Bank development projects, we find that synthetic fertilizer projects significantly increase conflict when they are located in mixed farmland areas that are proximate to pastoral regions, while they weakly reduce conflict when they are located in pure farmland areas that are not. This effect is large and significant relative to the impact of other agricultural projects, indicating that the pattern is due to fertilizer specifically rather than more general improvements in agricultural productivity.

Second, and again consistent with the proposed hypothesis, we find that rising international fertilizer prices significantly decrease the risk of conflict in mixed farmland areas relative to pure farmland areas. Rising prices for synthetic fertilizer increase the incentive for farmers to cooperate peacefully rather than resist the arrival of herders for the dry season.

Notably, both of our main empirical findings are present for armed conflict as measured by Acled, which includes smaller scale communal clashes, but not UCDP, which focuses on larger scale civil conflict events. That this is consistent across two different estimation approaches is

reassuring.

Our findings have implications for economic and political policies that aim to foster peace between groups. In this specific context, mutual economic interdependence appears to increase the opportunity cost of bilateral conflict. Generalizing beyond this context is an important subject for future research.

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