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Temperature, maize yield, and civil conflicts in sub-Saharan Africa

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Abstract Civil conflicts have swept through many parts of sub-Saharan Africa in the past half century. Recently, scholars from backgrounds as diver as climate science, economics, political science, and anthropology have explored the effects of climate change on these civil conflicts, with mixed results. Our empirical results confirm effects of temperature on the incidence of civil conflict. The key findings are as follows: (i) between 1970 and 2012 in sub-Saharan Africa, a high temperature during maize growing season reduced the crop's yield, which in turn increased the incidence of civil conflict and (ii) future expected warming is expected to increase civil conflict incidence by 33% in the period 2031–2050, and by 100% in the period 2081–3010, compared to levels between 1981 and 2000. These results highlight the importance of sufficient food supplies and adaptation to increased climate warming to facilitate peace in sub-Saharan Africa.

1 Introduction

Conflicts around the world have resulted in major humanitarian and economic losses and have perpetuated states of poverty. Conflict has been one of the most distinct characteristics of sub-Saharan Africa (SSA) since the 1960s. Africa has the second highest conflict-related death toll in the world after Asia: 33.5% of all battle-related deaths between 1989 and 2014

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occurred in Africa.[1] However, there is no firm consensus on fundamental solutions to these conflicts. The complexity of the conflicts in SSA is related to the fact that most African conflicts are civil and fought within; as such, international norms, institutions, and political intervention might not be appropriate to resolve SSA's problems.

Recently, numerous studies have tested the idea that civil conflict and global climate change over the past half century are related (see Hsiang et al. (2013) for an overview). For example, incidence of civil conflict was correlated with periods of higher temperatures (Burke et al. 2009), insufficient rainfall (Miguel et al. 2004; Kelley et al. 2014), and factors of global climate variation, such as El Niño (Hsiang et al. 2011).[2] However, this relationship has been challenged by the results of studies that found weak or no associations between climate and civil conflict (Buhang 2010); consequently, criticism has arisen that these direct connections between climate and civil conflict are a type of environmental determinism (Raleigh et al. 2014). A major source of this debate lies in the inconclusiveness of the link between climate and conflict.

This study aimed to identify a causal relationship between climate and civil conflict. Our hypothesis is that changes in temperature influence the likelihood of civil conflict incidence through its effects on agricultural outcomes. The empirical strategy to confirm this hypothesis consists of two main ideas: we employed the two-stage least squares regression method in which crop yield was first regressed on growing season temperature; then, the incidence of civil conflict was predicted from the resulting measure of temperature-induced crop yield. This empirical strategy solves the problem of reverse causality in which conflict can influence agricultural productivity. We chose maize yield as a factor that is influenced by climate conditions; in turn, the subsequent maize yield affects civil conflict. By narrowing the analytical focus to one crop's yield, we were able to identify a precise link through which temperature influences civil conflict. In addition to maize yield channel for temperature-civil conflict link, our model also allows possible alternative channel by which temperature could affect the incidence of civil conflict; to do so, we included annual mean temperature as regressor for the incidence of civil conflict.

The main findings are summarized as follows. In the sample of 37 SSA countries between 1970 and 2012, a high temperature during growing season reduced maize yield, which in turn increased the incidence of civil conflict. This temperature-induced maize yield effect on the incidence of civil conflict was heterogeneous across the sampled countries and was greater for countries with lower maize yield. In addition to this temperature-induced maize yield effect on civil conflict incidence, annual mean temperature is also positively related to the incidence of civil conflict, implying that there may exist alternative mechanism that temperature is related to the incidence of civil conflict. Using bootstrap estimates and simulated temperature from the CMIP5 climate models, we found that the expected, continued increase in temperature will increase the incidence of civil conflict by 33% in the period 2031–2050, and by 100% in the period 2081–3010, compared to the mean frequency of civil conflict incidence between 1981 and 2000.

Our results statistically confirmed that a temperature-modulated agricultural yield effect exists on the incidence of civil conflict. By using individual crop yields and their growing season temperatures, this causal link was relatively more precise than studies using aggregate measures in existing literature. Our results emphasize the importance of transitioning to high-heat, stress-tolerant crop varieties and developing agricultural adaptation practices that

[1] This statistic is based on UCDP Battle-Related Deaths Dataset v.5.

[2] However, no signal for anthropogenic climate change on civil conflict was found in the previous literature.

can withstand increasingly unfavorable climatic conditions. This paper does not investigate all potential channels by which climate conditions may influence civil conflict, which we leave for future research.[3]

The rest of the paper will proceed as follows: In Section 2, we discuss the data used in our analysis. Section 3 presents the theoretical model and empirical specification. The main results are presented in Section 4, and Section 5 summarizes the findings.

2 Data

2.1 Maize yields

The Food and Agriculture Organization (FAO) database was the source of the data use for annual maize yield (ton/ha) to measure agricultural productivity. We chose maize for the following reasons. First, maize is a major crop in terms of production and consumption in most SSA countries (Smale et al. 2013). It accounts for 30% of the total SSA area under cereal production (FAO 2000). Moreover , although much of the rest of the world uses maize primarily as livestock feed, African countries use 95% of their maize production as a human food source. Second, the effects of temperature variation on maize yields are measurable because maize is susceptible to hot temperature anomalies (Lobell and Burke 2010). Other crops (such as cassava and groundnut) grow underground, and climatic conditions only have indirect effects. To ensure the quality of the data, we excluded three or more consecutive years of identical yield in a country from the analysis.[4]

Despite its importance as a human food source, maize yields are generally low in SSA compared to the rest of the world (Shiferaw et al. 2011). In our sample, the SSA's average maize yield is about one-third of the average global yield. However, as Fig. 1a shows, maize yields have gradually increased in SSA, with recent increases partly attributed to the introduction of a new variety of maize and increased fertilizer applications (Deryng et al. 2014).

2.2 Civil conflict

Our dependent variable in empirical analysis is the incidence of civil conflict. Following Nunn and Qian (2014), a country's civil conflict incidence at time t is equal to 1 if there is at least one civil conflict, whether it starts at t or is ongoing from $t-1$, in which there are at least 25 battle-related deaths. Otherwise, it is equal to 0. Therefore, civil conflict incidence is the union of civil conflict onset and duration (Elbadawi and Sambanis 2002; Montalvo and Reynal-Querol 2005). The data for this measure were based on the UCDP/PRIO Armed Conflict Data Set, version v4-2014a.

Rates of civil conflicts in SSA show inter-annual variability in our sample. In Fig. 1b, the proportion of countries with civil conflict incidence reached its peak at 0.29 in 1994, then decreased to 0.11 in 2005; however, it has increased again since 2005. The distribution of civil conflict incidence is not uniform across SSA countries. The mean civil conflict incidence is about 0.166; however, countries such as Ethiopia, Sudan, and Uganda show three times more civil conflict incidences than the mean in our sample period.

[3] Previous studies examined some of these channels to estimate the impact of climate conditions on civil conflict (see Miguel et al. (2004) and Bazzi and Blattman (2014) and Smith (2014)).

[4] Repeated observations can be due to data reporting or inputting errors. The results we derived in this paper do not change by including these observations.

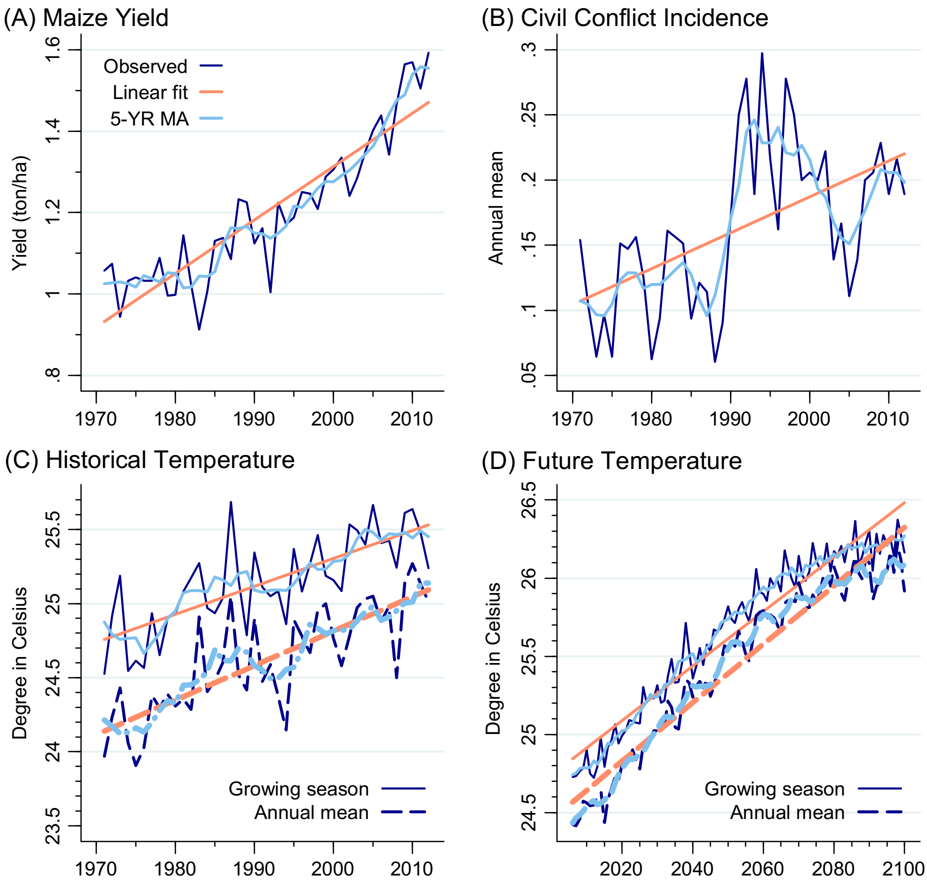

Fig. 1 Trends on maize yield, civil conflict incidence, maize-growing season temperature, and annual mean temperature. **a** and **b** show annual maize yield and civil conflict incidence, respectively. **c** shows mean temperature in maize-growing season (*solid*) and annual mean temperature (*dash*) in our historical sample. **d** extends information in **c** to year 2100 by using mean of the 18 CMIP5 climate model outputs in the period of 2006–2100

2.3 Historical temperature

The mean temperature during the maize-growing season and annual mean temperature were the key variables in representing historical temperature conditions. We computed these variables from the temperature data of the dataset CRU TS v.3.22, which we obtained from the Climatic Research Unit of the University of East Anglia (Harris et al. 2014). These data provide monthly average temperatures between January 1970 and December 2012 on a 0.5° grid around the world. ArcGIS was used to identify the grid points of countries' temperature data.

The maize-growing seasons in SSA vary by geographic region. For example, the maize-growing season in west Africa is from May to October, but from November to May in southern Africa. Following Lobell et al. (2008), the 37 countries sampled for this study were grouped into five regions based on their maize-growing seasons: central Africa (CAF), east Africa (EAF), southern Africa (SAF), the Sahel (SAH), and west Africa (WAF). A country's maize-growing season temperature in a given year was computed as the area-weighted mean of the temperatures during that year's growing season, as based on that country's grids.

Between 1970 and 2012, the maize growing season temperatures in all regions of SSA increased by 0.9 °C based on the linear trend (Fig. 1c). During the same period, the average global temperature increased at a rate of about 0.15–0.20 °C per decade (IPCC 2014). Therefore, changes in maize-growing season temperature might be related to large-scale climate change that has occurred over the past half century (IPCC 2014).

We included annual mean temperature (and their squared term) in regression to allow any other channels that temperature might have to influence the incidence of civil conflict. Alternatively, we also used non-growing season temperature of maize (and its squared term) for the same purpose. Figure 1c shows that temporal patterns of annual mean temperature closely mimic those of maize-growing season temperature, except that annual mean temperature is lower than growing season temperature since it includes relatively cold season temperatures as well.

2.4 Future temperature

Future maize-growing season and annual mean temperature are based on simulations from the 18 climate change models from the Fifth phase of the Coupled Model Intercomparison Project (CMIP5).[5] Each model provides a predicted monthly mean temperature for the period of 2006–2100 under the RCP4.5 emissions scenario. Using ArcGIS, we matched the predicted temperatures from grids of model to countries' grid points. We assumed that the maize-growing seasons for each of SSA's five regions would remain the same in the future and computed maize-growing season temperature based on the same months used in historical data.

Maize-growing season temperature is expected to increase by about 1.75 °C between 2006 and 2100 (Fig. 1d), and a similar pattern of increase can be seen in terms of annual mean temperature during the same period. This confirms continued warming in SSA during 2006–2100.

2.5 Nitrogen fertilizer consumption

Nitrogen fertilizer consumption was computed from the FAO database, which provides annual consumption (kiloton) by country. Fertilizer use is generally low across SSA compared to the rest of the world. High prices (due to reliance on imported fertilizers) and high transportation costs of fertilizers make it less profitable to use fertilizer in the region; however, in our sample, increased mean consumption of nitrogen fertilizer was observed, from 20.6 in the 1970s to 46.3 between 2000 and 2012.

2.6 Socioeconomic variables

In this paper, we include total natural resource rent (i.e., the sum of all natural resource rents as a proportion of GDP) and a logarithm of population to represent socioeconomic background. Both variables are based on World Bank Development Indicators. Total natural resource rent captures the structure of economy, and population represents possible size effect of each country.

[5] The list of climate models used is presented in Supplementary Materials.

3 Model

3.1 Theoretical background

The literature on political economy has considered the main causes of civil conflict to include poverty (Fearon and Laitin 2003), economic shocks (Bazzi and Blattman 2014), political exclusion (Fearon 2006), weak institutions with resource-dependent economies (Humphreys 2005), or some combination of these factors.

A recently growing body of empirical studies has linked changes in climatic conditions with civil conflicts. Burke et al. (2009) found significant correlations between temperatures and civil conflicts from 1981 to 2002. Likewise, Zhang et al. (2007) found a relationship between paleo-temperatures and war frequency. These studies argue that temperature changes influence agricultural production, and that subsequent temperature-induced food shortages increase the incidence of conflicts.

The mechanism behind how climate influences civil conflict by changing agricultural production can be understood as follows. Decreases in crop production due to climatic warming (Schlenker and Lobell 2010; Lobell et al. 2011) lower the incomes of rural people in poverty. These lower incomes increase the opportunity costs of participating in peaceful farming activities and decrease the opportunity costs of participating in alternative means of generating income, such as looting or stealing (Chassang and Padro-i-Miquel 2009; Dal Bó and Dal Bó 2011; Fjelde 2015). Some people may prey on others and be likely to engage in conflict. Rebels will find it easier to recruit people facing dire economic situations (Chassang and Padro-i-Miquel 2009). For example, the 1989 crop failure in the southern part of Rwanda contributed to the country's 1990 civil conflicts (Justino 2006). Moreover, low agricultural production lowers the incomes of regimes through loss of tax revenues and the expense of importing food. Groups or parties who oppose them often challenge regimes during these periods of insufficient financial resources (Kim 2016). In addition, a country that receives food aid to alleviate hunger after a crop failure might inappropriately distribute that aid, which might generate conflict among armed groups (Nunn and Qian 2014). In all of above scenarios, climate-induced crop failure could lead to conflict.

3.2 Empirical specification

Identifying causality in this study is difficult because conflicts affect the capacity to produce food. Conflicts might reduce agricultural production by lowering the number of agricultural workers through direct attacks, forced recruitment, and/or loss of soil fertility from interrupted cropping. A study by the FAO (2000) found that civil conflicts in SSA were major contributors to food insecurity in the 1990s.

We developed an empirical specification to avoid reverse causality based on our study's hypothesis. In the first-stage regression, agricultural yield was regressed on growing season temperature to compute the predicted yield outcome. Here, growing season temperature was considered an instrumental variable for agricultural yield. For growing season temperature to be a valid instrument, it must (1) be strongly correlated with agricultural yield and (2) not directly influence conflict other than its effect on yield. Moreover, if growing season temperature is a valid instrument, then the predicted crop yield is not reversely influenced by civil conflict. In the second-stage regression, the incidence of civil conflict was regressed on the predicted yield derived in the first-stage regression. The two-stage regression with a valid instrument (growing season temperature) is the two-stage least squares (2SLS) regression. We employed 2SLS to identify a causality between climate and conflict.

Previous relevant studies that have used 2SLS include Miguel et al. (2004), Koubi et al. (2012), Smith (2014), and Caruso et al. (2016). Miguel et al. (2004) and Smith (2014) used rainfall as their instrumental variable to examine the effect of rainfall-induced GDP per capita and rainfall-induced food prices on civil conflict, respectively. Koubi et al. (2012) used temperature and precipitation to instrument GDP growth and predicted GDP growth to explain civil conflict. However, neither temperature nor precipitation is significantly related to GDP growth in their sample, which raises questions about the validity of their instruments.

The current study differs from the above in the following ways. First, we used maize yield instead of aggregate quantities (such as GDP per capita or food prices) as a factor that is influenced by climate conditions; in turn, the subsequent maize yield affects the incidence of civil conflict. Caruso et al. (2016) specification is most closely related to our paper for their use of specific crop yield as the instrument. They used the minimum temperature during the core month of Indonesia's rice-growing season to examine temperature-induced rice production as a predictor of violent events.

Second, although temperature-induced crop failure has been a popular theoretical ground for civil conflict, it may not be the only mechanism that temperature could influence civil conflict. For example, Bollfrass and Shaver (2015) showed that at the sub-national level, non-agricultural regions experienced similar positive correlation between temperature and civil conflict as agricultural regions, suggesting that temperature may have alternative means to affect civil conflict. To account for alternative mechanism, we included annual mean temperature and its squared term as regressors in the second-stage regression. Note that maize-growing season temperature cannot be used to test temperature's alternative mechanism because the instrument is an excluded variable in the second-stage regression.

Our empirical specification was as follows.

$$Y_{i,t} = \beta_1 T_{i,t} + \beta_2 \bar{T}_{i,t} + \beta_3 \bar{T}_{i,t}^2 + \mathbf{X}_{i,t}\Gamma + \mathbf{D}_i + t + \varepsilon_{i,t} \quad (1)$$

$$C_{i,t} = \alpha_1 Y_{i,t} + \alpha_2 \bar{T}_{i,t} + \alpha_3 \bar{T}_{i,t}^2 + \mathbf{X}_{i,t}\Gamma' + \mathbf{D}_i + t + \mu_{i,t} \quad (2)$$

In the first-stage regression (1), maize yield in country i at time t ($Y_{i,t}$) is regressed on the following variables: maize-growing season temperature ($T_{i,t}$), the set of country-specific variables ($\mathbf{X}_{i,t}$), the country fixed effect ($\mathbf{D}_i$), the time trend (t), annual mean temperature ($\bar{T}_{i,t}$), and its squared term ($\bar{T}_{i,t}^2$) .[6] The set of country-specific variables includes a logarithm of the population, the natural resource dependency of the economy, and the one-period lagged value of the incidence of civil conflict ($C_{i,t-1}$), which captures the dynamic effects of civil conflict.

The identification strategy of the second-stage regression (Eq. 2) compares the incidence of civil conflict ($C_{i,t}$) for years when the temperature-induced maize yield was high to years in which it was low. This is captured by coefficient α_1 in Eq. 2.

[6]Temperature could have a nonlinear effect on maize yield; therefore, including squared (or higher order) values for temperature could be a more appropriate specification (Schlenker and Roberts 2009). In this study's 2SLS framework, a nonlinear term should be an instrument for maize yield; however, the squared term of temperature was not significantly related to maize yield; as such, it was thus not a valid instrument (Supplementary Table 2). Accordingly, we maintained the linear specification of the first-stage regression.

4 Results

4.1 2SLS estimates

Under two un-instrumented regression analyses (ordinary least squares (OLS) and logistic regression), maize yield was not significantly related to the incidence of civil conflict (Table 1). As stated above, these estimates would be biased if maize yield suffered from endogeneity. The coefficient of annual mean temperature may be insignificant due to this endogeneity.

Table 2 displays the key findings of the 2SLS regression. In the first-stage regression, the maize-growing season temperature is negatively correlated with maize yield. In the second-stage regression, the instrumented maize yield is derived from the first-stage regression; it is significant and negatively related to the incidence of civil conflict (Stage 2, column (1), Table 2). The first- and second-stage results collectively imply that a high maize-growing season temperature reduced maize yield, which in turn increased the incidence of civil conflict in SSA.[7]

The existence of alternative mechanism linking temperature and civil conflict is demonstrated in the second stage of the 2SLS estimation. The coefficient of annual mean temperature is significant and negatively related to civil conflict incidence; its squared term is significant and positively linked with the incidence of civil conflict. Given the range of annual mean temperatures in our sample and the magnitude of coefficient estimates, an increase in annual mean temperature will lead to greater incidence of civil conflict. To further examine whether mean temperatures in non-growing seasons are responsible for significance of annual mean temperature, we ran the same 2SLS estimation where annual mean temperatures are replaced by mean temperatures in non-growing seasons of maize and found that the results are qualitatively similar (Supplementary Table 3). These findings suggest that temperature may have alternative source to influence civil conflict incidence other than by affecting maize yield.

We examined whether rainfall, an alternative climate variable, could induce changes in maize yield that, in turn, influences civil conflict incidence.[8] To do so, we ran the 2SLS regression where maize yield is instrumented by growing season rainfall. The results showed that although rainfall amount is positively related to maize yield in the first-stage regression, rainfall-induced maize yield had no significant effect on civil conflict in the second-stage regression (Supplementary Table 4). Note that previous studies found rainfall-induced GDP or food price to be significantly related to civil conflict (Miguel et al. 2004; Smith 2014) and temperature-induced rice production to be associated with civil conflict (Caruso et al. 2016). Although more research is needed, the link between rainfall and civil conflict is apparent through aggregate economic factors, whereas the connection between temperature and civil conflict is seen via micro-level crop yield.

To estimate the magnitude of maize yield's effects on the incidence of civil conflicts, we performed two logistic regressions. In one regression, civil conflict incidence is regressed

[7]This study also tested whether the effects of temperature-induced maize yield on the incidence of civil conflict depended on maize consumption. See Supplementary Material for details.

[8]Rainfall, like temperature, was based on CRU TS v.3.22 data and is the average value of monthly average rainfall during the maize-growing seasons.

Table 1 The impact of maize yield on the incidence of civil conflict by OLS and logistic regression

	OLS		Logistic	
	Coefficient	Robust S.E.	Coefficient	Robust S.E.
Dependent variable		Civil conflict incidence		
Maize yield	−0.018	(0.027)	−0.153	(0.313)
Civil conflict incidence$_{t-1}$	0.494***	(0.064)	2.580***	(0.351)
Annual mean temperature	−0.142	(0.195)	−1.997	(1.804)
Annual mean temperature, squared	0.003	(0.004)	0.041	(0.038)
Resource	0.001	(0.000)	0.008	(0.010)
Log(pop)	0.062	(0.202)	0.295	(2.050)
R^2	0.51			
Log pseudolikelihood			−321.069	
Observations	1431		1040	

Coefficients and robust standard errors (in parentheses) are reported. All specifications include fixed effects of country and time trend.
$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

on instrumented maize yield, and in the other, un-instrumented maize yield is used as the regressor. To estimate the marginal effect of growing season temperature on civil conflict incidence by changing maize yield, we removed annual mean temperature and its squared term from the regressions.

The results, presented in Fig. 2, show that an increase in instrumented maize yield decreased the probability of civil conflict; regarding un-instrumented maize yield, the change in the probability of civil conflict was marginal. The effect of maize yield on civil conflict was heterogeneous across the 37 sample countries. If a country's yield was around the average value between 2000 and 2012 and increased by one standard deviation, then the probability of civil conflict in that country would decrease, on average, by 0.061, with a standard deviation of 0.035.[9] This wide dispersion in the distribution of changes in probability is evidence of a significant difference in the effects of temperature-induced maize yield on the incidence of civil conflict across countries.

The effect of maize yield was stronger when the yield was smaller. According to the logistic regression analysis using instrumented maize yield in Fig. 2, a 1 °C increase in growing season temperature reduced maize yield by 0.17, on average. For a country like

[9] With increase in maize yield by one standard deviation, Rwanda had the largest reduction in the probability of civil conflict (0.144), whereas South Africa had the smallest (0.002).

Table 2 The impact of instrumented maize yield on the incidence of civil conflict by 2SLS regression

	(1)		(2)	
	Coefficient	Robust S.E.	Coefficient	Robust S.E.
Stage 2. Dependent variable		Civil conflict incidence		
Maize yield	−0.401**	(0.189)	−0.249**	(0.119)
Civil conflict incidence$_{t-1}$	0.485***	(0.058)	0.431***	(0.078)
Annual mean temperature	−0.522*	(0.311)	−0.381*	(0.221)
Annual mean temperature, squared	0.009*	(0.004)	0.007*	(0.003)
Resource	−0.000	(0.001)	0.000	(0.001)
Log(pop)	−0.098	(0.260)	−0.137	(0.343)
Stage 1. Dependent variable		Maize yield		
Growing season temperature	−0.192***	(0.046)	−0.204***	(0.064)
Nitrogen fertilizer consumption			0.002***	(0.000)
Civil conflict incidence$_{t-1}$	−0.022	(0.079)	−0.044	(0.069)
Annual mean temperature	−0.676	(0.441)	−0.482**	(0.236)
Annual mean temperature, squared	0.014*	(0.008)	0.011***	(0.004)
Resource	−0.004**	(0.001)	−0.004**	(0.001)
Log(pop)	−0.390	(0.762)	−1.298	(0.866)
Kleibergen-Paap *F* statistic	16.942		14.400	
Cragg-Donald Wald *F* statistic	19.042		25.703	
Observations	1431		1030	

Coefficients and robust standard errors (in parentheses) are reported. All specifications include fixed effects of country and time trend.
$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Angola, with an average yield of 0.61 during 2000–2012, a 1 ° C increase in growing season temperature increases probability of civil conflict by 0.12. In contrast, the same prediction for Cameroon, with an average maize yield of 2.1 during 2000–2012, the probability of civil conflict would increase by only 0.015. This demonstrates that the same magnitude of change in growing season temperature has a differentiated impact on probability of civil conflict, depending on a country's maize yield level.

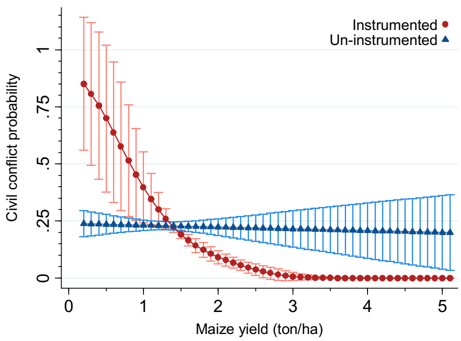

Fig. 2 Probability of civil conflict incidence during 1970–2012 as a function of maize yield. Estimated probabilities of civil conflict incidence as a function of instrumented and un-instrumented maize yield are reported with *circles* and *triangles*, respectively. Each probability estimate is accompanied by range plots that represent the 5–95% confidence interval

4.2 Validity of empirical model

The first test of the two requirements for valid instruments concerns whether the instrument exhibited a weak correlation with the endogenous variable of maize yield.[10] Weak instruments may produce biased coefficient estimates. The rule of thumb is that the Kleibergen-Paap F statistic (Kleibergen and Paap 2006) must be at least 10 to indicate a strong instrumental variable. The test results from our study found that the Kleibergen-Paap F statistic is 16.9 (Table 2). Note that the instrumented estimate is always biased, but less so than the OLS estimates to the extent that identification is strong. To evaluate how much less this estimate was biased, we compared it to OLS estimates and examined the Cragg-Donald Wald F statistic to assess the extent of weakness. The F statistic was about 19.04, which exceeded the Stock and Yogo (2005)'s cutoff value of 16.38 at 10%. These test results imply that our instrument of growing season temperature has a sufficiently strong correlation with maize yield.

The second test involves testing the exogeneity of growing season temperature (i.e., growing season temperature is uncorrelated with the error term). One test may exploit adding an additional instrument for maize yield and performing an over-identification test. Here, we chose nitrogen fertilizer consumption as an additional instrument. Maize is highly responsive to fertilizer, especially nitrogen fertilizer; most SSA countries, when they do use fertilizer, predominantly use it on maize (Kelly 2006). In addition, it is reasonable to expect that nitrogen fertilizer consumption would influence the incidence of civil conflict only through its effects on maize yield. Therefore, nitrogen fertilizer consumption may be a valid instrument.

Table 2 (Stage 1, column (2)) shows that nitrogen fertilizer consumption is significantly related to maize yield in the first-stage regression. As expected, the coefficient of nitrogen fertilizer consumption is positive, meaning that greater nitrogen fertilizer use increased maize yield. With two instruments, the Kleibergen-Paap F statistic is 14.4; thus, this set of two instruments is sufficiently correlated with maize yield. The Sargan-Hansen test for over-identification asserts the null hypothesis that a set of two instruments is exogenous. The test statistic was 2.168, its p value was 0.14, and thus the null hypothesis was not rejected, implying that covariates of two instruments and the error term are uncorrelated. However, this test result does not provide direct evidence that growing season temperature alone is

[10]Other relevant tests for 2SLS estimations are provided in the Supplementary Materials.

exogenous. Therefore, a supplementary test is to simply regress the incidence of civil conflict on maize-growing season temperature.[11] The results show that maize-growing season temperature is insignificantly associated with the incidence of civil conflict (Supplementary Table 5). In sum, our test results show that growing season temperature is unlikely to have direct association with the incidence of civil conflict in our sample; hence, the exogeneity condition for the instrument is likely to be satisfied.

In addition, we examine the possible effect of multicollinearity between maize-growing season temperature and annual mean temperature, due to their interrelated nature. Multicollinearity may result in large standard errors in least squares estimates. In the first-stage regression, multicollinearity may have caused an insignificant coefficient of annual mean temperature (Stage 1, column (1) in Table 2). However, the key point of including annual mean temperature is to capture alternative channel in which temperature could influence the incidence of civil conflict in the second-stage regression. In Stage 2 of Table 2, we found that annual mean temperature and its squared term are statistically significant in the second stage; therefore, multicollinearity does not invalidate the significance of alternative channel for temperature-civil conflict link.

4.3 Projections

We estimated the climate change impacts on future incidence of civil conflict. To do so, we evaluated existing literature such as Burke et al. (2009) and Schlenker and Lobell (2010) and combined a bootstrap estimation and simulated temperature from the climate models. More specifically, we ran 10,000 bootstraps on the 2SLS regression based on the historical data to estimate parameters.[12] This bootstrapping incorporates the uncertainty of parameter estimates. We then multiplied simulated growing season temperature and annual mean temperature from 18 climate model runs with parameter estimates to generate predicted maize yield values, which were then used to produce predicted values of future civil conflict incidence. By using multiple climate models, we incorporated the uncertainty of future estimates due to model differences. In sum, the future distribution of civil conflict incidence is based on 18,000 predicted values. For a comparison with the historical incidence of civil conflict, the mean probability of civil conflict incidence during 1981–2000 is set as the baseline probability, which is equal to 0.18.

Based on our bootstrap simulations, the predicted probability of civil conflict in the future is higher than the baseline probability (Fig. 3). During the period of 2031–2050, the median of predicted probability of civil conflict is 0.24, which is 33% higher than the baseline probability. Furthermore, the 25th–75th quantile interval does not include the baseline probability, which implies a significant deviation of civil conflict incidence from the baseline probability. In the more distant future (2081–2100), the median predicted probability of civil conflict will increase to 0.37, which is about 100% higher than the baseline probability. However, uncertainty regarding predicted probability rises as well, compared to the period of 2031–2050, and thus this result should be interpreted with caution.

Note that our future projection on civil conflict incidence does not incorporate the potential effects of policy change and agricultural development. Maize varieties with greater tolerance to heat and drought play an important role in adapting to climate change (Fedoroff et al.

[11] We thank an anonymous referee for suggesting this regression.

[12] We removed total natural resource rent and population from the bootstrap regressions since there is no projection of these variables extended to the year 2100.

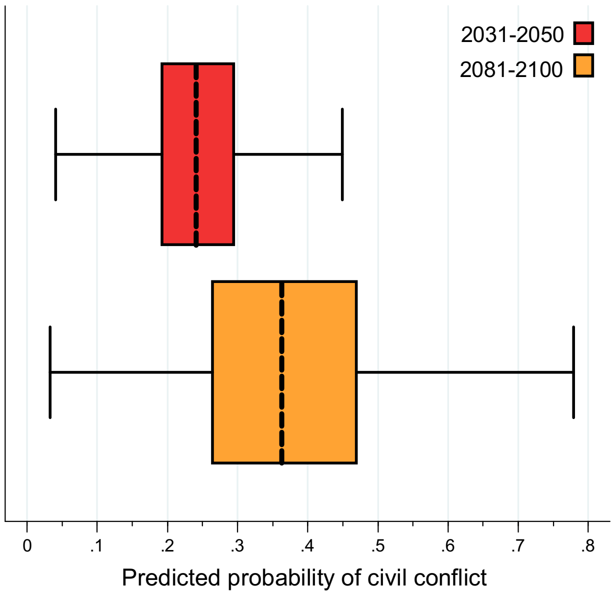

Fig. 3 Future projection of civil conflict incidence during 2031–2050 and 2081–2100. Each box with whiskers is based on 18,000 bootstrap runs per year. The *box* represents the 25–75 percentile range of predicted probability of civil conflict incidence, where *whiskers* extends this to the 5 and 95 percentiles. The median predicted probability is shown as a *dashed line*

2010; Hellin et al. 2012). Past experience demonstrates that new maize varieties can offset yield losses by up to 40% (Thornton et al. 2009). In sum, more civil conflict incidences are expected under crop failure caused by high temperatures, although future advances in maize crop practice could reduce these negative effects.

5 Conclusions

Our empirical analysis found that temperature-induced maize yield influences the incidence of civil conflict. Expected warming in the future will likely increase the likelihood of civil conflict incidence as a result of crop failure caused by high temperatures. These results imply that adapting to the warming atmosphere by widely adopting heat-tolerant crops could reduce the likelihood of civil conflict, as well as alleviate hunger and poverty.

Recent civil conflicts in SSA have been driven by a wider variety of factors than in the past. According to the United Nations (2009), the multidimensionality of factors contributing to civil conflicts requires multidimensional solutions from numerous fields. We believe that ensuring sufficient food production should be a building block of a lasting solution.

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References

Bazzi S, Blattman C (2014) Economic shocks and conflict: evidence from commodity prices. Am Econ J Macro 6:1–38

Bollfrass A, Shaver A (2015) The effects of temperature on political violence: global evidence at the subnational level. PLoS ONE 10:e0123505

Buhang H (2010) Climate not to blame for African civil wars. Proc Natl Acad Sci USA 107:16477–16482

Burke M-B et al (2009) Warming increases the risk of civil war in Africa. Proc Natl Acad Sci USA 106:20670–20674

Caruso R, Petrarca I, Ricciuti R (2016) Climate change, rice crops, and violence: evidence from Indonesia. J Peace Res 53:66–83

Chassang S, Padro-i-Miquel G (2009) Economic shocks and civil War. Q J Polit Sci 4:211–228

Dal Bó E, Dal Bó P (2011) Workers, warriors, and criminals: social conflict in general equilibrium. J Eur Econ Assoc 9:646–677

Deryng D, Conway D, Ramankutty N, Price J, Warren R (2014) Global crop yield response to extreme heat stress under multiple climate change futures. Environ Res Lett 9:034011

Elbadawi I, Sambanis N (2002) How much civil war will we see? Explaining the prevalence of civil war. J Conflict Resolut 46:307–334

FAO (2000) The state of food and agriculture 2000. Rome

Fearon J-D, Laitin D-D (2003) Ethnicity, insurgency, and civil war. Am Polit Sci Rev 97:75–90

Fearon J-D (2006) Ethnic mobilization and ethnic violence. In: Wittman D-A, Weingast B-R (eds) Oxford handbook of political economy. Oxford Univ Press, New York

Fedoroff N-V et al (2010) Radically rethinking agriculture for the 21st century. Science 327:833–834

Fjelde H (2015) Farming or fighting? Agricultural price shocks and civil war in Africa. World Dev 67:525–534

Harris I, Jones P-D, Osborn T-J, Lister D-H (2014) Updated high-resolution grids of monthly climatic observations—the CRU TS 3.10 Dataset. Int J Climatol 34:623–642

Hellin J et al. (2012) Climate change and food security in the developing world: potential of maize and wheat research to expand options for adaptation and mitigation. J Dev Agricul Econ 4:311–321

Hsiang S-M, Meng K-C, Cane M-A (2011) Civil conflicts are associated with the global climate. Nature 476:438–441

Hsiang S-M, Burke M, Miguel E (2013) Quantifying the influence of climate on human conflict, vol 341. doi:10.1126/science.1235367

Humphreys M (2005) Natural resources, conflict, and conflict resolution. J Conflict Resolut 49:508–537

IPCC (2014) Climate change 2014: impacts, adaptation, and vulnerability. In: Barros V-R et al (eds) Part B: regional aspects. Cambridge University Press, New York

Justino P (2006) On the links between violent conflict and chronic poverty: how much do we really know? Chronic Poverty Research Centre, University of Manchester, manuscript

Kelley C-P, Mohtadi S, Cane M-A, Seager R, Kushnir Y (2014) Climate change in the fertile crescent and implications of the recent Syrian drought. Proc Natl Acad Sci USA 112:3241–3246

Kelly V-A (2006) Factors affecting demand for fertilizer in sub-Saharan Africa. Agriculture and Rural Development Discussion Paper 23: World Bank

Kim N-K (2016) Revisiting economic shocks and coups. J Conflict Resolut 60:3–31

Kleibergen F, Paap R (2006) Generalized reduced rank tests using the singular value decomposition. J Econometrics 133:97–126

Koubi V et al (2012) Climate variability, economic growth, and civil conflict. J Peace Res 49:113–127

Lobell D-B et al (2008) Prioritizing climate change adaptation needs for food security in 2030. Science 319:607–610

Lobell D-B et al (2011) Nonlinear heat effects on African maize as evidenced by historical yield trials. Nature Clim Chang 1:42–45

Lobell D-B, Burke M-B (2010) On the use of statistical models to predict crop yield responses to climate change. Agr Forest Meteorol 150:1443–1452

Miguel E, Satyanath S, Sergenti E (2004) Economic shocks and civil conflict: an instrumental variables approach. J Polit Econ 112:725–753

Montalvo J-G, Reynal-Querol M (2005) Ethnic polarization, potential conflict, and civil wars. Am Econ Rev 95:796–816

Nunn N, Qian N (2014) US food aid and civil conflict. Am Econ Rev 104:1630–1666

Raleigh C, Linke A, O'Loughlin J (2014) Extreme temperatures and violence. Nat Clim Chang 4:76–77

Schlenker W, Lobell D-B (2010) Robust negative impacts of climate change on African agriculture. Environ Res Lett 5:014010

Schlenker W, Roberts M-J (2009) Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. Proc Natl Acad Sci USA 106:15594–15598

Shiferaw B et al (2011) Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. Food Sec 3:307–327

Smale M, Byerlee D, Jayne T (2013) Maize revolutions in sub-Saharan Africa. In: Otsuka K, Larson D-F (eds) An African Green Revolution. Springer, New York

Smith T-G (2014) Feeding unrest: disentangling the causal relationship between food price shocks and sociopolitical conflict in urban Africa. J Peace Res 51:679–695

Stock J, Yogo M (2005) Testing for weak instruments in linear IV regression. In: Andrews DWK (ed) Identification and inference for econometric models. Cambridge University Press, New York

Thornton P-K et al (2009) Spatial variation of crop yield response to climate change in East Africa. Global Environ Chang 19:54–65

United Nations (2009) Report of the Secretary-General on peacebuilding in the immediate aftermath of conflict. United Nations, New York

Zhang D-D et al (2007) Global climate change, war, and population decline in recent human history. Proc Natl Acad Sci USA 104:19214–19219