On climate change, water variability and conflicts

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A growing empirical literature associates climate anomalies with increased risk of violent conflict. This association has been portrayed as a bellwether of future societal instability as the frequency and intensity of extreme weather events are predicted to increase. This paper investigates the theoretical foundation of this claim. A seminal microeconomic model of opportunity costs – a mechanism often thought to drive climate-conflict relationships – is extended by considering realistic changes in the distribution of climate-dependent agricultural income. Results advise caution in using empirical associations between short-run climate anomalies and conflicts to predict the effect of sustained shifts in climate regimes: Although war occurs in bad years, conflict may decrease if agents expect more frequent bad years. Rather, theory suggests a non-monotonic relation between climate variability and conflict that emerges as agents adapt and adjust their behavior to the new income distribution. We identify three measurable statistics of the income distribution that are each unambiguously associated with conflict likelihood. Jointly, these statistics offer a unique signature to distinguish opportunity costs from competing mechanisms that may relate climate anomalies to conflict.

civil conflict | climate change | water resources | agriculture

Climate change is commonly portrayed as one of the most important potential threats to human, ecosystem, and societal well-being (e.g., 1). Perhaps the most direct of these threats is the purported link between climate anomalies and violent conflicts, a notion that is presently shaping political, military, and popular discourse (2)This attention underscores the need for understanding the institutional, economic, and psychological factors that collectively drive individuals and groups to fight. While there is growing consensus among academics that the relation between climate anomalies and conflicts is robust (3), competing explanations and notable exceptions remain. Interpretation and projection of empirical findings in the context of climate change requires careful theoretical consideration of underlying mechanisms. In this study, we relate hydrologic and microeconomic theory to mechanistically describe how changes in water resource availability might alter the emergence of negative income shocks, a potential driver of conflict that is sensitive to climate change (3).

Why do violent conflicts emerge and persist if they are so destructive? This paradox has long attracted the interest of political scientists and economists. The high cost of violence implies that peace is typically a better (Pareto-improving) alternative, and most grievances are believed to be resolved through bargaining (4). Violence might emerge from a bargaining breakdown that prevents a peaceful redistribution of land or resources (5). Among the suspected causes of bargaining breakdown (see 6) are the absence of institutional or social checks, which creates a disconnect between decision makers and foot soldiers who pay the price for violence; incomplete information, including miscalculations of opponents' strength or strategic withholding of private knowledge; and the inability to commit to a bargain, for example due to fluctuations in resource availability. Our analysis focuses on the last factor, because it is perhaps most directly affected by climate change (3, 7), rather than by historical, cultural, institutional and socioeconomic contexts. A growing empirical literature highlights the link between climate variability and negative income shocks as an important determinant of violence (7, 8): fighting tends to happen during bad years, particularly for non-state level conflicts short of civil war that do not require the levels of funding and mobilization necessary for organized armed rebellion (9).

In a seminal paper, Chassang and Padro-i Miquel (10) use an opportunity cost argument to provide a theoretical underpinning to the empirical relation between income shocks and conflict. The basic idea is that attacking diverts productive resources but yields an offensive advantage. There is little to lose in diverting resources to attack in bad years, but much to be gained from the expected future returns of captured resources. In bad years, the returns from attack outweigh the returns from peace. This prevents peaceful bargaining over resources, and parties go to war. This causal association between anomalously bad weather shocks and conflict occurrence has been robustly documented in the empirical literature. Motivated by both the theory and the empirical observations, many have argued that opportunity costs may be an important mechanism by which climate change can increase the propensity for conflict (see 3, 7). More extreme

Significance Statement

There is growing consensus among academics that climate change may amplify the risk of violent conflicts. While underlying mechanisms are poorly understood, negative income shocks associated with climate variability have been long-hypothesized to play an important role. We relate recent hydrologic and microeconomic advances to investigate the theoretical foundation of this claim. Results prescribe caution in interpreting empirical relations between climate variability and conflict in the context of climate change. While fighting preferentially occurs during climate anomalies, more frequent anomalies may not yield more conflicts. By shifting the entire distribution of rainfall, climate change effectively redefines the very notion of climate anomaly. Adaptation to this new normal can have a dominant, and often counterintuitive, effect on conflict probability.

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weather events and reduced crop productivity (e.g., 11) might increase the frequency and intensity of income shocks during which fighting tends to occur. This possibility is particularly important to consider in institutionally weak and ethnically fragmented regions where climate most directly impacts livelihoods (12–14) – ironically, regions believed to be particularly vulnerable to future climate change (15).

Two important knowledge gaps remain. First, existing studies look at anomalous weather events, which affect the cost but not the benefit of war. They find that parties go to war in 'bad' years. A changed climate, however, alters the *distribution* of annual rainfall. This affects the distribution of income, which in turn affects both the costs and benefits of fighting. Drought years will become more frequent as rainfall variability increases, which raises concerns about higher conflict likelihood. However, captured resources will also become less productive, which lowers the incentives for attack. An internally consistent prediction on the conflict impact of climate change has to account for both of these changes in agents' cost-benefit analysis in a way that, to our knowledge, existing projections do not. Second, competing mechanisms (other than opportunity costs) can explain the observed link between climate anomalies and conflict (see, e.g., 16) and current studies do not conclusively speak to their relative salience. Yet, effective policy design requires an accurate identification of the underlying drivers for conflict.

We address these gaps by linking the opportunity cost model proposed by Chassang and Padro-i Miquel (10) to a parametric distribution of climate-related income that is consistent with the current state of the art in hydrologic and agronomic models (17–19). We perform a comparative statics analysis (20) that accounts for agents' strategic adjustment to a changed environment. Results yield important, and perhaps counter-intuitive, insights on the two identified knowledge gaps. First, one must be cautious in using empirical associations between short-run climate anomalies and conflicts to predict the effect of sustained shifts in climate regimes. If precipitation becomes more variable, as climate models predict, conflicts will not necessarily become more frequent. Rather, conflict likelihood can go either up or down, as agents adapt and adjust their response to the new income distribution. Even shifts in climate *averages* will affect the income *variance*, and therefore conflict, due to non-linear processes that link climate to income. Second, we identify three measurable statistics of the income distribution that individually have an unambiguous effect on conflict and are jointly sufficient to predict the response of conflict to a change in climate. These testable predictions may help distinguish opportunity costs from competing mechanisms relating climate anomalies to conflicts.

It is important to note that the model is not a tool for making quantitative projections of climate-conflict trends in a specific geopolitical context, particularly given the multiple pathways by which societies can respond to climate or economic shocks (see 6, 16). Rather, the primary objective of the model is a careful theoretical treatment of opportunity costs as a mechanism often thought to drive the relationship between climate change and conflict. In doing so we elucidate the rich dynamics, and often counterintuitive outcomes, that emerge even under highly stylized theoretical representations of human behavior and climate (21).

Model overview

Consider two groups of farmers, whose annual income is subject to random rainfall variability, and who might fight for control over limited land and labor resources (22). Each year, the decision to attack is taken by weighing the immediate opportunity costs of fighting against future expected returns from the captured resources. The former is given by the current year's rainfall draw and the latter is jointly determined by the entire distribution of rainfall, by the probability of victory, and by the endogenous risk of conflict occurring in future years (see Materials and Method). Under these conditions, Chassang and Padro-i Miquel (10) show that conflict emerges in 'bad' years, when income falls below a threshold determined by its underlying distribution. Insofar as income is influenced by climate, their model offers a mechanism that can explain the empirical findings that relate climate anomalies to conflicts (16).

We extend the existing model by specifying a rainfall distribution and an income-generating crop function that are analytically tractable and consistent with governing meteorological and hydrological processes (see Materials and Methods). Doing so introduces a nonlinear relation between climate and income, which implications for conflict we discuss in the following section. The parametric distribution of income also allows us to compare predictions of conflict probabilities *across distributions* by altering parameters to emulate the effect of climate change (Figure 1). We initially focus on changes in the relative variability of seasonal rainfall, quantified by its coefficient of variation (CV_W). The focus on CV_W places our study at the intersection of empirical research exploring historic associations between conflict, income, and short-run anomalies of seasonal rainfall (see 7, 8)and climate modeling research predicting an increase in rainfall variability (e.g., 11). By performing a comparative statics exercise (20), we allow agents to adapt to changed costs and benefits by adjusting their fighting threshold. A changed climate affects both the present opportunity cost and the future returns from conflict, to which agents *adapt* by shifting the income threshold below which they will decide to fight. For analytical tractability, we favor this rather narrow definition of climate adaptation over a broader interpretation that would allow agents to endogenously optimize income distribution itself, e.g., through crop, policy and infrastructure selection.

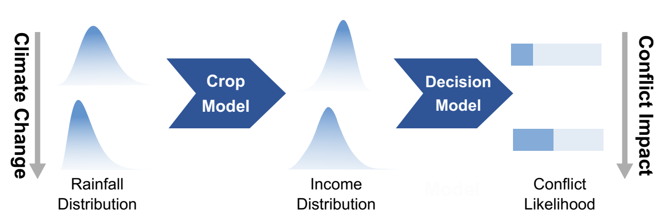

Fig. 1. Schematized relation between climate, crop and conflict models. Moving from left to right, rainfall distributions are related to income distributions via a deterministic model relating seasonal water availability to crop yield, taken as a proxy for income. Income distributions then inform a decision model for conflict. Changes in climate (top to bottom) alter the distribution of water availability, a change that propagates to an altered conflict likelihood.

Mean climate can affect income variance

Crop yields do not generally scale linearly with water supply (e.g., 19), and so changes in *mean* water availability will alter the *variance* of agricultural income. In particular, a crop chosen to be robust to climate variations will have mean water availability map to a flat region of its yield function (dark blue line in Figure 2 top). For such a crop choice, the effect of climate variability on income variability is minimal under existing climate conditions (dark blue line in Figure 2 bottom). However, a systematic decrease in water availability will enhance income variability due to the concave nature of the crop yield curve. This effect is particularly pronounced in the low water availability region (low W) of the crop yield curve, where curvature is maximal. There is a broad consensus in climate predictions that points to an increase in rainfall variability and an increase in mean temperatures (see, e.g., 11). The discussion below focuses on changing drought characteristics caused by an increase in rainfall variability. However, the nonlinearity of the climate-income link implies similar conclusions for sustained increases in mean temperature or for excess precipitation (see *Supporting Information*).

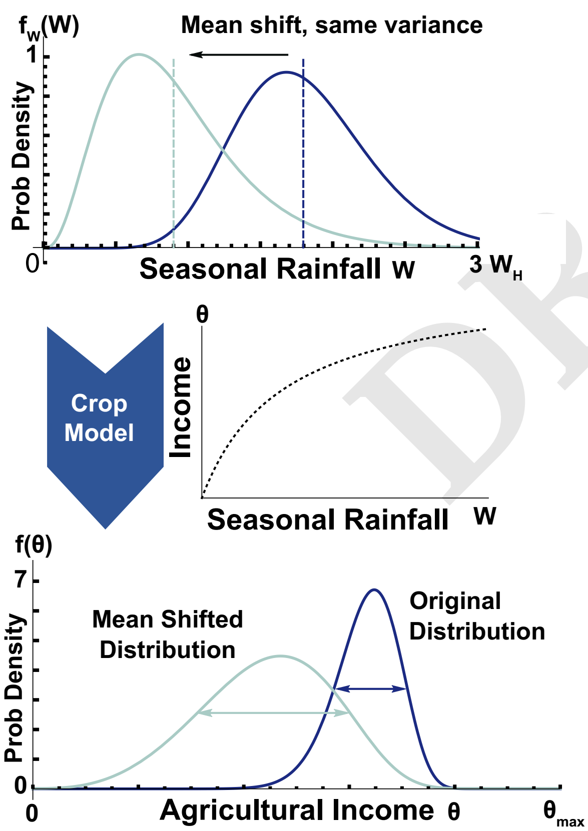

Fig. 2. Changes in mean climate can cause changes in income variability. A decrease in mean rainfall W (with variance conserved, *top*), causes the distribution to map to a more concave region of the crop model (middle), resulting in distributions of income θ with a larger variance σ_θ^2 (*bottom*). This increasing variance compounds the effect of a decreased mean income μ_θ and increases the coefficient of variation $CV_\theta = \sigma_\theta/\mu_\theta$ of income. Model parameters (see Materials and Methods): $W_H = 150$ mm, $\theta_{max} = 3$ currency units, $\sigma_W = 69.6$ mm, $\mu_W = 270$ mm (dark lines) and 135 mm (light lines).

Non-monotonic effect of climate variability on conflict

Despite the stylized nature of the opportunity cost model, changes in the coefficient of variability of water elicit complex nonlinear, and at times non-monotone, effects on the probability of conflict. Figure 3 illustrates how conflict probability increases monotonically with climate variability, captured by the coefficient of variation CV_W of rainfall, for some parameter combinations (red line), but the relationship becomes non-monotonic for others (pink line). Indeed, it is possible that conflict prevalence decreases with climate variability for small enough values of CV_W and a large enough offensive advantage in the odds of victory (see *Supplementary Information*). This behavior suggests that the opportunity cost framework does *not* consistently predict that a more variable climate will give rise to more prevalent conflicts. This insight is important to consider when using the framework to interpret empirical results. For instance, an empirical study finding an insignificant (Figure 3 point A) or negative (Figure 3 point B) relation between climate variability and conflict may not be incompatible with the opportunity cost framework. It also does not dismiss the possibility that a positive relation will emerge as CV_W increases under the effect of climate change (as seen in positive slopes at A' and B' on Figure 3).

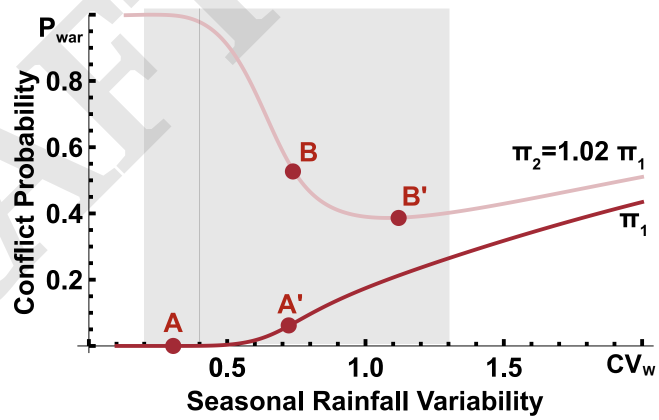

Fig. 3. Subtle changes in economic parameters can substantially alter the qualitative relationship between conflict probability and climate variability. A slight (2%) increase in the probability of first strike victory π (see Materials and Methods) introduces a non-monotone relationship between the coefficient of variation of seasonal rainfall (CV_W) and the predicted probability of conflict (P_{war}): a higher climate variability successively *decreases* and then increases the probability of conflict for a higher value of π (pink line), whereas the relationship remains monotonically increasing for a lower first strike advantage (red line). The shaded area shows the mean (vertical line) and 99% confidence interval of CV_W observed for seasonal (3-monthly) rainfall, constructed from daily observations at 671 locations within the United States (23). Model Parameters (see Materials and Methods): $\pi_1 = 0.5148$ (red), $\pi_2 = 0.5252$ (pink), $c = 0.9$, $\delta = 0.9$, $\mu_W = W_H = 150$ mm, $\theta_{\max} = 3$.

Governing Statistics and Strategic Adaptation

Changes in rainfall variability (CV_W) might cause farmers to alter the income threshold below which they will engage in conflict. This adaptation response can strongly influence the probability of conflict (P_{war}) as farmers weigh the current opportunity costs of attack against expected future profits. Opportunity costs are lower during a negative climate shock due to decreased crop productivity. Attacking then increases potential future profits for two reasons. First, the victor will capture her opponent's resources and permanently increase

Table 1. Qualitative effect of the three governing statistics of income distribution on the predicted probability of conflict

Marginal Change in income Statistic	Direct Effect on P_{war}	Adaptation effect on P_{war}
↑ Income Shock Frequency $F(\tilde{\theta})$	↑	↑
↓ Mean Income $E[\theta]$	-	↓
↓ Conflict destructivity $cE[\theta \mid \theta < \tilde{\theta}]$ (or ↑ income shock intensity)	-	↓

her own agricultural profits. Second, triggering a conflict during an income shock hedges against the possibility of a conflict ever occurring in future periods, when opportunity costs are higher on average. In the stark language of our our simple model, both incentives rely on the assumption that the defeated opponent exits the game forever. However, qualitatively similar incentives emerge if the defeated agent temporarily loses his land and ability to fight back, particularly when agents place a high emphasis on short-term profits.

Consequently, the opportunity cost model points to three fundamental statistics of the income distribution that govern the relationship between climate change, adaptation response and conflict: (i) The frequency of income shocks, defined as the probability $F(\tilde{\theta})$ that income falls below agents' conflict threshold $\tilde{\theta}$, has a direct effect on the probability of conflict. Any change to the income distribution that increases shock frequency will directly increase P_{war}. However, this direct effect also causes war to occur sooner in expectation, thereby reducing the future profits from (current) peace. This gives rise to a second, indirect, effect of an increase in income shock frequency: Because peace becomes less advantageous, farmers respond by increasing the income thresholds below which they attack, an adaptation that further exacerbates P_{war}. (ii) A decrease in mean income $E[\theta]$, for instance associated with a permanent decrease in mean rainfall, makes victory less profitable. Agents adapt to this by adjusting their income threshold for conflict. This causes a decrease in agents' threshold and, all other statistics being held constant, a decrease in P_{war}. (iii) Expected income during conflict-inducing shocks $E[\theta|\theta < \tilde{\theta}]$, as a measure of the intensity of income shocks, is proportional to the destructivity of conflicts and affects agents' incentive to fight through the hedging motive described above. More intense income shocks cause smaller expected losses in income during conflict years. Future conflicts are then less costly on average, which incentivizes agents to postpone fighting. Consequently (and perhaps surprisingly), the anticipation of more intense income shocks has a negative effect on P_{war}.

Changes in the three income statistics discussed above have independent and consistent (either positive or negative) effects on conflict prevalence, as summarized in Table 1. However, the influence of changes in *climate* on all three *income* statistics is complex and driven by the specific shape of the distribution that governs inter-seasonal climate variability. For a realistic distribution of water availability (see *Materials and Methods*), these relations are displayed in Figure 4 (top) and show that changes in water variability (CV_W) elicit different changes in each of the three income statistics, in terms of sign and magnitude. In particular, the income shock frequency response can either be positive or negative, depending on the value of CV_W and the equilibrium threshold for fighting (Figure 4 top, dark blue). In the bottom panel, we decompose the overall changes in conflict probability caused by increased climate variability ($\frac{\partial P_{\text{war}}}{\partial CV_W}$, in red) into its previously described fundamental components (Table 1). Depending on the relative magnitude of the responses, the overall relation between climate variability and conflict may itself be non-monotone (Figure 4 and Figure 3, pink). In particular, the figure shows that the relation can be dominated by agents' response to changes (dashed) in both mean income (gray dashed) and in the intensity of income shocks (i.e. conflict destructivity, light blue dashed). This insight is relevant in the context of recent literature focusing almost exclusively on the effect of changes in the *frequency* of income shocks on conflicts (e.g., 7). Our theoretical results suggest that farmer adaptation to other climate-driven income statistics, such as the *intensity* of income shocks, may be equally important to consider.

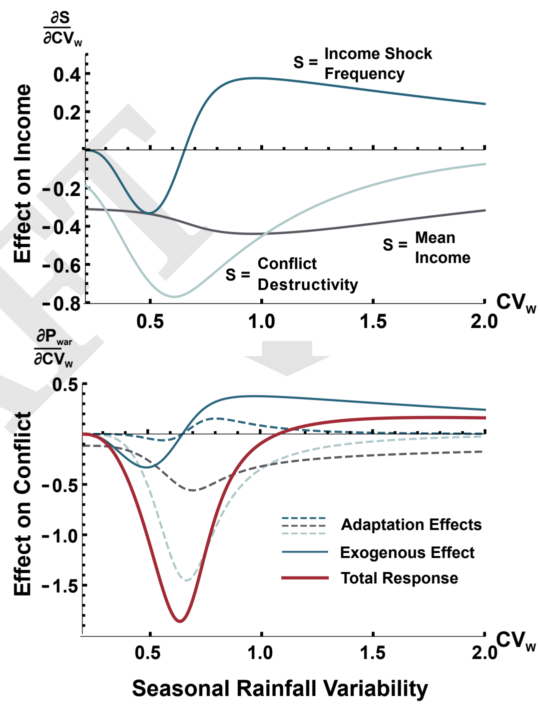

Fig. 4. Components of the climate-income-conflict relationship. *Top*: A marginal increase in rainfall variability affects each of the three governing statistics S of the income distribution: shock frequency $F(\tilde{\theta})$, mean income $E[\theta]$ and conflict destructivity $cE[\theta \mid \theta < \tilde{\theta}]$ (as a measure of shock intensity). The magnitude of each effect is expressed as a partial derivative with respect to CV_W. Variables θ, $\tilde{\theta}$, c and CV_W respectively indicate annual income (a random variable with cumulative density function F), the income threshold for conflict, the opportunity cost parameter and the coefficient of variation of rainfall (see Materials and Method). *Bottom*: Income shock frequency has a direct and axiomatic impact on the probability of conflict $P_{\text{war}} = F(\tilde{\theta})$ (solid blue). However, changes in all three income statistics affect P_{war} because agents adapt by changing their income threshold $\tilde{\theta}$ (dashed lines; see Table 1). The total contribution of these effects determines the non-monotonic response of P_{war} (red), which is also expressed as a partial derivative with respect to CV_W. Parameters (see Materials and Methods): $\pi = 0.523$, $c = 0.9$, $\delta = 0.9$, $\mu_W = W_H = 150$ mm, $\theta_{\max} = 3$.

Relation to Empirical Regularities

Chassang and Padro-i Miquel (10) point to two stylized facts that persistently emerge from the empirical literature on income and conflict: (i) conflicts tend to happen during bad income shocks and (ii) conflicts are more prevalent in low-income countries. At first sight, these regularities may appear at odds with our theoretical predictions suggesting that more intense income shocks and lower average income both *decrease* the propensity for conflict (Table 1).

At a closer look however, stylized fact (i) is a statement about low individual draws from a *given* distribution (horizontal direction in Figure 1), whereas Table 1 concerns sustained shifts in the *distribution* of income (vertical direction in Figure 1). In line with (10), conflict occurs in our model when income falls below a certain threshold. Table 1 is saying that a sustained shift in the distribution towards more extreme droughts causes agents to lower that threshold. In other words, agents fight in *anomalously* dry years for a given distribution, but they think twice about fighting for a given draw if dry years become the 'new normal'.

Regarding the second stylized fact, it is important to point out that the theoretical results in Table 1 concern *marginal* changes in each income statistic, with the two other statistics held constant. Any non-marginal change in distribution will also change the other two statistics because they are themselves determined by the threshold $\tilde{\theta}$. For instance, scaling annual income by a constant factor affects all three statistics in a way that they exactly cancel out (see *Supplementary Information*). This gives rise to the invariance of P_{war} to income scaling noted by Chassang and Padro-i Miquel (10). Similarly, a constant upward *shift* in income results in a *decrease* in P_{war} under reasonable assumptions, as shown in *Supplementary Information.* The reality may be best captured by a combination of the two: Rich countries have more income, and also less volatile income. The model would then indeed predict a lower probability of war.

Practical Implications

The theoretical arguments in this paper are a strong simplification of reality. The economic incentives we discuss represent a small subset of the social, political and historical processes that together give rise to violent conflicts. Nonetheless, they capture important dynamics through which climate-related income shocks may cause rational agents to be amenable to conflict. Theoretical insights from the model have three important implications that can guide policy and empirical research.

First, it is important to distinguish *climate* from *income* variability when examining their implications for conflicts. The non-linear and highly local effect of climate on agricultural income has been highlighted in several studies (e.g., 24, 25) and has a strong qualitative impact on conflict incentives. It emerges from a combination of natural (timing of rain events (26)), technical (crop choice (27)), economic (agricultural prices (28, 29)) and institutional (insurance and regulation (30)) processes that were often put in place precisely to decouple income from climate variability (31). However, as climate variability begins to exceed historical ranges, these hedging mechanisms may become less effective. For instance, a crop that is adapted to a certain precipitation range will be more susceptible to variation at lower rainfall levels due to the increased curvature of the crop function (see Figure 2). This curvature causes a change in *mean* climate to affect the *variability* of income, which propagates to conflict incentives. This stylized example highlights the necessity of a careful empirical characterization of the climate-income relationship to understand implications for conflicts.

Second, theoretical results may inform empirical research that seeks to disentangle opportunity cost motives from other mechanisms that predict conflict during bad years. Alternative hypotheses (see 16) include weakened government structures (caused by a drop in tax revenue), increased (perceived) inequality, climate-induced migration, as well as cognitive and physiological factors that contribute to aggression. All of these competing mechanisms also predict that current conflict is negatively correlated with current income. However, since none of the alternative explanations are forward-looking, they would predict either none, or perhaps a negative, correlation between current conflict and the income in prior years (see discussion in *Supplementary Information*). Opportunity costs are different: If agents update their belief about future incomes in a Bayesian way (some evidence of it is given in Deryugina (32)), a sequence of good years leads agents to expect greater gains from attack, and thus render them *more*, not less, aggressive in subsequent years. This is a testable implication that is unique to the opportunity cost argument and can thus serve to empirically assess its explanatory power.

Finally, caution must be exercised in using micro-economic income shock arguments to interpret empirical analyses of historic data and draw extrapolations for climate change. While the model does suggest a positive correlation between weather anomalies and conflict, it does not support the argument that conflicts will always be more prevalent if these anomalies occur more frequently due to climate change. Rather, the theory suggests a complex, and potentially non-monotonic, relation between climate variability and conflict. This complexity emerges both from non-linear climate to income relationships, and from strategic adaptation by agents to a changing income distribution. By affecting the entire distribution of climate, climate change will effectively define a "new normal". Agents strategically adapt to multiple facets of climate change by adjusting their response to income variability. In doing so, they redefine the very notion of climate anomalies and associated negative income shocks as they pertain to climate-related conflicts.

Materials and Methods

Conflict. Two groups of farmers occupy a common territory over an infinite number of periods (growing seasons). Three productive inputs determine crop yields and agricultural income: land, labor and water availability. Land and labor are equitably distributed between the two players (unequal distribution can be resolved through peaceful bargaining (see 10)) and constant across periods. However, rainfall varies randomly across periods, following a known probability distribution and affecting both groups identically. In each period, both groups observe rainfall and either group can unilaterally launch an attack to seize permanent control of the entire territory. If neither group attacks, peace prevails, all labor is put to productive use, and both groups keep control of their own land and labor. If either side attacks, violence prevails, and both groups divert a fixed share c of labor to armed conflict. In a one-sided attack, the attacker has an offensive advantage and wins with probability $\pi > 0.5$. In a simultaneous attack, both groups win with equal probability. The winner controls the entire territory forever, and the loser exits the game.

The decision to attack in each season t relies on weighing the expected future benefits of victory against the current opportunity cost of conflict. Peace will prevail if the expected returns of peace, $E[\mathcal{P}]$, are larger than the expected returns of launching a surprise attack, $E[\mathcal{W}]$:

$$\underbrace{\overbrace{\theta_t}^{\text{current season}} + \overbrace{\delta\, V^{\mathcal{P}}}^{\text{future seasons}}}_{\text{E}[\mathcal{P}]} > \underbrace{\overbrace{\pi\, 2\theta_t(1-c)}^{\text{current season}} + \overbrace{\pi\delta V^{V}}^{\text{future seasons}}}_{\text{E}[\mathcal{W}]} \qquad [1]$$

where θ_t is an income sampled from the PDF $f(\theta)$; $V^{\mathcal{P}}$ are the future expected returns of peacefully farming one's own land (discounted by a constant factor, δ); π is the probability of victory in a surprise attack; c is the fractional cost of the present season's production devoted to war; and V^V represents the expected returns of victory (discounted by δ). The factor 2 appears because the victorious farmer obtains both plots of land.

A key characteristic of the model is that the current opportunity cost is driven by an individual draw θ, while the future benefits are affected by the entire probability distribution F of income. Groups go to war when current income falls below a threshold $\tilde{\theta}$, which depends on economic parameters and the distribution F. Chassang and Padro-i Miquel (10) show that $V^V = 2E[\theta]/(1-\delta)$, where $E[]$ is the expectation operator. In contrast, $V^{\mathcal{P}}$ is an implicit equation that depends on the attack threshold, $\tilde{\theta}$, defined as the θ at which $E[\mathcal{P}] = E[\mathcal{W}]$ (see *Supplementary Information*). An implicit expression for $\tilde{\theta}$ is found by substituting V^V and $V^{\mathcal{P}}$ into 1, setting $\text{E}[\mathcal{W}] = \text{E}[\mathcal{P}]$, and rearranging:

$$\tilde{\theta} = \frac{\delta}{1-2P(1-c)}\left[(2P-1)\frac{E[\theta]}{1-\delta} + \frac{F(\tilde{\theta})\cdot cE[\theta \mid \theta < \tilde{\theta}]}{1-\delta(1-F(\tilde{\theta}))}\right] \qquad [2]$$

where $F(\tilde{\theta}) = \int_0^{\tilde{\theta}} f(x)\mathrm{d}x$, and $E[\,|\,]$ is the conditional expectation operator. The probability of war in any season is simply $P_{\text{war}} = F(\tilde{\theta})$.

Climate, water availability and crop productivity. We assume that both farmer groups are subject to the same crop productivity (θ_t) governed by seasonal water volume, W [L], normalized by catchment area. We use a model for lumped crop yield potential [M L^{-2}] as a proxy for agricultural income, θ. Water supply is assumed to be the yield-limiting factor (19), allowing us to map $f(\theta)$ directly to the distribution of water supply, $f_W(W)$. Although additional factors such as intraseasonal dry spells are known to affect crop yields , we do not include them in our model since our principal aim is to maintain emphasis on the human decision model, and yields have been shown to be primarily determined by total precipitation . Based on observations reported in (19), we specify a parsimonious boundary function relation for yield, $B(W)$:

$$\theta = \theta_{\max}\cdot\frac{W}{W+W_H}, \qquad [3]$$

where W_H is a half-saturation constant, and $\theta_{\max}$ is the maximum productivity. We assume land to be spatially homogeneous and situated in a watershed sufficiently flat for hydrologic conditions to be driven by vertical rainfall infiltration into the soil layer (33). We assume that water is derived from rainfall, allowing $f_W(W)$ to be approximated using a Gamma distribution (see 18, and *Supplementary Information*). Under these assumptions, an exact expression for $f(\theta)$ is:

$$f(\theta) = \qquad [4]$$
$$\frac{\exp\left(-\frac{\theta}{(\theta_{\max}-\theta)(\mu_W\, W_H^{-1})CV_W^2}\right)\left(\frac{\theta}{(\theta_{\max}-\theta)(\mu_W\, W_H^{-1})CV_W^2}\right)^{\frac{1}{CV_W^2}}}{\frac{\theta}{\theta_{\max}}(\theta_{\max}-\theta)\,\Gamma\left(\frac{1}{CV_W^2}\right)}.$$

where μ_W [L] and CV_W [–] are the mean and coefficient of variation of $f_W(W)$, respectively, and $\Gamma(-)$ is the Gamma function.

Response of P_{war} to Changing Water Resources. We determine the response of $P_{\text{war}} = F(\tilde{\theta})$ to water variability by numerically differentiating $F(\tilde{\theta})$ with respect to CV_W:

$$\frac{\mathrm{d}P_{\text{war}}}{\mathrm{d}CV_W} = \underbrace{\frac{\partial P_{\text{war}}}{\partial CV_W}}_{\text{mechanistic effect}} + \underbrace{\sum_{n=1}^{3}\frac{\partial P_{\text{war}}}{\partial\tilde{\theta}}\cdot\frac{\partial\tilde{\theta}}{\partial S_n}\cdot\frac{\partial S_n}{\partial CV_W}}_{\text{farmer adaptation}} \qquad [5]$$

where $S \in \{E[\theta], F(\tilde{\theta}), E[\theta \mid \theta < \tilde{\theta}]\}$ are the three fundamental statistics that govern $\tilde{\theta}$ (Equation 2). Total sensitivity of P_{war} is partitioned into direct and adaptation effects (following Burke et al. (7), Eq. 5). Changes in $f_W(W)$ alter the probability of an income shock in a given period (direct effect), thereby changing the probability that farmers will attack, $F(\tilde{\theta})$. The direct change to $f(\theta)$ also alters the expected returns from peace, $V^{\mathcal{P}}$ (see *Supplementary Information*). Farmers therefore adapt $\tilde{\theta}$ to a value that again satisfies 1 with equality (adaptation effect).

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