The Impact of Weather Risk on Tenure Security: Evidence from Smallholder Farmers in Tanzania

Lisa Murken *Working Group Leader, Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany; murken@pik-potsdam.de*
Gregor Mager *Doctoral Researcher, Environmental and Development Economics, Weihenstephan-Triesdorf University of Applied Sciences, Straubing, Germany; gregor.mager@tum.de*
Rahel Laudien *Postdoctoral Researcher, Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany; laudien@pik-potsdam.de*
Kati Kraehnert *Professor, Climate Impacts and Adaptation Research Group, Leibniz Institute for Economics Research (RWI), Essen, Germany; Faculty of Management and Economics, Ruhr University Bochum, Germany; Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany; kraehnert@rwi-essen.de*
Christoph Gornott *Professor, Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany; Agroecosystem Analysis and Modelling, University of Kassel, Witzenhausen, Germany; gornott@pik-potsdam.de*

ABSTRACT *We analyze whether exposure to weather risk affects the tenure security of smallholder farmers in rural Tanzania. Drawing on a household panel survey with three waves and high-resolution weather data, our identification strategy exploits exogenous variation in precipitation across time and space. Results from household fixed effects estimations show that exposure to weather risk significantly lowers farmers' perceived tenure security, while it increases land conflicts. Moreover, weather risk influences the likelihood that farmers acquire land certificates. These findings suggest that both land formalization and land dispute resolution mechanisms are needed to cushion the effects of weather risk.* (JEL Q15, Q54)

1. Introduction

Tenure insecurity is a major concern for smallholder farmers globally. In 2020, approximately 121 million people in sub-Saharan Africa feared that they would lose their land or property in the next five years (Prindex 2020). Tenure (in)security is frequently studied in the development literature, which typically analyzes the role of secure tenure for farmers to invest in their land and improve agricultural production (for reviews, see Robinson, Holland, and Naughton-Treves 2014; Lawry et al. 2017; Higgins et al. 2018; Tseng et al. 2021). However, little is known about the determinants of tenure (in)security. The tenure security of smallholder farmers is often presumed to be relatively stable over time and mainly a function of legal characteristics, such as tenure type, presence of a formal land title, and mode of acquisition. The role of weather for tenure security is rarely studied. Understanding the link between weather and tenure security is particularly important with progressing climate change, since weather extremes are set to increase in frequency and intensity, potentially threatening secure land tenure.

This article addresses this gap, providing new empirical evidence on the link between weather risk and the tenure security of smallholder farmers in Tanzania. Specifically, we answer the following questions: Does weather risk affect farmers' perceived tenure security and the occurrence of land conflicts? Does weather risk affect the acquisition of land certificates? Our empirical analysis builds on a household panel survey with three waves, implemented in central Tanzania between 2013 and 2018, which contains detailed information on tenure security, land conflicts, and land certificates. Using geo-referenced information

Land Economics • November 2024 • 100 (4): 668–689
DOI:10.3368/le.100.4.101422-0079R1
ISSN 0023-7639; E-ISSN 1543-8325

Supplementary materials are available online at: https://le.uwpress.org.

on households' location, the household survey data are combined with high-resolution gridded precipitation data (0.05°) and temperature data (0.25°). Our focus is on dry spells and precipitation variability, exploiting exogenous variation in precipitation across time and space. A household fixed effects model is employed to control for unobserved time-invariant heterogeneity across households.

Results show that exposure to dry spells and precipitation variability significantly lowers farmers' perceived tenure security. At the same time, exposure to both types of weather risk increases the risk of experiencing land conflicts. Precipitation variability mainly leads to increased land conflicts between farmers and pastoralists, whereas dry spells mainly increase the risk of land conflicts in the family and with neighbors, companies, and the government. Furthermore, exposure to precipitation variability strongly decreases the likelihood that farmers acquire land certificates, while exposure to dry spells increases the likelihood that farmers acquire land certificates within 1.5 years.

An investigation into potential mechanisms reveals that income fluctuations and changes in family labor dynamics due to weather variations may affect land tenure security. In the aftermath of dry spells or erratic rainfall, households experience reduced agricultural output and income, leading to increased off-farm employment and a reduced on-farm "guard labor" presence among family members. Consequently, this may weaken the household's ability to defend its land rights against external claims.

This article contributes to the literature in four ways. First, we provide novel empirical evidence on how different types of weather risk affect smallholder farmers' land tenure—something that receives little scholarly attention. Exceptions include Kalkuhl, Schwerhoff, and Waha (2020), who study sharecropping as a choice endogenous to climate risk, and Buggle and Durante (2021), who analyze the effects of climate risk on the development of social cooperation. Although a large body of literature examines the effects of extreme weather events on conflict (e.g., Hsiang, Burke, and Miguel 2013; Hsiang and Burke 2014; Burke, Hsiang, and Miguel 2015; Sarsons 2015), little research focuses on land conflicts.

Second, our analysis provides new empirical evidence on the determinants of farmers' tenure security, thus contributing to an under-researched field. We focus on *perceived* tenure security, which is arguably the most relevant dimension of tenure security for farmers' behavior since perceptions are thought to underlie human behavior (Dijksterhuis and Bargh 2001; Jenkins et al. 2018). The small body of existing research on the determinants of perceived tenure security builds on cross-sectional survey data (Yi, Köhlin, and Xu 2014; Ayamga, Yeboah, and Dzanku 2015; Ghebru and Lambrecht 2017; Ghebru and Girmachew 2019), which often do not allow for a causal identification of effects, except for Sipangule (2017). Our use of a detailed household panel survey and a household fixed effects approach allows us to control for unobserved time-constant household characteristics, which is a considerable improvement over cross-sectional analyses of tenure security.

Third, we add to the literature regarding the link between land conflicts and tenure security, which so far mainly considers concerns about land conflicts or expropriation as a measure of tenure insecurity (Jacoby, Li, and Rozelle 2002; Reerink and van Gelder 2010; Linkow 2016) and well-functioning tenure systems as a remedy against land conflicts (Boone 2014). We provide empirical evidence on both experiencing land conflicts and the perception of tenure security of smallholder farmers.

Fourth, we contribute to the debate on land formalization by analyzing how weather risk may incentivize farmers to acquire land certificates. A large body of literature studies the impact of land registration and formalization programs on tenure security, agricultural production, and other development outcomes (Place and Migot-Adholla 1998; Deininger and Chamorro 2004; Deininger and Feder 2009; Holden, Deininger, and Ghebru 2011; Ali, Deininger, and Goldstein 2014; Ali, Deininger, and Duponchel 2017; Kubitza et al. 2018). Yet few studies analyze the determinants of title acquisition, and we are not aware of studies that analyze the link between weather risk and the acquisition of land certificates.

2. Conceptual Framework: Link between Weather Risk and Tenure Security

We analyze the effect of weather risk on tenure security. Various definitions of tenure security are used in empirical research (Arnot, Luckert, and Boxall 2011). Often a distinction is made between de jure tenure security, implying a legal title to land, and de facto tenure security, understood as the actual tenure security as determined by objective factors, such as land ownership and government policies. Van Gelder (2010) extends this to a tri-partite view, adding perceived tenure security, which acknowledges that informal systems can also play an important role. The Food and Agriculture Organization offers one of the most frequently used definitions, framing tenure security as "the certainty that a person's rights to land will be recognized by others and protected in cases of specific challenges" (FAO 2002, 18). This includes components of both de facto and perceived tenure security, which can diverge if an individual's perceived tenure security does not correspond (fully) to the factual threats or enablers of tenure security. Yet a more comprehensive definition of de facto tenure security acknowledges the influence of perceptions and beliefs, as they shape actual security (Sjaastad and Bromley 2000). If enforcement of land laws is inadequate, de jure tenure security may also diverge from de facto tenure security (Platteau 2000).

We focus on perceived tenure security and hypothesize that weather risk may affect it in various ways. In addition, we study the effect of weather risk on land conflicts and land formalization through the acquisition of land certificates. This stems from the understanding that perceived tenure security, land conflicts, and land formalization are intricately linked. On the one hand, farmers' perception of the risk of land conflict (Linkow 2016) or the risk of expropriation (Reerink and van Gelder 2010; Huntington and Shenoy 2021) are commonly used to define tenure security. On the other hand, weak land institutions, unclear land rights, and insecure tenure are often assumed to contribute to conflicts over land (Deininger and Castagnini 2006; Boone 2014, 2017). According to Coasian logic, well-defined land (property) rights reduce transaction costs and lower the risk of conflict (Coase 1960). Land formalization is seen as a way of securing land rights, which is why tenure security is frequently defined in legal terms as having a formal, government-approved claim to land (Robinson and Diop 2022). The evolutionary theory of land rights contends, among others, that scarcity-induced land disputes increase the demand for tenure security and in turn formal land titling (Platteau 1996).

We hypothesize that direct and immediate effects of weather risk on perceived tenure security are unlikely. However, several intermediate channels through which weather risk may affect perceived tenure security are plausible. All are induced by resource scarcity or uncertain agricultural prospects that follow from weather risk. Weather variability lowers agricultural potential, for instance, through decreased water availability for crop production and livestock rearing, and can put agricultural livelihoods at risk, which may ultimately influence perceived tenure security.

First, weather risk may affect perceived tenure security in agricultural settings through a psychological channel. Adverse weather conditions, leading to resource scarcity and diminished agricultural prospects, may increase the perceived threat of losing access to one's land.

Second, weather risk is likely to induce conflicts, which in turn may influence perceived tenure security. The link between weather variability, climate, and conflicts is well established. A large empirical literature documents that weather and climate significantly affect the risk of conflict, which partially runs via agricultural production in rural areas (for reviews and meta-analyses, see Hsiang, Burke, and Miguel 2013; Hsiang and Burke 2014; Koubi 2019). In mixed agro-pastoral settings, dry periods or precipitation variability can spur conflicts around water and fodder access (Butler and Gates 2012), often between pastoralists and agriculturalists (McGuirk and Nunn 2020), which is also observed in Tanzania (Benjaminsen, Maganga, and Abdallah 2009). More generally, weather risk can also foster competition for resources and might put households in vulnerable positions, making them more prone to land conflicts in the family and with outsiders. Further, harsh weather does not always spur new conflicts but may induce latent conflicts to surface (Dell, Jones, and Olken 2014). Adverse weather conditions can, for instance, affect physical boundaries that are used to demarcate land, such as trees and streams. When these are altered or disappear, this can invite conflicts over land.

Third, perceived tenure security may be influenced by weather risk through a reduction in guard labor. As weather risk increases and agricultural production falls, households may have to rely more on off-farm employment. This could increase perceived tenure insecurity if fewer people—especially the household head—are present at the homestead to defend the household's land against outside claims. Economic theory predicts that households react to insecure property rights to land with guard labor, a substitute to productive labor in the agricultural context (Besley and Ghatak 2010). Out-migration is also linked to tenure security, with land registration projects in low- and middle-income countries often—but not always—found to increase out-migration, presumably because land is more secure and does not need to be guarded (Valsecchi 2014).

Fourth, weather-induced resource scarcity may also cause changes in the demand for land certificates. Weather risk may reduce agricultural production and deplete households' financial capital, thus making the acquisition of land certificates more difficult. Households' incentives for acquiring certificates are not well understood and, despite a shift from top-down land reforms in the 1980s and 1990s to more bottom-up and participatory approaches in the early 2000s, land formalization is largely viewed as externally imposed on households (Sjaastad and Cousins 2009). Experimental evidence from Tanzania shows that the costs of acquiring a land certificate play a key role in households' decision to apply for land certificates (Ali et al. 2016). At the same time, land conflicts may influence the demand for land certificates if these certificates are seen as a means of protection against land conflicts.

3. Land Tenure in Tanzania

Since the turn of the new millennium, Tanzania has seen intensifying competition for farmland and a rise in land conflicts (Odgaard 2003; Walwa 2020). In the 1990s, in the wake of a second wave of land reforms across several African countries, Tanzania's tenure system was reformed to recognize existing rights while simultaneously creating an effective land market. Tanzania's land reform of 1999 is considered among the most carefully designed reforms across Africa, striking a balance between protecting vulnerable groups, such as female-headed households, while improving efficiency and business opportunities (Pedersen 2015). However, it is also criticized as a centralistic, bureaucratized, and legalistic reform that commoditized land and opened up the land market for investments and alienation (Boone and Nyeme 2015).

Under the Village Land Act and the Land Act, both enacted in 1999, all land in Tanzania is classified as village land, reserve land, or general land. As of 2019, village land (which also comprises the land smallholder farm households use for farming) makes up almost 70% of all land in Tanzania (African Development Bank 2019). A large part of village land is land held under customary tenure laws, which are protected under the Village Land Act. Such land is directly managed by village authorities or other customary institutions. Reserve land consists of spaces for wildlife and natural parks, and general land is all land not falling under the first two categories; for instance, urban land and land leased by the government (Wily 2003). All land is vested in the president, who has the sole authority and power to transfer land from one category to another (Rwegasira 2012). Yet the regulation of other land matters, such as land allocation and dispute settlement, has been gradually decentralized since mainland Tanzania's independence in 1961. Authority in such matters now lies with village and district authorities. At the same time, customary practices that counteract village authorities are prohibited (Pedersen 2015).

Land titling requires several steps. The Village Land Act allows villages to have their land surveyed and to devise land use plans, which must be endorsed by district councils. Once this is completed, households can apply for Certificates of Customary Rights of Occupancy (CCROs) for their land, which are granted by village land councils (Schreiber 2017). Certificate costs vary but are reported to be high in the absence of systematic land formalization efforts (Aikaeli and Markussen 2022).

Implementing the 1999 land reform and formalization process in Tanzania has been slow (Rubakula, Wang, and Wei 2019; Aikaeli and Markussen 2022) and is among the slowest rollouts in sub-Saharan Africa (World Bank 2018). Since village land councils can issue CCROs autonomously, there is no central registry of all available CCROs, but a nationally integrated land management information system is planned (World Bank 2018). Bureaucracy in issuing land certificates varies across Tanzania, since the villages have authority over issuing CCROs but tend to be relatively homogeneous within regions. Compared with other countries and in contrast to issuing of individual titles, the process of titling communal land in Tanzania has been described as fast, involving few authorities (Notess et al. 2021). By 2017, most villages had mapped their outer boundaries, and about 13% had devised land use plans. Of the approximately 6 million smallholder farm households in Tanzania, an estimated 400,000 had obtained formal land titles as of 2017 (Schreiber 2017). Titling is partially driven by government initiatives, but self-initiated acquisition of land certificates by farmers also occurs. Given the high costs of formal titling in the absence of subsidized programs, households also resort to other forms of informal documentation, which are not issued by the government (Aikaeli and Markussen 2022). In focus-group discussions by researchers of Ardhi University, Tanzania, in part of the survey villages in July 2023, lack of enforcing existing land tenure regulations and land use plans was mentioned as a major issue impeding the proper functioning of land tenure systems in Tanzania.[1]

Land allocation, redistribution, and the misuse of land assigned for a specific purpose are frequent causes of disputes. Conflicts arise between farmers and pastoralists, between neighbors, between farmers and the government, between private companies, and even within households (Greco 2015; Bluwstein et al. 2018; Bergius et al. 2020). In Tanzania, highly mobile pastoralists and sedentary agropastoralist households exist. In some areas, pastoralists have not been allocated sufficient grazing land, leading them to venture into villages or reserve land to feed their livestock, particularly in dry years. This has led to violent clashes and continues to be an issue of high visibility and intense public debate in Tanzanian media and politics (Benjaminsen, Maganga, and Abdallah 2009; Walwa 2020). Land acquisitions by investors—from the private sector and the government—have also sparked discontent and conflict over land (Bélair 2021).

4. Data

Household Panel Survey Data

The database for the empirical analysis is the Trans-SEC household panel survey implemented by Sokoine University of Agriculture and University of Hannover as part of the Trans-SEC project.[2] The Trans-SEC survey collects detailed data on agricultural livelihoods and food security in Tanzania. It was implemented in six villages in two neighboring regions of central Tanzania: semi-arid Dodoma and subhumid Morogoro (Appendix Figure A1). These two regions jointly account for 70%–80% of the farming systems in Tanzania (Graef et al. 2014). The regions and study villages were selected to represent different cropping systems and varying degrees of market access and livestock integration. In each village, 150 households were randomly selected (from a total population of 800–1,500

[1] The focus group discussions were conducted as part of a follow-up project jointly carried out by Ardhi University and PIK. Focus groups were held with farmers and village leaders; the primary discussion topic was the implementation of agroforestry systems in the villages. We are grateful to Luitfred Kissoly and Nelson Ochieng for implementing the focus group discussions.

[2] See http://www.trans-sec.org.

households per village) (Graef et al. 2014; Brüssow et al. 2019). The survey includes three panel waves that were implemented in 2014, 2016, and 2018.

The sample size in the first wave was 899 households, of which 820 and 778 were reinterviewed in the second and third waves, respectively. Our analyses build on a balanced panel of 778 households that were surveyed in all three waves. Sample attrition between the first and third wave was 13.5%. If households that dropped out of the panel survey over time differ systematically in their land tenure security or exposure to conflict, our results may be biased. We conducted various tests to examine the drivers of panel attrition.[3] We concluded from those tests that attrition does not severely bias our estimates.

Households in these regions are smallholder farmers practicing primarily rain-fed agriculture as their main source of living. Livestock rearing is common in both regions but more prevalent in semi-arid Dodoma. Besides income from agricultural production, the survey records income from renting land, receiving remittances, self-employment, wage employment, and the extraction of natural resources. The survey emphasizes agricultural production and records plot-level information regarding land tenure, mode of land acquisition, formal status, main use of land, crop production, soil fertility, and input use in great detail. Maize, millet, sorghum, sunflower, sesame, and groundnuts are the main crops cultivated. The three panel waves cover the main agricultural seasons of 2013, 2016, and 2018 (Appendix Figure A2).[4] In the survey area, the main growing season starts in January, and harvest takes place in April. On average, households have 2.62 plots. Data cleaning (explained in the Appendix) involved removing outliers in plot size, agricultural production, and income.

Our main outcome variables of interest are recorded at the plot level. Since plots are not uniquely identified across waves, we could only match parts of the plot-level sample across the three panel waves.[5] In the balanced sample of households, the sample used in our main analyses, only 57% of plots (3,510 out

[3] Unconditional *t*-tests on differences in means indicate that dropped households do not differ significantly in their perceived tenure security and the reported incidence of land conflicts from households that remained in the panel (Appendix Table A1). Next we run a probit regression on the determinants of the probability of a household being interviewed in all three panel waves, using the same set of control variables as in the baseline model (Appendix Table A2). Tenure security and the experience of land conflicts, the key variables of interest, are not significantly correlated with households being interviewed in all three waves. Few other explanatory variables are statistically significant, and those that are have relatively small effect sizes. An added regressor test points into the same direction (Appendix Table A3): when regressing the experience of land conflicts or households' perceived tenure security on the main set of control variables constructed from wave 1 data, a dummy variable for panel attrition, and interaction terms between the attrition dummy and all control variables, the attrition dummy is not statistically significant at conventional levels in either model. Note, however, that livestock ownership has heterogeneous effects. While for households that stayed in the panel, the ownership of livestock is significantly and negatively correlated with the experience of land conflicts, this relation is significant and positive for households that dropped out of the survey. The effect is no longer significant if we instead employ the number of livestock (Appendix Table A3, columns (2) and (3)). For both outcomes, a likelihood ratio test on the null hypothesis that the interaction terms are jointly zero reveals that the model with interaction terms does not fit significantly better, with a *p*-value of 0.42 in the land conflicts regression and 0.65 in the tenure security regression.

[4] More precisely, data collection took place January–March 2014 (wave 1), November–December 2016 (wave 2), and November–December 2018 (wave 3). The reference period for questions on agricultural production is January–December 2013 (wave 1), September 2015–August 2016 (wave 2), and October 2017–September 2018 (wave 3).

[5] In the survey, plots were not assigned unique identifiers, as the survey implementers did not originally intend to match plots across waves. Instead, survey items were asked at plot level to record agricultural productivity as precisely as possible. Thus, we matched plots for each household based on the following criteria: main use of the plot, size, and mode of acquisition. Specifically, we matched plots if at least two of the three criteria matched across waves. As the plot size was at times difficult to estimate for respondents, we allowed for a divergence of the precise number of up to 25%. If the main use of the plot was homestead in one of the waves, we only considered it a match if this plot was labeled as homestead in all three waves. For the homestead we tolerated larger divergence in plot size across waves, since the homestead plots are usually rather small. For the other possible land uses (e.g., annual crops or permanent crops), we tolerated divergences if the other criterion matched. In some cases, households possessed only one plot in each wave, but only one of the above criteria matched. In these cases, we examined additional characteristics to facilitate plot matching. Such auxiliary information was derived from the plot's position in the plot roster used in the questionnaire and the tenure status.

of 6,139) could be matched with confidence across all three waves. Information on the year of acquisition for all 6,139 plots reveals that 7% of plots in the sample were obtained after 2013. We conducted attrition tests to examine the factors leading to plots not matching over time.[6]

Because of this rather high number of unmatched plots, we opted for using household-level variables in our main analysis and provide further analyses at the plot level as robustness test. Our choice to focus on household-level outcomes is also motivated by our interest in households' overall landholdings and tenure situation. One potential threat to our identification is that households sell or lease out land in response to weather influences. Although we cannot completely rule out such effects, only a few households reported selling land in response to a shock (e.g., weather shock, price shocks) (13, 4, and 10 households in the first, second, and third panel waves, respectively).

Another potential threat to our identification could stem from inappropriate aggregation from the plot to the household level. In the study villages, almost all plots directly border the homestead. Homesteads are mostly scattered across the villages, with a slightly higher concentration along roads and village centers. Each village is divided into 9–15 subvillages. The survey records the minutes needed to walk from the homestead to each plot. The median for this variable is zero minutes in all three waves, with average walking distances of 5.3–6.6 minutes per wave (Appendix Table A7). Even when considering means, this translates into an average distance between homestead and plots of approximately 0.5 km, depending on walking pace. The precipitation variables employed in our model have a resolution of approximately 5 km. Overall, given the proximity of plots to homesteads and the decentralized organization of agricultural villages in the sample, we are confident that the aggregation of the dependent variables from plot level to household level does not unduly bias the results.

The first outcome variable is perceived tenure security (see Table 1 for the full list of variables used and their definitions). For each plot, the survey records the perceived tenure security on a four-point ordinal scale (1 = not tenure secure at all; 2 = somehow tenure secure; 3 = almost tenure secure; 4 = very tenure

Table 1
Description of Key Variables

Variable	Description
Perceived tenure security	Household owns at least one plot that it perceives as very tenure secure
Land conflict	Household experienced a land conflict in the previous 12 months
New land certificate	Household acquired a new land certificate for a plot since the last panel wave or newly acquired a plot with a land certificate
Dry spell	Number of times a dry spell of 15 consecutive dry days (CDD15) occurred in the previous growing season, with each day < 0.5 mm precipitation
Precipitation CV	Coefficient of variation of the daily precipitation sum in the previous growing season
Median temperature	Median of the daily mean temperature in the previous growing season
Agricultural production	Crop production in kg / ha in the previous season
Total net income	Net annual household income, adjusted for purchasing power parity and converted to 2011 US$
Net wage income	Net annual wage income, adjusted for purchasing power parity and converted to 2011 US$
Wage employment	At least one household member was employed as wage laborer in the year preceding the interview

[6]Unconditional *t*-tests on the equality of means shows that matched and unmatched plots do not differ significantly in their perceived tenure security and reported incidence of land conflicts (Appendix Table A4). However, they are significantly different in their size; plots that cannot be matched over time are larger on average. There is also a slight difference with regard to land certificates attached to plots, with matched plots being more likely to be certified. As for the household-level attrition analysis, we run a probit regression on the determinants of plots being matched over all three survey waves (Appendix Table A5). Land certificates, livestock ownership, and the plot size are significantly correlated with plots being matched over time, but with rather small effect sizes. An added regressor test (Appendix Table A6) reveals that the attrition dummy is statistically significant only in the tenure security model. The coefficient is positive and sizable, potentially explaining the smaller weather effect observed in the plot-level analysis compared with the household-level analysis (Appendix Table A14).

secure). In the following, we only consider the fourth category (very tenure secure) for two reasons. First, our interest is in understanding the determinants of tenure security, compared with tenure insecurity. Second, we consider the highest and lowest category of the tenure security scale to be more accurately measured. We aggregate tenure security to the household level by creating a dummy variable taking the value equal to one if a household owns at least one plot it considers very tenure secure. The mean of this indicator variable increases from 0.36 in 2013 to 0.86 in 2018 (Table 2).

The second outcome variable is an indicator variable taking the value equal to one if a household self-reports having experienced any land conflicts in the 12-month reference period before each panel wave.[7] The survey records different types of conflicts around land, including conflicts with neighbors, pastoralists, family, the government, and private companies. Few households report experiencing several types of conflict. The incidence of land conflicts remained relatively stable over time, with about 10% of sample households reporting conflicts in each wave. Overall, 24% of households reported experiencing any type of land conflict at least once. Figure 1 shows how the frequency of specific types of land conflicts changed over time. Notably, land conflicts with neighbors decreased and conflicts with pastoralists increased over time, while all other conflict types remained relatively stable.

As the third outcome, we consider if households obtained a land certificate since the previous panel wave. We constructed a dummy variable that takes the value equal to one if household acquired a certificate for an existing plot or bought a new plot with a land certificate. A certificate does not necessarily mean a formal land title obtained from the government; it can also be other forms of written documentation commonly used in the village. Because our focus is on the change in land certificates over time, the sample for this analysis is restricted to the second and third waves.

[7] Unfortunately, no information was recorded on the intensity of the conflict. However, some households reported crop losses due to livestock intrusion onto their land.

Table 2 presents summary statistics by wave for the dependent variables, main explanatory variables, control variables, and channels. While characteristics such as household size, average farm size, and the number of plots farmed remain relatively stable over time, notable increases are observed in livestock ownership, agricultural production, and—albeit at a lower rate—total net income. The moderate increase in total net income despite the considerable rise in agricultural production can be explained by price dynamics. For instance, the price of maize in 2018 was 19% lower compared with 2016, possibly due to increased maize supply.

Weather Data

We focus on two weather indicators. The first is the occurrence of dry spells, defined as 15 or more consecutive dry days (CDD15). Prolonged dry periods over several successive days are detrimental to crops and agricultural livelihoods, making it a suitable variable in studies that examine the effects of weather on crop growth (Schlenker and Roberts 2009; Laudien et al. 2020). Specifically, CDD15 is defined here as the number of times a dry spell of 15 or more days occurred during the previous growing season, with a dry day defined as a day with less than 0.5 mm precipitation. The previous growing season refers to the growing seasons of 2013, 2016, and 2018 that began 9–12 months before each panel wave was implemented.

The second weather measure is precipitation variability, which we proxy with the coefficient of variation of the daily precipitation sum (precipitation CV). Precipitation variability is considered a main source of risk for agriculture (Aufhammer, Ramanathan, and Vincent 2012; Kalkuhl, Schwerhoff, and Waha 2020). Following Kalkuhl, Schwerhoff, and Waha (2020), we use the CV of precipitation and not the standard deviation, since the CV is scale-invariant.

In addition, median temperature during the previous crop-growing season is used as control in all specifications, since precipitation and temperature are highly correlated.

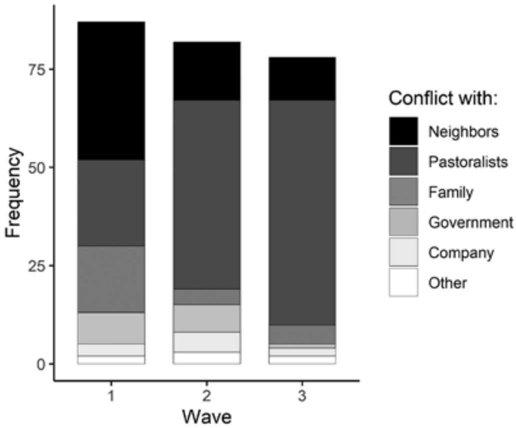
The precipitation measures are calculated from the Climate Hazards group InfraRed

Table 2
Summary Statistics for Key Variables

Variable	Mean	SD	Min.	Max.	*N*
Dependent variables					
Perceived tenure security (wave 1)	0.36	0.48	0	1	763
Perceived tenure security (wave 2)	0.53	0.50	0	1	760
Perceived tenure security (wave 3)	0.86	0.35	0	1	777
Land conflict (wave 1)	0.10	0.30	0	1	741
Land conflict (wave 2)	0.09	0.29	0	1	763
Land conflict (wave 3)	0.09	0.29	0	1	773
Pastoral land conflict (wave 1)	0.03	0.16	0	1	741
Pastoral land conflict (wave 2)	0.06	0.24	0	1	763
Pastoral land conflict (wave 3)	0.07	0.26	0	1	773
Other land conflict (wave 1)	0.07	0.26	0	1	741
Other land conflict (wave 2)	0.04	0.18	0	1	763
Other land conflict (wave 3)	0.02	0.15	0	1	773
New land certificate (wave 2)	0.02	0.14	0	1	766
New land certificate (wave 3)	0.14	0.35	0	1	766
Main explanatory variables					
Dry spell (wave 1)	0.19	0.39	0	1	778
Dry spell (wave 2)	0.41	0.49	0	1	778
Dry spell (wave 3)	1.45	0.50	0	2	778
Precipitation CV (wave 1)	2.02	0.17	1.67	2.31	778
Precipitation CV (wave 2)	1.74	0.16	1.47	2.03	778
Precipitation CV (wave 3)	1.54	0.12	1.35	1.86	778
Weather controls					
Median temperature (wave 1)	24.95	0.69	22.69	25.65	778
Median temperature (wave 2)	24.84	0.70	22.90	25.61	778
Median temperature (wave 3)	23.66	0.74	22.02	24.46	778
Household and farm controls					
Household size (wave 1)	4.91	2.26	1	18	778
Household size (wave 2)	5.28	2.33	1	19	778
Household size (wave 3)	5.37	2.32	1	15	778
Household owns livestock (wave 1)	0.67	0.47	0	1	778
Household owns livestock (wave 2)	0.82	0.39	0	1	778
Household owns livestock (wave 3)	0.82	0.39	0	1	778
Farm size (in ha) (wave 1)	1.60	1.03	0.00	6.07	770
Farm size (in ha) (wave 2)	1.69	1.03	0.02	6.27	771
Farm size (in ha) (wave 3)	1.51	0.92	0.002	6.18	777
Number of plots (wave 1)	2.59	1.16	1	7	770
Number of plots (wave 2)	2.45	1.05	1	7	766
Number of plots (wave 3)	2.82	1.24	1	7	777
Main channels					
Agricultural production (kg/ha) (wave 1)	1,643.55	2,155.63	0.00	14,645.78	739
Agricultural production (kg/ha) (wave 2)	1,647.68	1,849.42	0.00	11,627.17	752
Agricultural production (kg/ha) (wave 3)	3,079.35	4,323.61	204.99	33,286.53	773
Total net income (wave 1)	1,499.74	1,766.98	–584.70	10,306.70	778
Total net income (wave 2)	1,692.99	1,995.52	–235.69	11,821.62	778
Total net income (wave 3)	2,137.04	2,188.23	–252.26	11,385.66	778
Net wage income (wave 1)	276.14	1,086.49	0.00	17,060.92	778
Net wage income (wave 2)	138.00	386.48	0.00	7,056	778
Net wage income (wave 3)	224.10	627.45	0.00	10,277	778
Wage employment (wave 1)	0.35	0.48	0	1	778
Wage employment (wave 2)	0.42	0.49	0	1	778
Wage employment (wave 3)	0.39	0.49	0	1	777

Sources: Trans-SEC household panel survey (waves 1–3), CHIRPS (precipitation), and ERA5 (temperature).
Note: The balanced sample comprises 778 households surveyed in all three waves. For some households, information is missing for some variables.

Figure 1
Number of Households Experiencing Different Types of Land Conflict, by Wave



Source: Trans-SEC household panel survey (waves 1–3).

Precipitation with Stations (CHIRPS) precipitation dataset (Funk et al. 2015), and the temperature measure is calculated from ERA5 (Copernicus Climate Change Service 2017). CHIRPS has a resolution of 0.05° × 0.05° (approximately 5 × 5 km), which leads to 24 unique data points for the study area. CHIRPS is a state-of-the-art weather data product that blends weather station data with satellite data and provides reliable precipitation information for East Africa (Dinku et al. 2018). The resolution of ERA5 is 0.25° × 0.25°, giving six unique data points for the study region, one per village. The weather data are matched with the panel survey data, using the georeferenced location of households for matching the precipitation data.[8]

5. Empirical Framework

We first examine if weather risk affects farmers' perceived tenure security. We estimate a household fixed effects model of the following structural form:

$$S_{it} = \beta_1 weather\ risk_{it} + \delta X_{it} + \theta temp_{it} + \alpha_i + \pi + \gamma_t + \varepsilon_{it}, \quad [1]$$

where the perceived tenure security S of household i at time t is estimated as a function of $weather\ risk_{it}$ (the occurrence of dry spells or precipitation variability) in the previous growing season, a vector of time-varying household-level controls X, median temperature (*temp*) in the previous growing season, household fixed effects α_i, enumerator fixed effects π, wave fixed effects γ_t, and an error term ε_{it} that contains unobserved and time-varying heterogeneity as well as a random individual error component. Household fixed effects capture any observed or unobserved time-invariant heterogeneity across households. Enumerator fixed effects account for possible effects stemming from assigning enumerators to sample households.[9] Wave fixed effects control for any events that affect all households in a given year in similar ways. The main coefficient of interest is β_1, which measures the effect of weather risk on perceived tenure security. Weather risk is defined either as dry spells or as precipitation variability. Since temperature and precipitation are correlated, we control for median temperature in all specifications, as suggested in the climate econometrics literature (Auffhammer et al. 2013). We chose to cluster at the level of the precipitation data points, analogously to the literature that clusters at the level of treatment assignment in (quasi) experimental settings (Abadie et al. 2022).[10] Equation [1] is

[8] For 50 households, no GPS data are available. For these cases, we draw on information on the subvillage location and impute precipitation and temperature over the respective subvillage (out of a total of 48 subvillages).

[9] Across the three waves, 68 enumerators conducted the survey interviews, with most only joining the team during one panel wave. Auxiliary regressions revealed that enumerators were systematically assigned to sample households in which the head exhibited similar demographic characteristics. When removing enumerator fixed effects, the effects of weather risk on land conflicts and the acquisition of a land certificate remain qualitatively similar to baseline estimations, while the effects of weather risk are no longer statistically significant for the tenure security outcome. This can potentially be explained by different levels of subjectivity and sensitivity inherent in those outcomes. During survey interviews, the role of enumerators may be more influential when asking respondents about their perceived tenure security compared with asking respondents about the possession of land certificates or the experience of land conflicts. F-tests comparing models with and without enumerator fixed effects support the inclusion of enumerator fixed effects.

[10] Clustering standard errors at the household or village level yields only minimally larger standard errors. All main effects remain significant at least at the 10% level, except for the effect of precipitation variability on the acquisition of a new land certificate.

estimated with ordinary least squares (OLS) using a linear probability model, since logistic or probit regression in panels with few time periods and many cross-sectional units suffers from incidental parameter bias (Wooldridge 2013).

Time-varying household-level controls include household size, which may influence both tenure security and land conflicts, as a larger household can pose a threat for the claims of individual members. This may result in more frequent intrafamily land disputes. At the same time, a large household may find it easier to stand up to outside claims. The size of total farmland and farm fragmentation affects how easily a household can control its land holdings. Livestock ownership indicates asset wealth and socioeconomic status, which may protect from or attract land conflicts. Summary statistics of the complete set of control variables are shown in Table 2.

In the most parsimonious model, we do not include any household-level controls to estimate the full effect of the respective weather risk variable on tenure security and avoid overcontrolling. We then add time-varying household-level controls. All controls constitute potential intermediate outcomes that may be affected by weather conditions, thus possibly absorbing part of the effect on the main outcomes of interest. The estimated coefficients of weather risk in the full model with controls thus indicate the direct (not full) effect size. However, owing to the likely endogeneity of most time-varying controls to the land tenure outcomes of interest, the coefficients can no longer be interpreted causally in the full model.

To estimate the effect of weather risk on land conflict, we follow a similar approach as in equation [1], using the same controls and fixed effects.

The second research question examines if exposure to weather risk increases the likelihood that smallholder farmers acquire a land certificate. We estimate the following equation:

$$new\ title_{it} = \beta_2 weather\ risk_{it-1} + \delta X_{it} + \theta temp_{it} + \alpha_i + \pi + \gamma_t + \varepsilon_{it}. \qquad [2]$$

The outcome variable of interest is the acquisition of a new land certificate either for an existing plot or for a newly acquired plot since the last panel wave. The measures for weather risk, *weather risk*$_{it-1}$, are now lagged by one year (i.e., dry spells and precipitation CV two growing seasons before each interview). This accounts for the fact that land documentation often requires some time, making a certain time lag in the response likely. Although land documentation can be lengthy, certificates can be obtained within a couple of months in the study region, since all villages in the sample have land use plans in place and their outer village boundaries are mapped. Informal written land documentation can be obtained even faster. The model is estimated for waves 2 and 3. The same sets of control variables and fixed effects are used as in equation [1]. In addition, we control for the current value of the weather risk measure, *weather risk*$_{it}$.

6. Results and Discussion

Weather Effects on Perceived Tenure Security and Land Conflicts

Table 3 presents regression results for equation [1], with the outcome variable being households' perceived tenure security in the previous growing season. Column (1) shows the full effect of dry spells on perceived tenure security. Exposure to dry spells during the growing season decreases households' perceived tenure security. The estimated coefficient of dry spells is significant at the 1% level, and the result holds when controlling for time-varying household-level characteristics (column (2)). In columns (3) and (4), we test the effect of the precipitation CV on perceived tenure security. We find a highly significant effect on perceived tenure security. Households exposed to high precipitation variability report considerably lower perceived tenure security. When again including the full set of controls in column (4), the coefficient of the precipitation CV on tenure security remains at similar levels.

Next we analyze the effect of weather risk on land conflicts. Table 4 shows the results for all land conflicts combined (columns (1)–(4)),

Table 3
Effects of Weather on Perceived Tenure Security (OLS)

	Perceived Tenure Security			
Dependent Variable	(1)	(2)	(3)	(4)
Dry spell	–0.05***	–0.05***		
	(0.01)	(0.01)		
Precipitation CV			–0.23***	–0.23***
			(0.05)	(0.06)
Median temperature	–0.20	–0.20	–0.06	–0.06
	(0.13)	(0.13)	(0.08)	(0.08)
Household controls	No	Yes	No	Yes
Household fixed effects	Yes	Yes	Yes	Yes
Enumerator fixed effects	Yes	Yes	Yes	Yes
Wave fixed effects	Yes	Yes	Yes	Yes
R-squared	0.79	0.79	0.79	0.79
N	2,288	2,288	2,288	2,288

Sources: Trans-SEC household panel survey (waves 1–3), CHIRPS (precipitation), and ERA5 (temperature).
Note: Standard errors are clustered at the level of the precipitation data points.
* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Table 4
Effects of Weather on Land Conflict (OLS)

	Any Land Conflict				Conflicts with Pastoralists		Other Land Conflicts	
Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dry spell	0.05***	0.05***			0.02*		0.03***	
	(0.01)	(0.01)			(0.01)		(0.01)	
Precipitation CV			0.16***	0.16***		0.10***		0.06***
			(0.02)	(0.03)		(0.02)		(0.02)
Median temperature	–0.13***	–0.13***	–0.25***	–0.25***	–0.11**	–0.17**	–0.02	–0.08***
	(0.04)	(0.04)	(0.07)	(0.08)	(0.04)	(0.07)	(0.02)	(0.02)
Household controls	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enumerator fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.52	0.52	0.52	0.52	0.55	0.56	0.46	0.45
N	2,266	2,266	2,266	2,266	2,266	2,266	2,266	2,266

Sources: Trans-SEC household panel survey (waves 1–3), CHIRPS (precipitation), and ERA5 (temperature).
Note: Standard errors are clustered at the level of the precipitation data points.
* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

conflicts with pastoralists (columns (5) and (6)), and other land conflicts (columns (7) and (8)) (i.e., conflict parties other than pastoralists). Columns (1)–(4) show strong positive effects of dry spells and the precipitation CV on the experience of land conflicts in the baseline model and when including household controls. In other words, households are considerably more likely to experience land conflicts after exposure to weather risk. When differentiating between conflicts with pastoralists and other land conflicts, the coefficient estimates indicate that the effect of precipitation variability can mainly be explained with increased conflicts between farmers and pastoralists, while the effect of dry spells on land conflicts is mainly driven by land conflicts other than with pastoralists.

Consequences of Weather Risk: Acquisition of Land Certificates

Table 5 shows the results for equation [2], obtained with OLS. Columns (1)–(3) present the effect of dry spells on either the acquisition of a new land certificate for an existing plot or

Table 5
Effects of Weather on the Acquisition of Land Certificates (OLS)

	New Land Certificate					
Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)
Dry spell (lag 1)	0.04***	0.03***	0.03***			
	(0.01)	(0.01)	(0.01)			
Dry spell		−0.02	−0.01			
		(0.02)	(0.02)			
Precipitation CV (lag 1)				−0.06*	−0.21***	−0.16**
				(0.03)	(0.05)	(0.06)
Precipitation CV					−0.27***	−0.22**
					(0.08)	(0.09)
Median temperature	0.13***	0.06	0.07	0.14***	−0.02	0.01
	(0.04)	(0.10)	(0.08)	(0.04)	(0.04)	(0.05)
Household controls	No	No	Yes	No	No	Yes
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Enumerator fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Wave fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.66	0.66	0.68	0.66	0.67	0.68
N	1,521	1,521	1,516	1,521	1,521	1,516

Sources: Trans-SEC household panel survey (waves 1–3), CHIRPS (precipitation), and ERA5 (temperature).
Note: Standard errors are clustered at the level of the precipitation data points.
* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

the acquisition of a new plot with a certificate. Since obtaining a new land certificate can take some months in the study area, we expect effects to materialize with a time lag. Thus, the first lag of the respective weather variable is the relevant measure. Column (1) shows the results when only including lagged dry spells, column (2) also controls for dry spells occurring in the current period, and column (3) includes household controls. In all three specifications, exposure to dry spells occurring about 1.5 years before the survey interview increases the likelihood of acquiring a land certificate. In contrast, the results presented in columns (4)–(6), again using a stepwise approach, indicate that households exposed to precipitation variability about 1.5 years before the survey interview are considerably less likely to acquire a new land certificate. This result is in line with the large negative effects found of precipitation variability on tenure security (Table 3) and the positive influence on land conflicts (Table 4).

The positive effect of dry spells could suggest that farmers view the acquisition of land certificates as a means of protecting themselves against future land disputes. A potential explanation for the differential effects of both weather risk measures on land certificate acquisition could lie in the type of land conflict that is influenced by the respective weather event. Precipitation variability is correlated with conflicts between farmers and pastoralists, where land certificates cannot protect farmers from pastoralists' infringements on their land. On the contrary, conflicts with family members, neighbors, the government, or outside companies may be easier to address with land certificates.

Potential Impact Channels from Weather to Land Tenure

We examine potential channels from weather risk to perceived tenure security, land conflicts, and land certificate acquisitions. First, we analyze if weather risk translates into changes in agricultural production. Columns (1) and (2) in Table 6 present results of an OLS regression of dry spells and the precipitation CV, respectively, on agricultural production (measured in kg/ha). We use the inverse hyperbolic sine transformation to transform the outcome variable to account for the highly skewed distribution. The inverse hyperbolic sine transformation has the advantage of handling zero values, in contrast to the log transformation. Results show that dry spells and higher levels

Table 6
Potential Weather Impact Channel (OLS)

	Agricultural Production (kg/ha) (Inverse Hyperbolic Sine)		Net Household Income (Inverse Hyperbolic Sine)		Net Wage Income (Inverse Hyperbolic Sine)		Wage Employment	
Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dry spell (lag 1)	−0.11**		0.12		0.22		0.03	
	(0.05)		(0.08)		(0.16)		(0.02)	
Dry spell	−0.45***		−0.18***		0.14 *		0.02**	
	(0.02)		(0.06)		(0.07)		(0.01)	
Precipitation CV (lag 1)		−0.25		0.43		0.84**		0.14
		(0.24)		(0.54)		(0.32)		(0.09)
Precipitation CV		−1.30***		−0.94***		0.88***		0.13***
		(0.08)		(0.30)		(0.26)		(0.04)
Median temperature	−1.02	−0.08	−0.33	0.34	2.41***	2.16***	0.34***	0.30***
	(0.84)	(0.62)	(0.38)	(0.31)	(0.65)	(0.53)	(0.09)	(0.07)
Household controls	No	No	No	No	No	No	No	No
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enumerator fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.58	0.57	0.39	0.40	0.58	0.58	0.58	0.58
N	2,252	2,252	2,322	2,322	2,322	2,322	2,321	2,321

Sources: Trans-SEC household panel survey (waves 1–3), CHIRPS (precipitation), and ERA5 (temperature).
Note: Standard errors are clustered at the level of the precipitation data points.
* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

of the precipitation CV in the current season strongly decrease household's agricultural production, with both coefficients significant at the 1% level. Effects are persistent for dry spells occurring 1.5 years before the survey interview but not for the lagged precipitation CV. The point estimates in column (2) (−1.30) suggest a reduction in agricultural production of approximately 2.3% following a 1% increase in precipitation variability.

The drop in agricultural production after experiencing weather risk in the current growing season translates into significant decreases in net household income, which is again transformed using the inverse hyperbolic sine transformation (Table 6, columns (3) and (4)). This is in line with a solid body of evidence documenting weather effects on income (Dell, Jones, and Olken 2012, 2014; Kotz, Levermann, and Wenz 2022). Effects on net income are not persistent over time, with the first lags of the weather risk variables being not significant at conventional levels. Part of the negative income shock following weather risk is offset by increased wage income (columns (5) and (6)) due to increased wage employment (columns (7) and (8)), which points to (partly) effective income smoothing strategies.

Regarding perceived tenure security: these effects on the households' economic situation can point to a potential mechanism related to guard labor. The increases in wage employment following weather risk suggest that households respond to weather risk with less labor used for protecting their land, which could decrease perceived tenure security. At the same time, such reduced presence on the land can make the household more exposed to conflicts.

The negative income shock could further exacerbate tenure insecurity, as it makes households more vulnerable to outside land claims and reduces their ability to apply for (costly) land certificates. Ali et al. (2016) show that income plays an important role in the acquisition of land certificates, although other studies do not find a significant relation between income and tenure security (Yi, Köhlin, and Xu 2014; Sipangule 2017).

Robustness Tests

We conduct a series of robustness tests to assess the reliability of our findings. The tests are split into two parts: tests at the household level and tests on perceived tenure security, land conflicts, and land certificate acquisitions at the plot level.

At the household level, we employ an alternative definition of the main outcome variable, perceived tenure security, as the robustness test. Instead of using an indicator variable, we calculate the share of farmland considered very tenure secure by households (see summary statistics in Appendix Table A8). Results, shown in Appendix Table A9, are very similar to baseline results. Second, we use an alternative definition of tenure security that combines the third and fourth category (almost tenure secure and very tenure secure) of the survey item from which the main outcome is constructed. We define an indicator variable taking the value equal to one if a household holds at least one plot it considers almost tenure secure or very tenure secure and a variable representing the share of farmland perceived as almost tenure secure or very tenure secure (Appendix Table A10). Results are very similar to the baseline model when using the share variable but not when using the indicator variable. This may be explained with the fact that by the time of the third panel wave, almost all households farmed at least one plot respondents felt either almost or very secure about, thus eliminating much of the variation (Appendix Table A8).

Note that in the baseline model, we control for median daily temperature in the previous growing season, which correlates with precipitation. Next we test the sensitivity of our findings to using an alternative measure of temperature, maximum daily temperature, which is more likely to have an immediate effect on crops (except for its interaction with precipitation). Appendix Tables A11–A13 show results with maximum daily temperature instead of median daily temperature as the control variable. Appendix Table A11 shows results for the effect of dry spells and precipitation variability on perceived tenure security. The signs of the main effects of interest remain the same as in the baseline models, although effect sizes are considerably smaller, and the estimated coefficients for precipitation variability are no longer statistically significant at conventional levels. Appendix Table A12 shows results for the occurrence of land conflicts. The estimated coefficients of dry spell and precipitation variability are of comparable magnitude and have similar significance levels as the baseline results. Last, in Appendix Table A13, we show results for the effect of dry spells and precipitation variability with a one-year time lag on the uptake of land certificates. Again, the size of the estimated effects of dry spell and precipitation variability is smaller than in the baseline results and partly at lower levels of significance. Taken together, we interpret those results as evidence that findings are robust to the exact definition of temperature, an important control variable.

Threats to the validity of our findings could also arise from inappropriate aggregation of land tenure variables to the household level. In section 4, we explain our motivation to study tenure security primarily at the household level. We now study drivers of tenure security at the plotlevel and compare this with the household-level findings by using the matched panel of plots (3,510 out of 6,139) to repeat some of the main analyses at the plot level. We estimate equations [1] and [2] without household-level controls but with plot-level fixed effects. Outcome variables are defined at the plot level, namely an indicator variable taking the value equal to one if a plot is considered very tenure secure, an indicator variable for the experience of a land conflict on the plot and the first difference of a land certificate on a plot. The results generally confirm the household-level results but with two important differences: the negative effect of dry spells on perceived tenure security is weaker and the precipitation CV does not have a significant impact on the acquisition of new land certificates. The first difference can potentially be explained with plot-level attrition effects and changes in the plot sample due to new plot acquisitions in between waves. The second difference may be attributable to the fact that the plot-level analysis cannot account for newly acquired plots with land certificates. Unconditional *t*-tests on the difference in means indicate that matched plots have a smaller average size compared with unmatched plots and are more likely to be documented with a land certificate. Given the high number of unmatched plots, the plot-level analysis needs to be interpreted carefully, but it generally confirms the results obtained at the household level.

Implications for Land Policies and Programs

Our results underscore the importance of better understanding short-term influences on tenure security to design appropriate and well-targeted land tenure interventions. This may entail establishing or improving accessible and well-functioning dispute resolution mechanisms for land conflicts, particularly in areas that are affected by weather risk, to alleviate effects of extreme weather on households' land tenure. In Tanzania, specific land tribunals are designated at the ward and district levels, with the High Court Land Division and the Court of Appeal forming the highest instance at national level (Rwegasira 2012). However, evidence shows that this system is overburdened and prone to corruption (Massay 2013; Rubakula, Wang, and Wei 2019).

Our results suggest that the policy response to land conflicts and tenure insecurity should consider the type of weather risk households face in a given region, as this may influence which response—notably land formalization or the improvement of land dispute resolution—is most appropriate. The role of weather risk for tenure security is particularly concerning given the climate change context: with increasing climate change, dry spells and erratic precipitation are expected to become more likely (Kendon et al. 2019), which could result in higher tenure insecurity and more frequent land conflicts in the future.

Further, our results shed light on the importance of access to land formalization. While several studies report negative side effects of land formalization projects on smallholder farmers (for reviews, see Sjaastad and Cousins 2009; Lawry et al. 2017), our results evidence that some farmers seek land certificates to protect themselves against previously experienced weather-driven land conflicts. However, land certificates only offer limited protection for conflicts between farmers and pastoralists who do not threaten ownership claims to land but infringe on land to graze their herds. Such conflicts are driven by precipitation variability, which requires other policy solutions for farmers (and pastoralists) affected by such conflicts. Potential solutions encompass enhanced mediation mechanisms to address conflicts between farmers and pastoralists as well as proactive programs designed to enforce extant regulations governing resource access for both groups. This includes clear demarcation of land boundaries, land use plans, and formal acknowledgment of the resource rights for each group.

Generally, land certificates are not equally accessible for all socioeconomic groups. Marginalized social groups may find it more difficult to gain access to certificates, while certificates are of little help against powerful and well-organized interests (e.g., the state). The president has considerable power over land in Tanzania. In the past, even formal land certificates have not always protected rural communities from expropriation.[11] In addition, the growing formalization of land tenure frequently gives rise to intrahousehold land disputes, often resulting from exclusionary practices disproportionately affecting women and younger men (Odgaard 2005). In African countries, land ownership and control are typically characterized by significant inequalities across sociodemographic groups, particularly along gender lines. However, accurately quantifying the extent of these disparities remains a challenge (Doss et al. 2015). In the Trans-SEC household survey, the survey item on land tenure in almost all cases was reported by household heads. Hence, the data likely overlook intrahousehold disputes over land that would have been reported by other members.

[11] In Tanzania, all land is vested in the president, which means it cannot formally be owned by farmers. As such, the president has considerable power over land and can for instance transfer land from one category to another (village land, reserve land, general land), which also influences the way the land is governed and the purposes it can be used for. The state can obtain land for public purposes (e.g., infrastructure development). In theory, if the state wants to acquire land for public purposes, it needs to notify and consult the affected landowners and determine and pay a just and fair compensation based on the market value of the land. In the case of customary land tenure, a consultative process with the community needs to be held. However, in practice, the implementation of these regulations varies.

7. Conclusion

We provide new empirical evidence on the impact of weather risk on farming households' perceived tenure security, land conflicts, and acquisition of land certificates. Our analysis builds on a household panel survey implemented in rural Tanzania between 2013 and 2018 that included detailed information on farmers' tenure security. We use the occurrence of dry spells and the coefficient of variation of precipitation in the previous crop-growing season as measures of weather risk to study how weather affects tenure security.

Our results contribute to the literature in several ways. First, we provide novel evidence on the effect of weather on land tenure, which is so far mainly studied in cross-sectional settings (Kalkuhl, Schwerhoff, and Waha 2020). We show that exposure to weather risk decreases perceived tenure security, is associated with increased land conflicts, and even influences interest in land certificates. While dry spells and precipitation variability increase the exposure to land conflicts, the types of land conflict vary. Precipitation variability mainly increases exposure to land conflicts between farmers and pastoralists, while dry spells predominantly increase all other types of land conflicts, such as within the family or with neighbors.

Our second main finding is that tenure security is dynamic over time and influenced not just by plot-level characteristics but also by larger-scale weather risk.

Third, we add to the debate on interactions of tenure security, land conflicts, and land documentation by showing how exogenous shocks affect the three tenure security characteristics at the same time.

Finally, we contribute to the debate on land formalization by documenting the effects of weather risk on the acquisition of land certificates. These results are mixed. While precipitation variability significantly lowers the likelihood that farmers acquire a land certificate, dry spells—with a one-year time lag—are associated with an increased acquisition of certificates. This difference could be explained with the different conflict types driven by the respective weather events. Other potential channels include decreases in agricultural production because of weather risk, which is stronger in the case of precipitation variability.

One limitation of this study is its geographical scope. We caution that our findings may not be general to all of Tanzania, as the household panel survey was only implemented in six villages. Nevertheless, those study villages were selected to cover a wide range of Tanzanian farming systems, and the land tenure system is characteristic of what has been called the new African customary land tenure (Chimhowu 2019), which is increasingly formalized. Consequently, our findings hold potential relevance for regions with a similar climate and where agriculturalists and pastoralists interact, particularly in the semi-arid areas of East Africa and the Sahel.

As a further limitation, the nature of the survey does not allow for detailed intrahousehold analyses, which could mask important dynamics about the perception of tenure security and the benefits of land certificates in the household.

Our findings shed light on some debated questions in land policy. Secure tenure is not only important for farmers to adapt to climate change, it is itself affected by weather risk, which is set to increase with progressing climate change. Given the strong link between dry spells, precipitation variability, and tenure security, improving the tenure security of smallholder farmers will likely grow in importance with increasing climate change. Otherwise, there is a risk of tenure insecure and vulnerable households being trapped in situations of insecure land tenure for sustained periods of time. The main policy implication is that land tenure interventions, such as land registration projects or conflict resolution programs, should consider farmers' vulnerability to weather risk and target its efforts accordingly.

Acknowledgments

We are grateful for comments from Svenja Fluhrer, Bisrat Haile, Luitfred Kissoly, Giulia Malevolti, Lukas Mogge, Niklas Murken, Claudio Ngassa, Ephraim Nkonya, Nelson Ochieng, Julian Röckert, participants of the

2021 LANDac conference, the 2021 Households in Conflict workshop, the International Association for the Study of the Commons Land Commons conference, the 2022 PEGNet conference, the 2023 Centre for the Study of African Economies conference, and participants in the Adaptation in Agricultural Systems Ph.D. seminar at PIK. We particularly thank Anja Faße and the research staff at the University of Hannover and the Sokoine University of Agriculture for implementing the panel survey and for making the data available to us. The research was funded by the German National Academic Foundation, the SCARF project funded by the International Climate Initiative (IKI), and the Agrica project funded by the German Federal Ministry for Economic Cooperation and Development (BMZ). The household survey was collected as a part of the Trans-SEC project, which was funded by the German Federal Ministry of Education and Research and cofinanced by BMZ. We thank the Leibniz Centre for Agricultural Landscape Research for coordinating the Trans-SEC project. Responsibility for the content of this article lies solely with the authors.

References

Abadie, A., S. Athey, G. W. Imbens, and J. M. Wooldridge. 2022. “When Should You Adjust Standard Errors for Clustering?” *Quarterly Journal of Economics* 138 (1): 1–35. https://doi.org/10.1093/qje/qjac038.

African Development Bank. 2019. *Review of Land Tenure Systems to Support the Creation of an Enabling Enviroment for Agricultural Transformation: Report on Tanzania*. Available at https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Review_of_the_land_tenure_systems_-_Report_on_Tanzania.pdf.

Aikaeli, J., and T. Markussen. 2022. “Titling and the Value of Land in Tanzania.” *Journal of International Development* 34 (3): 512–31. https://doi.org/10.1002/jid.3615.

Ali, D. A., M. Collin, K. Deininger, S. Dercon, J. Sandefur, and A. Zeitlin. 2016. “Small Price Incentives Increase Women’s Access to Land Titles in Tanzania.” *Journal of Development Economics* 123: 107–22. https://doi.org/10.1016/j.jdeveco.2016.06.001.

Ali, D. A., K. Deininger, and M. Duponchel. 2017. “New Ways to Assess and Enhance Land Registry Sustainability: Evidence from Rwanda.” *World Development* 99: 377–94. https://doi.org/10.1016/j.worlddev.2017.05.016.

Ali, D. A., K. Deininger, and M. Goldstein. 2014. “Environmental and Gender Impacts of Land Tenure Regularization in Africa: Pilot Evidence from Rwanda.” *Journal of Development Economics* 110: 262–75. https://doi.org/10.1016/j.jdeveco.2013.12.009.

Arnot, C., Luckert, M., and Boxall, P. 2011. “What Is Tenure Security? Conceptual Implications for Empirical Analysis.” *Land Economics* 87 (2): 297–311. https://www.jstor.org/stable/41307215.

Auffhammer, M., S. M. Hsiang, W. Schlenker and A. Sobelz. 2013. “Using Weather Data and Climate Model Output in Economic Analyses of Climate Change.” *Review of Environmental Economics and Policy* 7 (2): 181–98. https://doi.org/10.1093/reep/ret016.

Auffhammer, M., V. Ramanathan, and J. R. Vincent 2012. “Climate Change, the Monsoon, and Rice Yield in India.” *Climatic Change* 111: 411–24. https://doi.org/10.1007/s10584-011-0208-4.

Ayamga, M., R. Yeboah, and F. Dzanku. 2015. “Determinants of Farmland Tenure Security in Ghana.” *Ghana Journal of Science, Technology and Development* 2 (1): 1–21. https://doi.org/10.47881/43.967x.

Bélair, J. 2021. “Farmland Investments in Tanzania: The Impact of Protected Domestic Markets and Patronage Relations.” *World Development* 139: 105298. https://doi.org/10.1016/j.worlddev.2020.105298.

Benjaminsen, T. A., F. P. Maganga, and J. M. Abdallah. 2009. “The Kilosa Killings: Political Ecology of a Farmer-Herder Conflict in Tanzania.” *Development and Change* 40 (3): 423–45. https://doi.org/10.1111/j.1467-7660.2009.01558.x.

Bergius, M., T. A. Benjaminsen, F. Maganga, and H. Buhaug. 2020. “Green Economy, Degradation Narratives, and Land-Use Conflicts in Tanzania.” *World Development* 129: 104850. https://doi.org/10.1016/j.worlddev.2019.104850.

Besley, T., and M. Ghatak. 2010. “Property Rights and Economic Development.” In *Handbook of Development Economics*. Vol. 5, edited by Dani Rodrik and Mark Rosenzweig, 4525–95. Amsterdam: North-Holland. https://doi.org/10.1016/B978-0-444-52944-2.00006-9.

Bluwstein, J., J. F. Lund, K. Askew, H. Stein, C. Noe, R. Odgaard, F. Maganga, and L. Engström. 2018. “Between Dependence and Deprivation: The Interlocking Nature of Land Alienation in Tanzania.” *Journal of Agrarian Change* 18 (4): 806–30. https://doi.org/10.1111/joac.12271.

Boone, C. 2014. *Property and Political Order in Africa: Land Rights and the Structure of Politics*. Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/CBO9781139629256.

———. 2017. “Sons of the Soil Conflict in Africa: Institutional Determinants of Ethnic Conflict over Land.” *World Development* 96: 276–93. https://doi.org/10.1016/J.WORLDDEV.2017.03.012.

Boone, C., and L. Nyeme. 2015. “Land Institutions and Political Ethnicity in Africa: Evidence from Tanzania.” *Comparative Politics* 48 (1): 67–86. https://doi.org/10.5129/001041515816075123.

Brüssow, K., C. Gornott, A. Faße, and U. Grote. 2019. “The Link between Smallholders’ Perception of Climatic Changes and Adaptation in Tanzania.” *Climatic Change* 157 (3): 545–63. https://doi.org/10.1007/s10584-019-02581-9.

Buggle, J. C., and Durante, R. 2021. “Climate Risk, Cooperation and the Co-evolution of Culture and Institutions.” *Economic Journal* 131 (637): 1947–87. https://doi.org/10.1093/ej/ueaa127.

Burke, M., S. M. Hsiang, and E. Miguel. 2015. “Climate and Conflict.” *Annual Review of Economics* 7 (1): 577–617. https://doi.org/10.1146/annurev-economics-080614-115430.

Butler, C. K., and S. Gates. 2012. “African Range Wars: Climate, Conflict, and Property Rights.” *Journal of Peace Research* 49 (1): 23–34. https://doi.org/10.1177/0022343311426166.

Chimhowu, A. 2019. “The ‘New’ African Customary Land Tenure. Characteristic, Features and Policy Implications of a New Paradigm.” *Land Use Policy* 81: 897–903. https://doi.org/10.1016/j.landusepol.2018.04.014.

Coase, R. H. 1960. “The Problems of Social Cost.” *Journal of Law and Economics* 3: 1–44.

Copernicus Climate Change Service. 2017. “ERA5: Fifth Generation of ECMWF Atmospheric Reanalyses of the Global Climate.” Available at https://cds.climate.copernicus.eu/cdsapp#!/home.

Deininger, K, and R. Castagnini. 2006. “Incidence and Impact of Land Conflict in Uganda.” *Journal of Economic Behavior and Organization* 60 (3): 321–45. https://doi.org/10.1016/j.jebo.2004.04.008.

Deininger, K., and J. S. Chamorro. 2004. “Investment and Equity Effects of Land Regularisation: The Case of Nicaragua.” *Agricultural Economics* 30 (2): 101–16. https://doi.org/10.1016/j.agecon.2002.09.004.

Deininger, K., and G. Feder. 2009. “Land Registration, Governance, and Development: Evidence and Implications for Policy.” *World Bank Research Observer* 24 (2): 233–66. https://doi.org/10.1093/wbro/lkp007.

Dell, M., B. F. Jones, and B. A. Olken. 2012. “Temperature Shocks and Economic Growth: Evidence from the Last Half Century.” *American Economic Journal: Macroeconomics* 4 (3): 66–95. https://doi.org/10.1257/mac.4.3.66.

———. 2014. “What Do We Learn from the Weather? The New Climate-Economy Literature.” *Journal of Economic Literature* 52 (3): 740–98. https://doi.org/10.1257/jel.52.3.740.

Dijksterhuis, A., and J. A. Bargh 2001. “The Perception-Behavior Expressway: Automatic Effects of Social Perception on Social Behavior.” In *Advances in Experimental Social Psychology*. Vol. 33, edited by M. P. Zanna, 1–40. Washington, DC: Academic Press.

Dinku, T., C. Funk, P. Peterson, R. Maidment, T. Tadesse, H. Gadain, and P. Ceccato. 2018. “Validation of the CHIRPS Satellite Precipitation Estimates over Eastern Africa.” *Quarterly Journal of the Royal Meteorological Society* 144: 292–312. https://doi.org/10.1002/qj.3244.

Doss, C., C. Kovarik, A. Peterman, A. Quisumbing, and M. Van Den Bold. 2015. “Gender Inequalities in Ownership and Control of Land in Africa: Myth and Reality.” *Agricultural Economics* 46 (3): 403–34. https://doi.org/10.1111/agec.12171.

FAO (Food and Agriculture Organization of the United Nations). 2002. *Land Tenure and Rural Development*. FAO Land Tenure Studies. Rome: FAO.

Funk, C., P. Peterson, M. Landsfeld, D. Pedreros, J. Verdin, S. Shukla, and G. Husak, *et al*. 2015. “The Climate Hazards Infrared Precipitation with Stations: A New Environmental Record for Monitoring Extremes.” *Scientific Data* 2: 150066. https://doi.org/10.1038/sdata.2015.66.

Ghebru, H., and F. Girmachew. 2019. “Perceived Tenure (In)Security in the Era of Rural Transformation Gender-Disaggregated Analysis from Mozambique.” Feed the Future Innovation Lab for Food Security Policy Research Paper 303017. East Lansing, MI: Michigan State

University/Feed the Future Innovation Lab for Food Security.

Ghebru, H., and I. Lambrecht. 2017. "Drivers of Perceived Land Tenure (In)Security: Empirical Evidence from Ghana." *Land Use Policy* 66: 293–303. https://doi.org/10.1016/J.LANDUSEPOL.2017.04.042.

Graef, F., S. Sieber, K. Mutabazi, F. Asch, H. K. Biesalski, J. Bitegeko, W. Bokelmann, *et al*. 2014. "Framework for Participatory Food Security Research in Rural Food Value Chains." *Global Food Security* 3 (1): 8–15. https://doi.org/10.1016/j.gfs.2014.01.001.

Greco, E. 2015. "Landlords in the Making: Class Dynamics of the Land Grab in Mbarali, Tanzania." *Review of African Political Economy* 42 (144): 225–44. https://doi.org/10.1080/03056244.2014.992403.

Higgins, D., T. Balint, H. Liversage, and P. Winters. 2018. "Investigating the Impacts of Increased Rural Land Tenure Security: A Systematic Review of the Evidence." *Journal of Rural Studies* 61: 34–62. https://doi.org/10.1016/j.jrurstud.2018.05.001.

Holden, S. T., K. Deininger, and H. Ghebru. 2011. "Tenure Insecurity, Gender, Low-Cost Land Certification and Land Rental Market Participation in Ethiopia." *Journal of Development Studies* 47 (1): 31–47. https://doi.org/10.1080/00220381003706460.

Hsiang, S. M., and M. Burke. 2014. "Climate, Conflict, and Social Stability: What Does the Evidence Say?" *Climatic Change* 123 (1): 39–55. https://doi.org/10.1007/s10584-013-0868-3.

Hsiang, S. M., M. Burke, and E. Miguel. 2013. "Quantifying the Influence of Climate on Human Conflict." *Science* 341 (6151). https://doi.org/10.1126/science.1235367.

Huntington, H., and A. Shenoy. 2021. "Does Insecure Land Tenure Deter Investment? Evidence from a Randomized Controlled Trial." *Journal of Development Economics* 150: 102632. https://doi.org/10.1016/j.jdeveco.2021.102632.

Jacoby, H. G., G. Li, and S. Rozelle. 2002. "Hazards of Expropriation: Tenure Insecurity and Investment in Rural China." *American Economic Review* 92 (5): 1420–47. https://doi.org/10.1257/000282802762024575.

Jenkins, A. C., P. Karashchuk, L. Zhu, and M. Hsu. 2018. "Predicting Human Behavior toward Members of Different Social Groups." *Proceedings of the National Academy of Sciences* 115 (39): 9696–9701. https://doi.org/10.1073/pnas.1719452115.

Kalkuhl, M., G. Schwerhoff, and K. Waha, K. 2020. "Land Tenure, Climate and Risk Management." *Ecological Economics* 171: 106573. https://doi.org/10.1016/j.ecolecon.2019.106573.

Kendon, E. J., R. A. Stratton, S. Tucker, J. H. Marsham, S. Berthou, D. P. Rowell, and C. A. Senior. 2019. "Enhanced Future Changes in Wet and Dry Extremes over Africa at Convection-Permitting Scale." *Nature Communications* 10 (1). https://doi.org/10.1038/s41467-019-09776-9.

Koubi, V. 2019. "Climate Change and Conflict." *Annual Review of Political Science* 22: 343–60. https://doi.org/10.1146/annurev-polisci-050317-070830.

Kotz, M., A. Levermann, and L. Wenz. 2022. "The Effect of Precipitation Changes on Economic Production." *Nature* 601: 223–27. https://doi.org/10.1038/s41586-021-04283-8.

Kubitza, C., V. V. Krishna, K. Urban, Z. Alamsyah, and M. Qaim. 2018. "Land Property Rights, Agricultural Intensification, and Deforestation in Indonesia." *Ecological Economics* 147: 312–21. https://doi.org/10.1016/j.ecolecon.2018.01.021.

Laudien, R., B. Schauberger, D. Makowski, and C. Gornott. 2020. "Robustly Forecasting Maize Yields in Tanzania Based on Climatic Predictors." *Scientific Reports* 10 (1): 1–12. https://doi.org/10.1038/s41598-020-76315-8.

Lawry, S., C. Samii, R. Hall, A. Leopold, D. Hornby, and F. Mtero. 2017. "The Impact of Land Property Rights Interventions on Investment and Agricultural Productivity in Developing Countries: A Systematic Review." *Journal of Development Effectiveness* 9 (1): 61–81. https://doi.org/10.1080/19439342.2016.1160947.

Linkow, B. 2016. "Causes and Consequences of Perceived Land Tenure Insecurity: Survey Evidence from Burkina Faso." *Land Economics* 92 (2): 308–27. https://doi.org/10.3368/le.92.2.308.

Massay, G. 2013. "Adjudication of Land Cases in Tanzania: A Bird Eye Overview of the District Land and Housing Tribunal." *Open University Law Journal* 4 (2): 167–82.

McGuirk, E. F., and Nunn, N. 2020. *Transhumant Pastoralism, Climate Change, and Conflict in Africa*. Working Paper no. 28243. Cambridge, MA: National Bureau of Economic Research.

Notess, L., P. Veit, I. Monterroso, I., Andiko, E. Sulle, A. M. Larson, A.-S. Gindroz, J. Quaedvlieg, and A. Williams. 2021. "Community Land Formalization and Company Land

Acquisition Procedures: A Review of 33 Procedures in 15 Countries." *Land Use Policy* 110: 104461. https://doi.org/10.1016/j.landusepol.2020.104461.

Odgaard, R. 2003. "Scrambling for Land in Tanzania: Process of Formalisation and Legitimisation of Land Rights." In *Securing Land Rights in Africa*, edited by A. Benjaminsen and C. Lund, 71–89. London: Frank Cass.

———. 2005. "The Struggle for Land Rights in the Context of Multiple Normative Orders in Tanzania." In *Competing Jurisdictions: Settling Land Claims in Africa*, edited by S. M. Evers, M. Spierenburg, and H. Wels. Leiden, Netherlands: Brill.

Pedersen, R. H. 2015. "A Less Gendered Access to Land? The Impact of Tanzania's New Wave of Land Reform." *Development Policy Review* 33 (4): 415–32. https://doi.org/10.1111/dpr.12121.

Place, F, and S. E. Migot-Adholla. 1998. "The Economic Effects of Land Registration on Smallholder Farms in Kenya: Evidence from Nyeni and Kakamega Districts." *Land Economics* 74 (3): 360–73. https://doi.org/10.2307/3147118.

Platteau, J.-P. 1996. "The Evolutionary Theory of Land Rights as Applied to Sub-Saharan Africa: A Critical Assessment." *Development and Change* 27 (1): 29–86. https://doi.org/10.1111/j.1467-7660.1996.tb00578.x.

———. 2000. "Allocating and Enforcing Property Rights in Land: Informal versus Formal Mechanisms in Subsaharan Africa." *Nordic Journal of Political Economy* 26 (1): 55–81.

Prindex. 2020. *Prindex Comparative Report: A Global Assessment of Perceived Tenure Security from 140 Countries*. Overseas Development Institute. Available at https://www.prindex.net/reports/prindex-comparative-report-july-2020.

Reerink, G., and J.-L. van Gelder. 2010. "Land Titling, Perceived Tenure Security, and Housing Consolidation in the Kampongs of Bandung, Indonesia." *Habitat International* 34 (1): 78–85. https://doi.org/10.1016/j.habitatint.2009.07.002.

Robinson, B. E., and M. Diop. 2022. "Who Defines Land Tenure Security? *De Jure* and *De Facto* Institutions." In *Land Tenure Security and Sustainable Development*, edited by M. B. Holland, Y. J. Masuda, and B. E. Robinson, 43–56. Cham, Switzerland: Palgrave Macmillan. https://doi.org/10.1007/978-3-030-81881-4_3.

Robinson, B. E., M. B. Holland, and L. Naughton-Treves. 2014. "Does Secure Land Tenure Save Forests? A Meta-analysis of the Relationship between Land Tenure and Tropical Deforestation." *Global Environmental Change* 29: 281–93. https://doi.org/10.1016/j.gloenvcha.2013.05.012.

Rubakula, G., Z. Wang, and C. Wei. 2019. "Land Conflict Management through the Implementation of the National Land Policy in Tanzania: Evidence from Kigoma Region." *Sustainability* 11 (22). https://doi.org/10.3390/su11226315.

Rwegasira, A. 2012. *Land as a Human Right: A History of Land Law and Practice in Tanzania*. Dar es Salaam, Tanzania: Mkuki na Nyota. https://doi.org/10.2307/j.ctvk3gmx4.

Sarsons, H. 2015. "Rainfall and Conflict: A Cautionary Tale." *Journal of Development Economics* 115: 62–72. https://doi.org/10.1016/j.jdeveco.2014.12.007.

Schlenker, W., and M. J. Roberts. 2009. "Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change." *Proceedings of the National Academy of Sciences* 106 (37): 15594–98. https://doi.org/10.1073/pnas.0906865106.

Schreiber, L. 2017. "Registering Rural Rights: Village Land Titling in Tanzania, 2008–2017." Tanzania: Global Challenges Land. Available at https://successfulsocieties.princeton.edu/sites/successfulsocieties/files/LS_Tanzania_Land_GC_CC_1.pdf.

Sipangule, K. 2017. "Agribusinesses, Smallholder Tenure Security and Plot-level Investments: Evidence from Rural Tanzania." *African Development Review* 29 (S2): 179–97. https://doi.org/10.1111/1467-8268.12271.

Sjaastad, E. and D. W. Bromley. 2000. "The Prejudices of Property Rights: On Individualism, Specificity, and Security in Property Regimes." *Development Policy Review* 18: 365–89. https://doi.org/10.1111/1467-7679.00117.

Sjaastad, E., and B. Cousins. 2009. "Formalisation of Land Rights in the South: An Overview." *Land Use Policy* 26 (1): 1–9. https://doi.org/10.1016/j.landusepol.2008.05.004.

Tseng, T. W. J., B. E. Robinson, M. F. Bellemare, A. BenYishay, A. Blackman, T. Boucher, M. Childress, *et al*. 2021. "Influence of Land Tenure Interventions on Human Well-Being and Environmental Outcomes." *Nature Sustainability* 4 (3): 242–51. https://doi.org/10.1038/s41893-020-00648-5.

Valsecchi, M. 2014. "Land Property Rights and International Migration: Evidence from Mexico." *Journal of Development Economics* 110: 276–90. https://doi.org/10.1016/j.jdeveco.2014.01.010.

van Gelder, J.-L. 2010. “What Tenure Security? The Case for a Tripartite View.” *Land Use Policy* 27 (2): 449–56. https://doi.org/10.1016/j.landusepol.2009.06.008.

Walwa, W. J. 2020. “Growing Farmer-Herder Conflicts in Tanzania: The Licenced Exclusions of Pastoral Communities Interests over Access to Resources.” *Journal of Peasant Studies* 47 (2): 366–82. https://doi.org/10.1080/03066150.2019.1602523.

Wily, L. A. 2003. *Community-Based Land Tenure Management: Questions and Answers about Tanzania’s New Village Land Act, 1999*. London: International Institute for Environment and Development.

Wooldridge, J. M. 2013. *Introductory Econometrics: A Modern Approach*. 5th ed. Boston: Cengage Learning.

World Bank. 2018. “Land Tenure Improvement Project Information Document: Tanzania.” Available at https://documents1.worldbank.org/curated/en/934461589985643361/pdf/Project-Information-Document-Land-Tenure-Improvement-Project-P164906.pdf.

Yi, Y., G. Köhlin, and J. Xu. 2014. “Property Rights, Tenure Security and Forest Investment Incentives: Evidence from China’s Collective Forest Tenure Reform.” *Environment and Development Economics* 19 (1): 48–73. https://doi.org/10.1017/S1355770X13000272.