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International Climate Migration: Evidence for the Climate Inhibitor Mechanism and the Agricultural Pathway

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Abstract

Research often assumes that, in rural areas of developing countries, adverse climatic conditions increase (climate driver mechanism) rather than reduce (climate inhibitor mechanism) migration, and that the impact of climate on migration is moderated by changes in agricultural productivity (agricultural pathway). Using representative census data in combination with high-resolution climate data derived from the novel Terra Populus system, we explore the climate-migration relationship in rural Burkina Faso and Senegal. We construct four threshold-based climate measures to investigate the effect of heat waves, cold snaps, droughts and excessive precipitation on the likelihood of household-level international outmigration. Results from multi-level logit models show that excessive precipitation increases international migration from Senegal while heat waves decrease international mobility in Burkina Faso, providing evidence for the climate inhibitor mechanism. Consistent with the agricultural pathway, interaction models and results from a geographically weighted regression (GWR) reveal a conditional effect of droughts on international outmigration from Senegal, which becomes stronger in areas with high levels of groundnut production. Moreover, climate change effects show a clear seasonal pattern, with the strongest effects appearing when heat waves overlap with the growing season and when excessive precipitation occurs prior to the growing season.

Keywords

Climate change; environment; international migration; Terra Populus; agricultural pathway; climate inhibitor mechanism

Introduction

Greenhouse gas (GHG) emissions have started to alter the global climatic system resulting in an overall warming trend and an increase in the frequency and severity of weather events such as storms, floods, and droughts (IPCC, 2013). All countries will be impacted by climate change and associated climate variability and weather extremes, but the impacts will

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be felt most strongly by people living in less developed agricultural societies that depend heavily on the environment for income generation and sustenance (Huq *et al.*, 2003). Residents of these countries frequently lack access to technology and infrastructure (e.g., irrigation) that may be used in industrialized nations to moderate adverse climate impacts (Gutmann & Field, 2010). Some authors have brought attention to the possibility of large numbers of climate change migrants by mid-century (Myers, 2002; Stern, 2007). Although scholars have criticized these studies as overly simplistic and inaccurate (Gemenne, 2011), evidence from the longer course of human history shows that climatic variability and weather extremes have influenced human migration behavior across the globe (McLeman & Smit, 2006). Similar evidence for the impact of climate on migration patterns can be found in the literature for more recent years (Bohra-Mishra *et al.*, 2014; Hunter *et al.*, 2013; Mueller *et al.*, 2014; Nawrotzki *et al.*, 2013). For the African continent, this research finds that climate factors largely increase short distance, domestic migration but may decrease the probability of international moves (e.g., Findley, 1994; Henry *et al.*, 2004).

Climate change has the potential to influence migration drivers through various pathways including adverse impacts on the agricultural sector (Mueller *et al.*, 2014) and armed conflicts (Burke *et al.*, 2009; Nawrotzki *et al.*, 2009). While the agricultural pathway is assumed in most studies on the climate-migration association (Mueller *et al.*, 2014), it is rarely tested empirically.

The present study contributes to the growing literature on climate-migration through a detailed investigation of adverse climatic conditions as drivers or inhibitors of international migration from Burkina Faso and Senegal, and by exploring empirical evidence for the agricultural pathway. Although the majority of climate related displacements will likely be internal (Findlay, 2011), we focus on international migration because of its policy relevance and the widespread fear surrounding uncontrollable flows of climate migrants fleeing their countries to seek shelter elsewhere (Kaenzig & Piguet, 2014). Rather than relying on region-specific small-scale survey data as in earlier work (Henry *et al.*, 2004), we combine nationally representative census data with spatially and temporally high-resolution climate information obtained through the novel Terra Populus system. As a methodological advancement, this study employs sophisticated multilevel models in combination with geographically weighted regressions to investigate climate-crop interactions, spatial patterns, and seasonal climate effects. While earlier work for Africa predominantly focused on changes in rainfall patterns (Findley, 1994; Henry *et al.*, 2004), we use monthly temperature and precipitation data over a 46-year period to explore temperature effects as important migration drivers (e.g., Bohra-Mishra *et al.*, 2014; Mueller *et al.*, 2014).

Climate as migration driver versus inhibitor

Climate-related modifications in migration behavior can manifest as either an increase (climate driver mechanism) or decrease (climate inhibitor mechanism) in mobility, and the nature of the response depends on many factors including a household's adaptive capacity, wealth, access to various forms of capital, and the general political and cultural context (Black *et al.*, 2011b; Jonsson, 2010; Kaenzig & Piguet, 2014; Morrissey, 2014).

Climate driver mechanism

The New Economics of Migration (NEM) theory is often used as a framework to explain why climate change may increase international migration (Hunter *et al.*, 2013; Nawrotzki *et al.*, 2013). Central for this study is the self-insurance function of NEM, in which households employ migration to diversify income streams and guard against climate related economic uncertainties and shocks (Massey *et al.*, 1993; Stark & Bloom, 1985). If economic conditions degrade, households can rely on a stable income stream through remittances from a member residing elsewhere. The self-insurance function of migration is best realized if the household member is sent to an international destination in which the weather and market conditions are uncorrelated to those at home (Massey *et al.*, 1993). A number of studies have demonstrated that adverse climatic conditions can indeed increase the risk of international outmigration (Barrios Puente *et al.*, 2015; Feng & Oppenheimer, 2012; Gray & Bilsborrow, 2013; Hunter *et al.*, 2013; Nawrotzki *et al.*, 2015). However, these studies predominantly emerge for Latin America, which may be explained, in part, by the unique historical, economic, social, and political context of this region (Kaenzig & Piguet, 2014).

Climate inhibitor mechanism

In contrast, climate related economic recessions may lead to a reduction in the likelihood of international migration and “trap” people in place (Black *et al.*, 2011b). When agricultural income declines, households may lack the resources to finance an expensive international move (Henry *et al.*, 2004). In support of this argument, studies from Burkina Faso and Mali found that droughts increased temporal, short-distance migration but decreased international moves (Findley, 1994; Henry *et al.*, 2004).

In short, while empirical evidence suggests that climate change may drive migration, studies of African countries (e.g., Findley, 1994; Henry *et al.*, 2004) often find that adverse climatic conditions inhibit international migration. Based on this observation we ask: Do adverse climatic conditions increase (climate driver mechanism) or decrease (climate inhibitor mechanism) international outmigration from Burkina Faso and Senegal?

The agricultural pathway - connecting climate and migration

A large fraction of the population in Burkina Faso (90.0%) and Senegal (77.5%) is employed in the agricultural sector (CIA, 2014). A lack of wealth and financial resources prevents rural households from employing technological means to guard against the adverse impacts of climate change (Gutmann & Field, 2010). For example, only 0.2% (Burkina Faso) and 1.3% (Senegal) of the permanently cropped farmland was irrigated in 2000 (FAO, 2015).

Climate change may destabilize livelihoods when droughts or heat waves increase and lead to a decline in agricultural income, employment opportunities, or food production for sustenance (Mueller *et al.*, 2014). In the face of economic strain, households first employ *in-situ* (in place) adaptation strategies such as changing farming practices, borrowing money from family and friends, selling assets, and accessing public assistance programs (Gray & Mueller, 2012). However, when these *in-situ* options are exhausted or insufficient, households may modify their migration behavior to improve their livelihood security (McLeman, 2011). Based on this reasoning, much of the research on climate and migration assumes that the impact of climate on migration is mediated through the agricultural sector, without empirically testing this assumption (e.g., Mueller et al., 2014). In the absence of data on farm income and production, we employ two proxy indicators, the crop harvested area and a seasonal specification of the climate measures to empirically explore our second research question: Is there empirical evidence for the agricultural pathway in the climate-migration association for Burkina Faso and Senegal?

If the agricultural pathway correctly describes the climate –migration relationship in Burkina Faso and Senegal, we would expect to see stronger effects of climate change on international migration for areas with the highest level of agricultural dependence. In regions with large areas harvested, households are more likely to be employed in the agricultural sector and use agricultural output for sustenance and income generation (Morton, 2007). However, in addition to this spatial pattern we would also expect to observe a clear temporal pattern. It is widely known that the impact of climate variability on agricultural production is strongest during the crop-specific growing season (Lobell & Field, 2007; Lobell *et al.*, 2013; Schlenker & Roberts, 2009). With the agricultural pathway, we would therefore expect to observe the strongest association between climate variability and migration during the growing season months (Nawrotzki *et al.*, 2013).

Data and Case

Data

We employ data from the new TerraPop extraction system (Kugler *et al.*, 2015; MPC, 2013). The sociodemographic data available via TerraPop originate from IPUMS-International (MPC, 2015; Ruggles *et al.*, 2003). We extracted a 10% density sample of the harmonized census data for Burkina Faso and Senegal for the most recent census rounds available through TerraPop (Burkina Faso: December 16, 2006; Senegal: December 15, 2002). These two countries allow for the study of the climate – international migration relationship because the census collected household-level information on international outmigration. Due to our focus on the agricultural pathway, we restrict our sample to rural households in line with much prior work (Gray & Mueller, 2012; Hunter *et al.*, 2013; Nawrotzki *et al.*, 2013). Households are defined as rural when located in agglomerations of less than 10,000 people in Senegal and based on administrative classifications in Burkina Faso.

Our sample comprises 133,686 households in Burkina Faso and 57,052 households in Senegal, located in 45 provinces (Burkina Faso) and 31 departments (Senegal) as the finest geographical unit available (second administrative level). TerraPop was designed to facilitate population – environment research through the integration of microdata, area-level and raster data (Kugler *et al.*, 2015). Of primary importance for the present study was high resolution (0.5 × 0.5 degrees) temperature and precipitation data, constructed by the University of East Anglia's Climate Research Unit (CRU) (Harris *et al.*, 2014). TerraPop provided summaries of the climate data at the province/department level attached as contextual variables to the microdata records.

Case

For a study of climate-migration, both the migration and climate context are important. Burkina Faso and Senegal have an established history of international labor migration. International migration beyond West Africa has not been particularly popular in Burkina Faso, likely due to well-established ties to Ivory Coast and Ghana, although there is a small Burkinabè diaspora in France (Adepoju, 1995). Migration to Europe is much more prevalent among Senegalese, with France counting historically among the primary destinations due to colonial ties. In the 1990s, Italy and Spain emerged as alternative destinations in response to increased border restrictions by France (Beauchemin *et al.*, 2014; FM, 2007). Preferred destinations for Senegalese within Africa include Mali, Mauritania, and Guinea (Beauchemin *et al.*, 2014; FM, 2007). Migrants often find employment in the farming and construction sectors and the labor requirements result in a highly gendered migration stream composed predominantly of young working age males (Beauchemin *et al.*, 2014; Cordell *et al.*, 1998; Roncoli *et al.*, 2001). However, recent trends of diversification in the employment sectors have resulted in more gender-balanced migration streams (Adepoju, 2003; Cordell *et al.*, 1998). Although long-term migration occurs (Kress, 2006), migration is often seasonal in nature and migrants return home during the harvest period to help on the family farm (Adepoju, 1995).

The history of migration emerges in a unique geo-climatic context of semi-arid to arid West Africa. Figure 1 provides a visual depiction of the climatic conditions in Burkina Faso and Senegal.

Figure 1 shows substantial intra-country variation in temperature and precipitation following a clear south-north gradient (Ingram *et al.*, 2002). In this study we explore the impact of climate variability on international migration patterns. As such, Figure 2 shows trajectories in temperature (Panel A) and precipitation (Panel B) over a 50-year time period.

Figure 2 illustrates a long-term warming trend of about 1 °C over the past 50 years, in line with historical observations (Funk *et al.*, 2012; Nicholson, 2001). Although climate change is already evident, climate models project a much larger temperature increase between 3 and 6 °C by the end of the century for Western Africa (Niang *et al.*, 2014). For precipitation, we observe an average decline of about 8 mm/month over the 50-year period, reflective of projected trends for much of West Africa (Niang *et al.*, 2014). In short, an established history of international migration combined with the experience of long-term warming and precipitation decline make Burkina Faso and Senegal useful cases for the study of the influence of climate variability on human mobility.

Measures and Methods

Outcome variable

Within the cultural context of rural West Africa, migration needs to be understood as a household-level livelihood strategy (Adepoju, 2004). As part of the census questionnaire, households were asked to specify the number of members that had left for an international destination during the past five years, leading up to the census date. This variable was dichotomized to a value of 1 if a household had experienced a migration event and zero otherwise. The focus on international migration has the benefit of isolating moves for livelihood considerations from domestic moves that are frequently related to family formation (Henry *et al.*, 2004). As a common feature of most developing countries, migration is often circular (Hampshire & Randall, 1999). People continue to maintain strong links with their place of origin and usually return to their home village at some point (Henry *et al.*, 2004). Summary statistics of all variables employed in the present study are provided in Table 1.

Primary predictors

Agronomic research shows that temperature and precipitation extremes above certain thresholds are more harmful for crop yield than average changes (Lobell *et al.*, 2013; Schlenker & Roberts, 2009). As such, we computed a set of climate measures reflecting the percentage of months during which a certain threshold was surpassed. The threshold for temperature effects was defined as one standard deviation above the 30-year (1961-1990) long-term average maximum temperature (heat waves), or one standard deviation below the long-term average minimum temperature (cold snaps). For precipitation measures, we used a threshold of one standard deviation below the long term average precipitation (drought) or one standard deviation above the long term average (excessive precipitation). For each of the months during the six-year period (71 months) leading up to the census date, we computed the percentage of times that a threshold was surpassed. The use of a six-year period reflects roughly a one-year time lag relative to the five-year window during which migration occurred (Nawrotzki *et al.*, 2013). To jointly account for temperature and precipitation effects (Auffhammer *et al.*, 2013), we constructed a climate impact index, measuring the simultaneous occurrence of heat waves and droughts.

Household-level controls

To measure differential access to *social capital*, we construct a dummy variable indicating the marital status (married=1) and religious affiliation (1 = Muslim, 0 = other) of the household head. A marital union provides access to social networks of the spouse and may therefore facilitate migration (Abu *et al.*, 2014; Hampshire & Randall, 1999). Similarly, the social norms, ties, expectations, and sanctions of a particular religious group may influence the decision to migrate (cf., Smidt, 2003).

Human capital is reflected by six variables: The age of the household head captures varying probabilities of outmigration during different stages of the life cycle. The education level accounts for different access to employment opportunities at the origin and destination (Lindstrom & Ramirez, 2010). The child (0-14 years) and retiree (65+ years) dependency ratios reflect the percentage of the household population in a given age range relative to the total household size (UNPD, 2012). In addition, the proportion of household members employed and the number of persons in the household reflects access to human capital important for migration (Abu *et al.*, 2014).

Physical capital was captured by a dummy variable for home ownership (1 = owner) and an additive wealth index. We constructed the wealth index as an additive scale of nine variables, measuring access to services, dwelling characteristics, and possession of appliances

(Cronbach's alpha = 0.75) (Mberu, 2006; Nawrotzki *et al.*, 2013). In the African context, research has found a general trend of increasing participation in labor migration with increasing household wealth (Hampshire & Randall, 1999; Hunter *et al.*, 2014).

Province/department level controls

We approximated the density of migrant networks, as a strong predictor of future migration (Fussell & Massey, 2004), by computing the percentage of households with international migration experience in the particular province/department during the prior census round (Burkina Faso: 1996; Senegal: 1988). Based on MODIS urban extents (Schneider *et al.*, 2009), we employ a measure of the percentage of urban land in each province/department as a proxy indicator for local employment opportunities in non-agricultural sectors. Important for the exploration of the agricultural pathway, gridded crop data from the Global Landscape Initiative (Monfreda *et al.*, 2008), available through TerraPop, allows measuring the area of each province/department harvested (sqm/100ha) with cotton (Burkina Faso) and groundnuts (Senegal) as the crops of primary economic importance (CIA, 2014). The GLI data describes the crop area harvested around the year 2000, estimated based on agricultural census and survey information (Monfreda *et al.*, 2008).

Because the general climatic conditions (e.g., historically hot vs. cold) may influence migration probabilities (Nawrotzki *et al.*, 2013), we computed two dummy variables that indicated whether the 30-year (1961-1990) long-term average temperature and precipitation of a given province/department was above or below the country mean.

Estimation strategy

To investigate the impact of climate variability on the odds of household-level migration, we employed logistic regression models. Owing to the hierarchical data structure (households are nested within provinces/departments), we employed a multi-level version of the conventional logit models as formally described in Equation 1.

$$logit\left(y_{ij}\right) = b_0 + b_1\left(cv_j\right) + \sum_{n=2}^{k} b_n\left(x_z\right) + u_j \quad (1)$$

In equation 1, a logit link function is used to estimate the binomial migration response of households i located in province/department j. Parameter b_0 constitutes the conventional intercept, while the effect of climate variability (cv_j), which operates at the province/department j, is reflected by parameter b_1. Due to the substantial correlation among the climate variables, we estimated separate models for each climate predictor. The models control for the effect (b_n) of n to k socio-demographic and spatial characteristics (x_z), which may influence migration patterns at the household ij or province/department level j. The parameter u_j constitutes the province/department random effects term, which accounts for the clustering of households within administrative units. The variance components were transformed to Median Odd Ratios (MOR) (Larsen & Merlo, 2005) to facilitate comparisons with the fixed-effects coefficients.

To explore the spatial patterns in the climate-migration relationship we employed a geographically weighted regression (GWR). Using a distance weight function (bi-square adaptive kernel), the GWR fits separate models for each province/department, resulting in local estimates that allow for the exploration of spatial patterns (Fotheringham *et al.*, 2002; Gollini *et al.*, 2015).

Results and Discussion

To capture the various factors influencing the probability of an international move (Brown & Bean, 2006), we built a multivariate base model (Table 2). Tests for multicollinearity showed that baseline temperature and precipitation controls for Burkina Faso are highly correlated (r = −0.95) and we control only for baseline temperature in the models for Burkina Faso. Using this model specification, the variance inflation factor (VIF) values for all predictors remained below 3.6, indicating that multicollinearity does not bias the estimates.

Table 2 shows many similarities in the influence of sociodemographic factors on the probability of migration for both countries. The typical international migrant from Burkina Faso and Senegal comes from a relatively large household in which few members achieved primary education. The household usually owns their home, is comparatively wealthy (Hunter *et al.*, 2014), and has good access to migrant networks (Fussell & Massey, 2004). Marital status and religion are important predictors only for Burkina Faso where migration is more likely from non-Muslim households in which the household head is unmarried (cf., Gubhaju & De Jong, 2009). In contrast, higher levels of migration from Senegal occurred from households with a higher proportion of retirees, located in departments with limited access to urban infrastructure and limited primary sector activity (e.g., groundnut production). Migration dynamics differ in directionality across sociodemographic dimensions such as the age of the household head, the presence of dependent children, and the proportion of adults employed, suggestive of country-specific differences in the cultural, geo-historical, and political context.

Climate effects

To investigate the influence of different climatic effects on international out-migration, we added one climate variable at a time to the multivariate base model (Table 3). To test for influential area units, we performed a jackknife-type procedure in which we iteratively removed one province/department from the sample and re-estimated the models (Nawrotzki, 2012; Ruiter & De Graaf, 2006). This test revealed a high degree of robustness of the reported estimates.

Table 3 shows few significant climate coefficients, consistent with the notion that climate effects on international migration are usually indirect in nature and difficult to detect (Black *et al.*, 2011a). For Burkina Faso, an increase of 10% in heat-wave months (about 7 months across the 6-year observation period) led to a decline in the odds of an international move by 20% (Odds ratio [OR] = 0.80). This observation may be explained in reference to the agricultural pathway. For example, cotton production is sensitive to heat stress and temperatures exceeding 28-30 °C, which usually leads to a rapid decline of fruit retention, delayed crop maturity, and strongly reduced lint yield and quality (Brown, 2008). Negative effects of temperature on agricultural production are well documented for various other crop types (Lobell & Field, 2007; Lobell *et al.*, 2013; Schlenker & Roberts, 2009). Households in rural areas of Burkina Faso heavily depend on agricultural production for income generation and sustenance (Reardon *et al.*, 1992). With little technological infrastructure available, adverse climate variability may translate into a decline in agricultural income and job availability. In the face of income decline, households may lack the resources to finance an expensive international move, leading to a decline in migration rates (Henry *et al.*, 2004).

In contrast, for Senegal, an increase of 10% in months with excessive precipitation led to an approximately 4 times higher probability of international migration (OR=3.84). Sufficient water is important for plant growth and agricultural production and may lead to higher crop yields and agricultural income (Mueller *et al.*, 2014). In general a linear function describes the yield response to water supply, with increased production under conditions of higher levels of irrigation or rainfall (Steduto *et al.*, 2012). For example, the amount of rainfall is the primary determinant of groundnut yield in many arid and semi-arid countries with little irrigation capacity (Reddy *et al.*, 2003). Studies for Senegal have shown that a doubling in water supply (390 to 760 mm) led to a 2.5 fold increase in pod yield (1592 to 3900 kg/ha) (Sarr *et al.*, 2004). Yet, if too much rainfall results in flooding and waterlogging, crop production and livelihoods may be negatively impacted (Conway *et al.*, 2005). However, given that 4 out of the 6 years of the observation window (1997-2002) showed below average precipitation (see Figure 2) and because of the arid to semi-arid overall climatic conditions in Senegal, an increase in precipitation was likely beneficial for agricultural production by increasing the water supply without surpassing thresholds to flooding.

In combination, these results help answer our first research question (Do adverse climatic conditions increase or decrease international outmigration from Burkina Faso and Senegal?). The findings show that adverse climate conditions decrease international outmigration, suggestive of the climate inhibitor mechanism. While positive climatic conditions enable an international move, adverse climatic conditions appear to “trap” rural people in place (Black *et al.*, 2011b).

Climate-agriculture interactions

In the next step of the analysis, we interacted the climate measures with the cotton/ groundnuts harvested area to investigate whether agriculturally dependent regions are more susceptible to climate effects (Table 4).

We observe only one significant interaction emerging for Senegal. Table 4 shows that the effect of droughts varies substantially by the proportion of the department's area harvested with groundnuts. Figure 3 illustrates the conditional interaction effect. For departments in Senegal involved in the production of groundnuts to a limited degree (e.g., 10th percentile), the effect of droughts on the probability to migrate is weak. However, the effect becomes stronger (steeper slope) with higher levels of dependence on groundnuts (e.g., 90th percentile). Further confirming the *inhibitor mechanism*, we observe that droughts depress international moves from Senegal for agriculturally dependent regions (c.f., Henry *et al.*, 2004). Although groundnuts are well adjusted to semi-arid and arid conditions, droughts and resulting water deficits can substantially reduce crop production and yield (Kambiranda *et* *al.*, 2011; Reddy *et al.*, 2003). When households' food supply, income and jobs heavily depend on groundnut production, drought associated yield losses will undermine the resource base necessary for sending a member to an international destination. To explore the spatial distribution of the observed interaction, we employed a GWR model (Figure 4).

Figure 4 shows that the strongest negative effects of droughts on international outmigration emerged for a number of departments in the southwestern region of Senegal bordering Gambia (Kaffrine, Nioro du Rip, Kaolack and Foundiougne on the northern border of Gambia and Sedhiou and Bignona on the southern border). These areas are highly dependent on agricultural production and show the highest levels of area planted with groundnuts (Figure 4b).

Seasonality of climate effects

As a final step in our analysis, we investigated seasonal patterns of the climate - migration association. Records of planting and harvesting dates (Sacks *et al.*, 2010) for important crop types in Burkina Faso and Senegal suggest that the average growing season length ranges between 4 and 6 months. As such, we computed climate measures using a moving window of 5 months (e.g., Jan-May, Feb-Jun, etc.), starting in the month reported in Figure 5. As a robustness test, we also estimated climate effects with window sizes of 4 and 6 months and observed largely similar patterns.

Figure 5 Panel A shows that the effect of an increase in heat waves in the district of residence on international migration from Burkina Faso is strongest during the 5-month periods starting between July and October. These periods roughly overlap with the crop growing season ranging from June to November (Imran *et al.*, 2013). Heat waves are particularly problematic during sensitive stages of the growing cycle of cotton such as flowering (Oosterhuis & Robertson, 2011), which explains the adverse effect on international migration.

We also observe seasonal patterns for the effect of excessive precipitation on international outmigration from Senegal. The average crop growing season lasts from July to December (Sacks *et al.*, 2010). Interestingly, the largest beneficial effects of increased precipitation are observed prior to the growing season months (5-month periods starting February to April). Crops rely heavily on stored soil moisture in the early stage of development. The soil moisture stored during early months is slowly released during the growing season with beneficial impacts on plant growth and maturation (cf., McLeman *et al.*, 2010). The importance of antecedent climate conditions for current plant growth is a well-known ecological phenomenon (Ogle *et al.*, 2015).

Interaction models and seasonal patterns help answer our second research question (Is there empirical evidence for the agricultural pathway in the climate-migration association for Burkina Faso and Senegal?). We find some evidence in support of the agricultural pathway. Droughts showed the strongest effects on migration in Senegalese departments with high agricultural dependence. In addition, we observed clear seasonal patterns between climate variability and migration response that overlap with the growing season for temperature effects and predate the growing season for precipitation effects.

Conclusion

In this study we combined census data with high-resolution climate data obtained via the novel TerraPop data extract system. Methodologically, this study improves on prior work by using a set of climate measures that captures monthly variation in temperature and precipitation at the province/department level in combination with nationally representative census data from Burkina Faso and Senegal. Substantively, this study offers an investigation of the climate driver versus the climate inhibitor mechanisms and adds to our understanding of the agricultural pathway. Due to the indirect nature of climate effects on agriculturally dependent livelihoods, it is no surprise that we observe few significant climate effects on international migration. While excessive precipitation is positively associated with international migration from Senegal, heat waves decrease the probability of international migration from Burkina Faso. The directionality of the climate effects provides empirical support for the climate inhibitor mechanism: among marginalized populations in rural Africa, adverse climate conditions inhibit international migration while beneficial climate conditions enable international moves. Adverse climate conditions likely undermine the resource base necessary for financing an international move (Henry *et al.*, 2004). In addition, our findings provide support for the agricultural pathway. Results from interaction models demonstrate that the effect of droughts on international migration from Senegal is strongest for areas heavily involved in groundnut production. This interaction predominantly emerges for departments in the southeastern part of Senegal at the border to Gambia. Clear seasonal patterns in the climate-migration relationship provide additional evidence for the agricultural pathway.

Although carefully conducted, this study is not without limitations. For example, census data does not allow us to explicitly account for destination pull factors, which likely influence the decision to migrate. Similarly, we lack information on agricultural income and employment, which limits our exploration of the agricultural pathway to the use of proxy-indicators such as crop harvested area and seasonality effects.

With these limitations in mind, our findings have a number of important policy implications. Contrary to the assumption that adverse climate conditions will lead to massive population displacement (Myers, 2002; Stern, 2007), our findings suggest that adverse climatic conditions may trap people in place, at least in poor African countries. Immobility may be problematic when migration is viewed as means for climate change adaptation (Black *et al.*, 2011b). Money and goods remitted home may play a major role in financing rural adaptation to climate change. For example, in Africa remittances to home communities quadrupled to nearly US$40 billion between 1990 and 2010, and are associated with reductions in poverty, improved health and education outcomes, and increased business investments (Ratha *et al.*, 2011). As such it would be beneficial to make channels for voluntary migration available that would allow rural households to leverage international migration as a means to improve livelihood security.

Our results further suggest that agricultural dependence increases sensitivity to droughts in Senegal. Given the importance of agriculture to livelihoods in Senegal, governments and aid donors could help increase livelihood resilience by facilitating access to improved crop varieties, providing farmers with the knowledge about alternative cropping techniques, and expanding irrigation infrastructure where feasible (WB, 2008). In addition, improving access to weather-indexed crop insurance schemes may reduce households' sensitivity to adverse climate shocks and stabilize livelihoods (WB, 2005).

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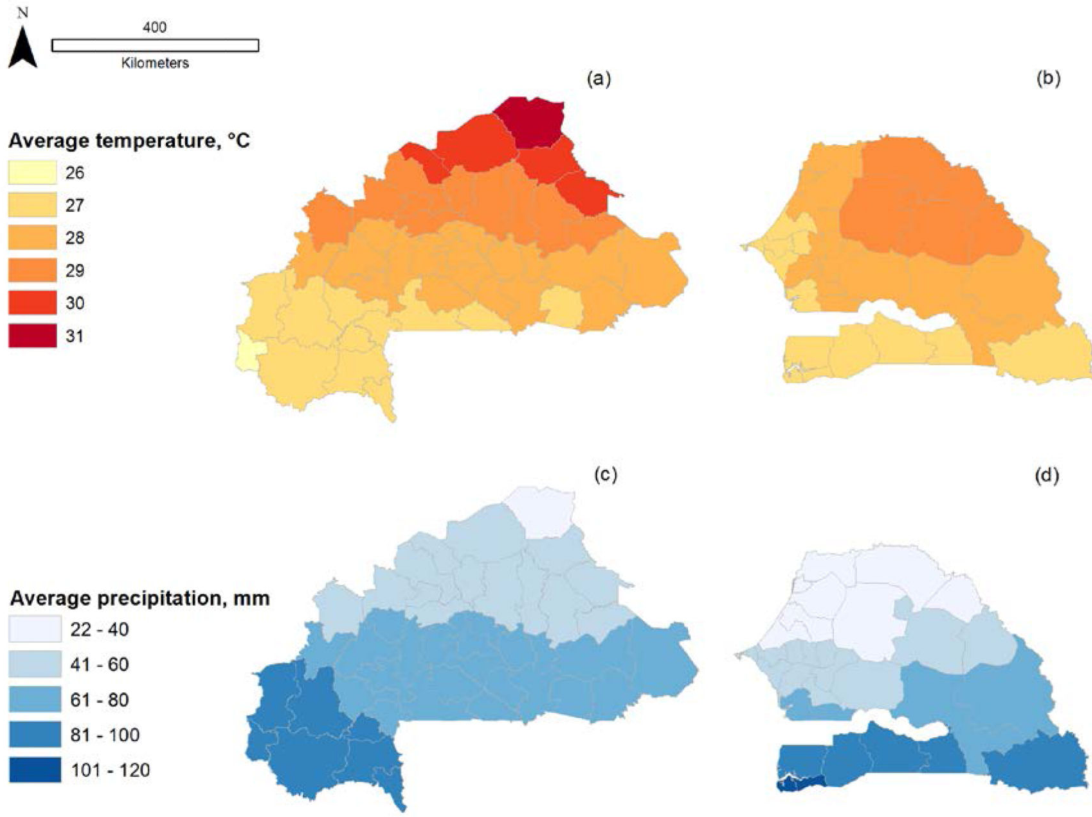


Figure 1.

Maps of average annual temperature and precipitation during the baseline period (1961-1990) for Burkina Faso (a, c) and Senegal (b, d)

Notes: Baseline climatic conditions computed from gridded monthly temperature and precipitation data, constructed by the University of East Anglia's Climate Research Unit (CRU) (Harris *et al.*, 2014) and available through TerraPop (Kugler *et al.*, 2015; MPC, 2013).

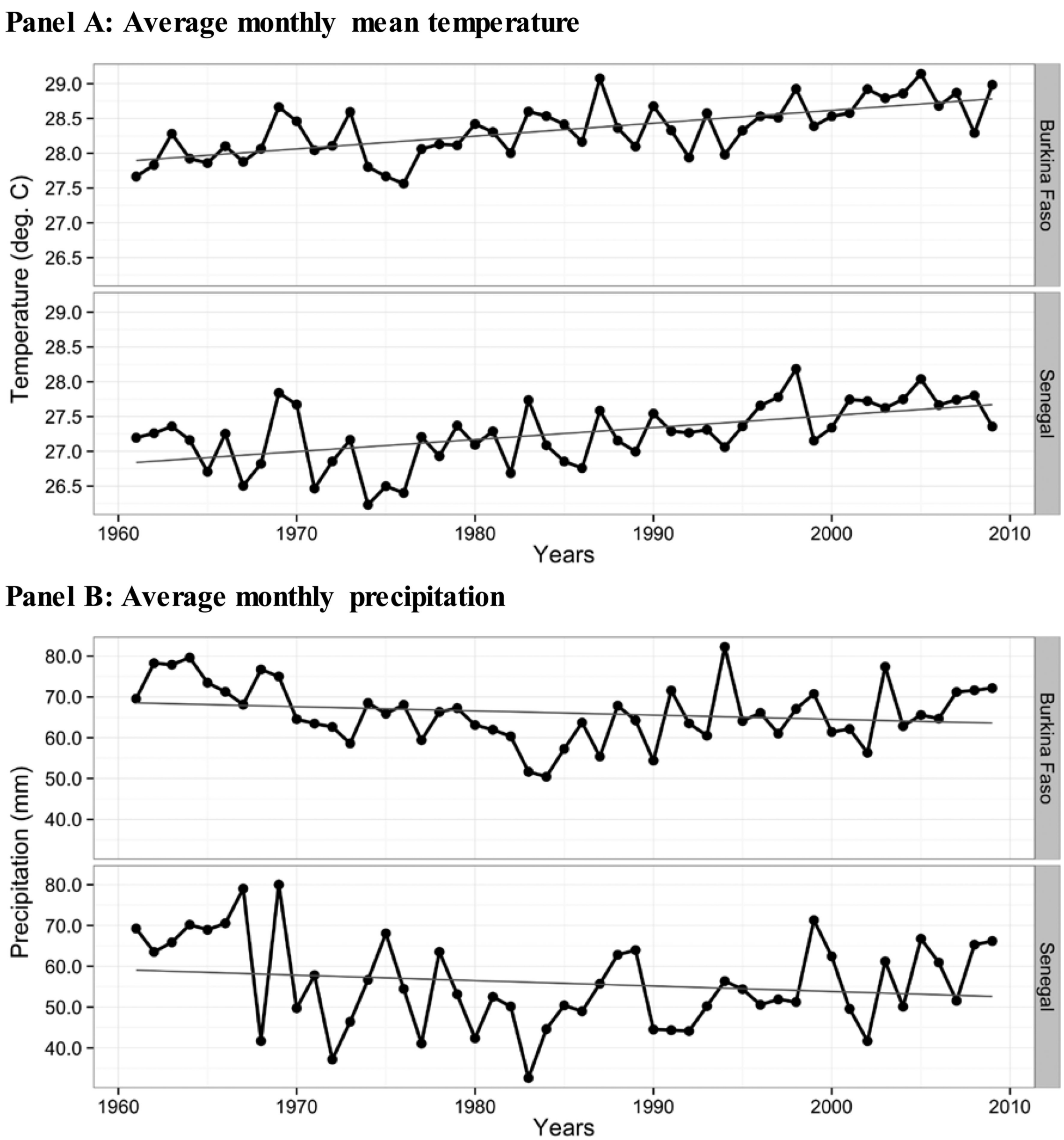


Figure 2.

Trajectory of average temperature and precipitation for Burkina Faso and Senegal across time

Notes: Time series computed from gridded monthly temperature and precipitation data, constructed by the University of East Anglia's Climate Research Unit (CRU) (Harris *et al.*, 2014) and available through TerraPop (Kugler *et al.*, 2015; MPC, 2013).

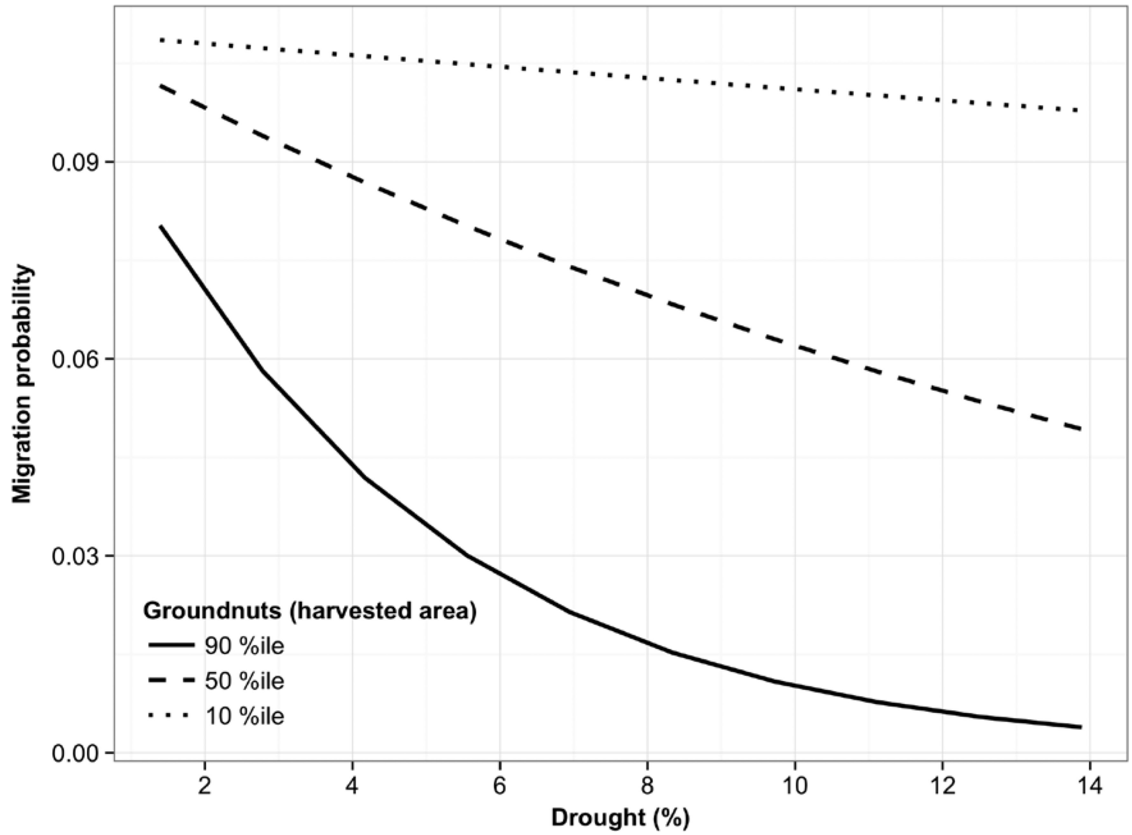


Figure 3.
Interaction between droughts and groundnuts harvested area in Senegal

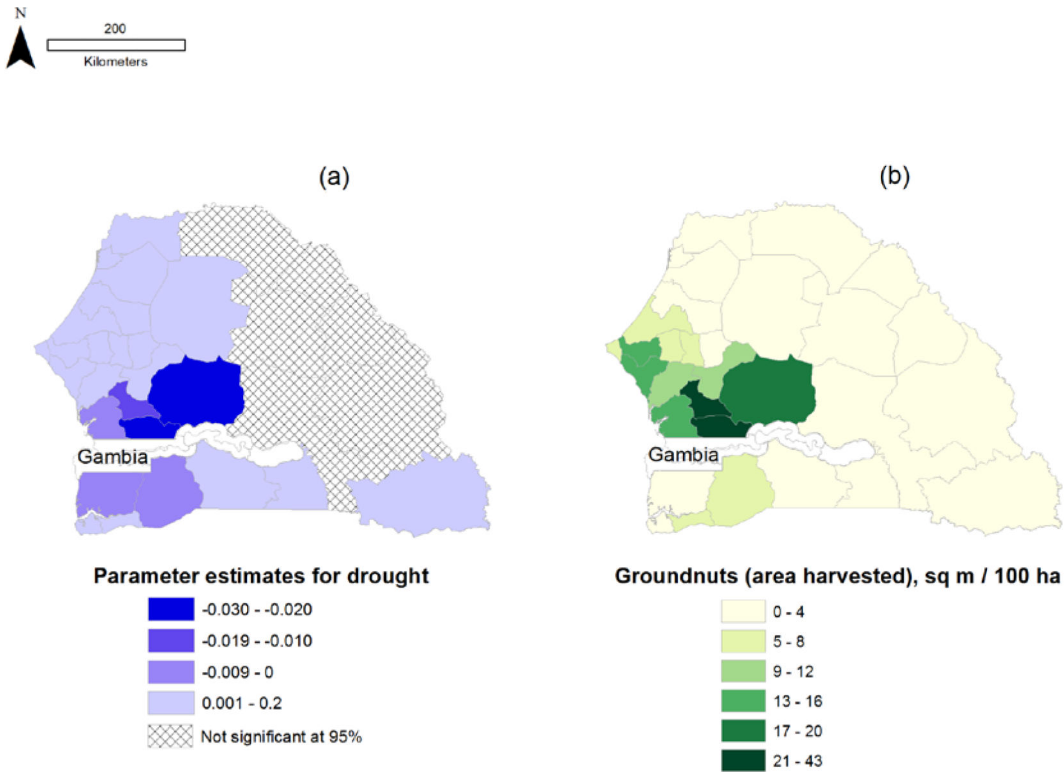
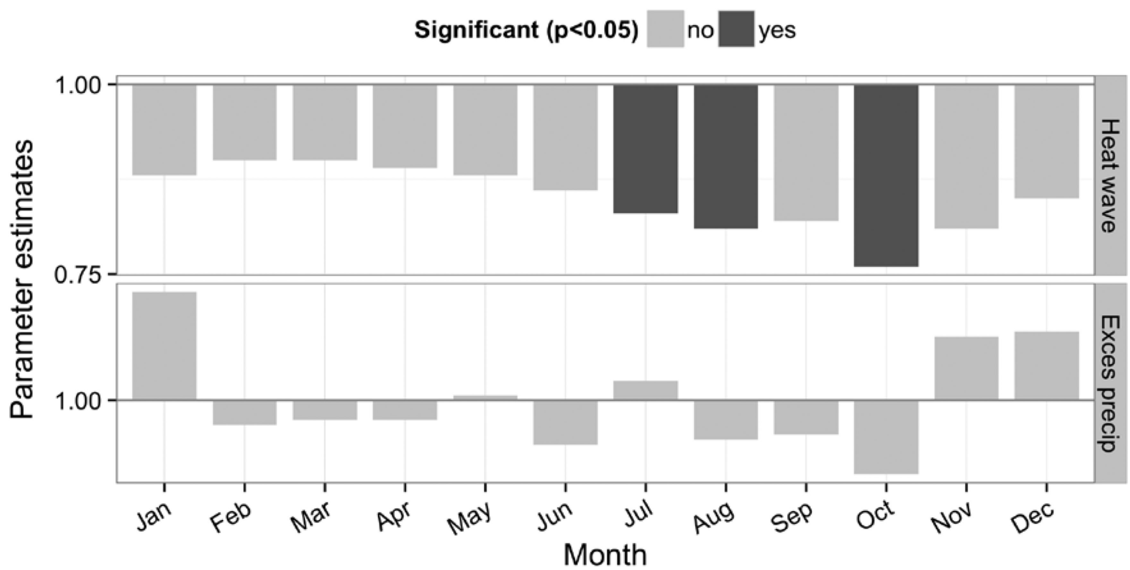


Figure 4.
Local estimates of the impact of drought on international migration (a), and groundnuts harvested area (b) for Senegal

Panel A: Burkina Faso



Panel B: Senegal

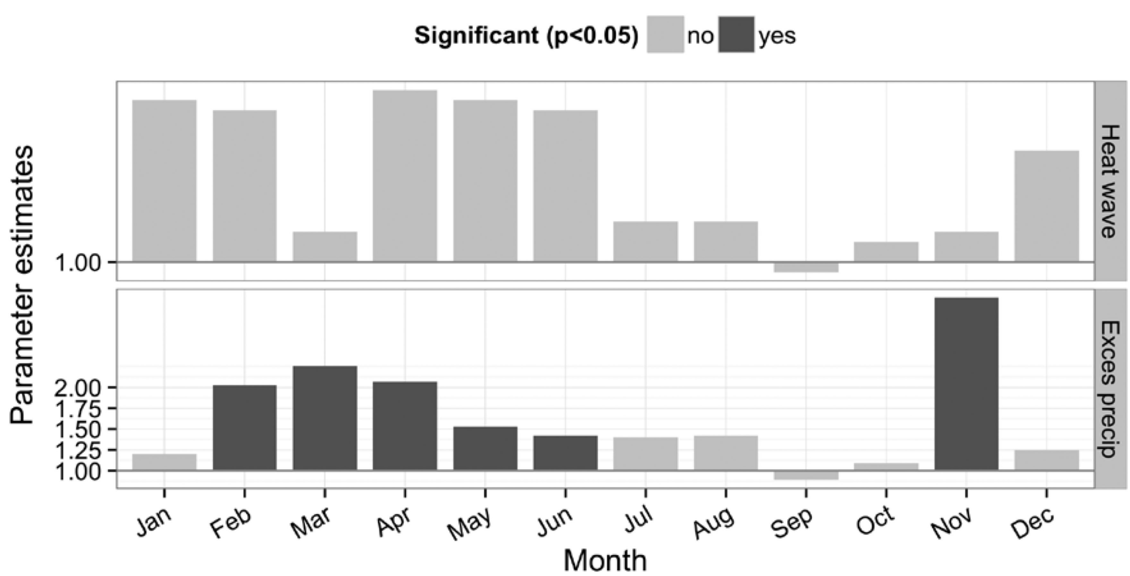


Figure 5.

Effects of climate change on international migration for various growing season specifications

Notes: Parameter estimates reported in odd ratios; seasonal climate measures were computed using a 5-month window starting with the months for which the coefficients are reported.

Table 1

Summary statistics of variables included in the analysis of the impact of climate change on international migration from Burkina Faso and Senegal

	Unit	Min	Max	SD	Sample mean	
					BF	SN
Outcome variable						
Migrant HH	1|0	0	1	0.3	0.10	0.11
Household controls						
Head married	1|0	0	1	0.26	0.90	0.99
Muslim	1|0	0	1	0.46	0.60	0.96
Age of head	years	15	98	15.92	42.97	49.56
Primary education	%	0	100	14.16	4.45	5.98
Child dep. ratio	%	0	90	20.92	39.32	43.56
Retiree dep. ratio	%	0	100	12.71	4.60	4.60
Employed in HH	%	0	100	26.11	50.59	35.31
Persons in HH	count	1	99	5.21	6.32	10.32
Home owner	1|0	0	1	0.27	0.93	0.91
Wealth index	count	0	9	1.64	0.88	2.36
Province/department controls						
Network density	%	0.37	27.95	6.89	12.05	4.38
Urban land	%	0	4.68	0.67	0.16	0.48
Cotton/groundnuts	sqm/100ha	0	42.71	6.40	0.72	6.70
Baseline climate hot	1|0	0	1	0.50	0.49	0.55
Baseline climate wet	1|0	0	1	0.50	0.49	0.52
Climate measures						
Heat wave	%	19.44	55.56	8.39	34.2	39.11
Cold snap	%	0	18.06	3.60	2.07	3.32
Drought	%	0	13.89	3.50	6.20	5.60
Exces precip	%	5.56	16.67	2.28	10.19	9.36
Climate impact index	%	9.72	34.03	5.14	20.2	22.36
Sample size						
Households	count				133686	57052
Provinces/departments	count				45	31

Notes: min, max, and SD computed acro ss samples; Source: data obtained via Terra Populus; BF = Burkina Faso (2006 census), SN = Senegal (2002 census).

Table 2

Base models predicting the odds of international migration from Burkina Faso and Senegal

	Burkina Faso		Senegal	
	b	sig.	b	sig.
Variables				
Intercept	0.02	***	0.02	***
Head married	0.87	***	1.10	
Muslim	0.75	***	0.95	
Age of head [a]	0.97	***	1.05	***
Primary education [a]	0.94	***	0.97	*
Child dep. ratio [a]	1.02	***	0.97	***
Retiree dep. ratio [a]	1.01		1.08	***
Employed in HH [a]	1.01	**	0.93	***
Persons in HH [a]	1.09	**	1.54	***
Home owner	2.07	***	1.63	***
Wealth index	1.02	**	1.39	***
Network density [a]	1.99	***	2.83	***
Urban land	0.97		0.65	*
Cotton/groundnuts	0.93		0.98	*
Baseline climate hot	1.30		1.30	
Baseline climate wet			0.75	
Model statistics				
Random intercept	1.451		1.573	
BIC	79620		33811	
N (households)	133686		57052	
N (provinces/departments)	45		31	

Notes: Parameter estimates reported in odds ratios

[a] coefficients reflect an incremental change of 10 units

* $p<0.05$

** $p<0.01$

*** $p<0.001$

Table 3

Effects of climate on the odds of international outmigration from Burkina Faso and Senegal

	Burkina Faso		Senegal	
	b	**sig.**	**b**	**sig.**
Heat wave	0.80	*	1.13	
Cold snap	0.95		0.89	
Drought	1.01		0.72	
Exces precip	0.98		3.84	**
Climate impact index	0.78		1.21	

Notes: Coefficients reported in odds ratios; coefficients reflect a 10% change in the number of months across the observation window during which a particular climate event was observed; each climate effect was estimated using the fully adjusted base model (Table 2).

*** p<0.001

* p<0.05

** p<0.01

Table 4

Interactions between climate and crop area harvested on the odds of international outmigration from Burkina Faso and Senegal

	Clim		Crop		Clim × Crop	
	b	sig.	b	sig.	b	sig.
Burkina Faso						
Heat wave	0.80	*	1.04		0.94	
Cold snap	0.96		0.93		1.04	
Drought	0.98		0.97		0.88	
Exces precip	1.00		0.87		1.37	
Climate impact index	0.78		1.04		0.90	
Senegal						
Heat wave	1.24		0.96	*	1.03	
Cold snap	0.77		0.96	*	0.87	
Drought	0.33	*	0.93	**	0.88	*
Exces precip	2.32		0.98		0.85	
Climate impact index	1.40		0.97		1.05	

Notes: Coefficients reported in odds ratios; coefficients reflect a 10% change in the number of months across the observation window during which a particular climate event was observed; each interaction was estimated controlling for all variables included in the fully adjusted base model (Table 2); Clim = estimates of climate measures, Crop = estimates of crop harvested area (Burkina Faso: cotton; Senegal: groundnuts); Clim × Crop = estimates of interaction effects between climate measures and area harvested; variables were centered;

*** p<0.001

* p<0.05

** p<0.01