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RESEARCH ARTICLE

# Migration response to drought in Mali. An analysis using panel data on Malian localities over the 1987-2009 period

Dimitri Defrance,[1] Esther Delesalle,[2] and Flore Gubert[3]*

[1]The Climate Data Factory, Paris, France; [2]UMR Développement et Sociétés and IEDES-Paris 1 Sorbonne, Nogent-sur-Marne, France and [3]IRD, Université PSL, LEDa, Université Paris Dauphine, CNRS, Paris, France
*Corresponding author. E-mail: gubert@dial.prd.fr

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**Abstract**
This paper combines population and climate data to estimate the volume of migration induced by the drought events that have hit Mali since the late 1980s. The results show that droughts have had the effect of decreasing net migration rates in the affected localities. This is true for both men and women, regardless of their age. The effect of drought episodes, however, is found to differ according to localities and households' capacity to adapt to climatic constraints: it fades in localities characterized by more diversified crops and in areas that receive more rainfall on average. Climate shocks also had an impact on international mobility: over the 2004–2009 period, around 2300 additional departures per year can be attributed to the droughts that hit Mali during the 2000s. We forecast that, under different climate scenarios and population growth projections, mobility induced by drought events will substantially grow in the next decades.

**Keywords:** climate change; migration; Mali

**JEL classification:** Q54; Q15; F22; O55

## 1. Introduction

Population mobility has been a common response to drought in various settings, with many examples coming from Sub-Saharan Africa. During the great drought of 1969–1974, for example, there were marked population shifts from the arid zones bordering the Sahara towards the cities of the Sahel, which grew by 6–10 per cent during this period (Findley, 1994). More recently, in 2011, the Horn of Africa was hit by one of its worst drought-related food crises which triggered large-scale internal and cross-border displacements.

With global warming threatening to dramatically shift climatic patterns and resulting in warmer and more frequent hot days and nights, increases in heat wave frequency and heavy precipitation events, especially in regions in the low latitudes, warnings have been raised about the impact of these changes on human migration (see, e.g., the World Bank's *Groundswell* report released in September 2021; Clement *et al.*, 2021). In countries less affected by climate change, in particular the OECD countries, this often translates into very alarming newspaper headlines about the number of climatic or environmental migrants likely to request asylum or protection and in presenting climate change and migration as a security risk. Yet estimates of the number of people likely to be affected by climate change and forced to migrate are notoriously difficult to provide. This results in future forecasts on climate migrants ranging from 25 million (Myers, 1997) to 1 billion people by 2050, with 200 million being the most widely-cited estimate (Myers, 2002; Stern, 2007).

One of the reasons that explains such a wide variation in migration estimates is that in most circumstances it is impossible to distinguish climate migrants, i.e., individuals for whom climate factors are the sole driver, from "non-climate migrants". This is especially true in contexts where labor migration is a central element in the livelihoods of many rural households and a "normal" element of their life rather than an exception (de Haan, 1999). The challenge is hence to assess to what extent climate change alters or will alter existing migration patterns, both temporal and permanent, which people in climate-vulnerable areas are already engaged in for securing their livelihoods. This paper is a step in this direction.

Our aim is to gather population and climate data to conduct a geographically disaggregated analysis and assess to what extent drought episodes that have hit Mali since the end of the 1980s have influenced the scale and patterns of migration flows within and out of the country over the two decades of the 1990s and 2000s. Conducting such an analysis is helpful to understand how the climate has contributed to shaping the spatial distribution of the Malian population in the past, in order to better anticipate what could happen in the future and project emigration responses to future climate change scenarios. Mali is an interesting case to study for several reasons.

First, Mali's economy heavily relies on agriculture and agropastoralism: 66 per cent of its population is engaged in this sector of activity, which accounts for more than 35 per cent of gross domestic product (FAO, 2015). With only 8.9 per cent of cultivated land having irrigation facilities, agricultural production is dominated by small-scale, rainfed subsistence agriculture. Climate anomalies recorded in Mali in the past 30 years and their likely impact on agricultural productivity and livelihoods thus provide an opportunity to examine the relationship between climate and migration.

Second, given its size, Mali is characterized by a diversity of agro-ecological zones. The Desert or arid zone receives less than 400 mm per year and has historically relied on pastoralism and trans-Saharan trade. The Sahelian or semi-arid zone receives between 400 and 800 mm per year of precipitation and is suitable for rainfed millet and sorghum. The Sudanian or semi-humid zone receives more than 800 mm per year of precipitation and allows the cultivation of cotton, an important cash crop, in addition to traditional crops, maize and fruits (see figure A1 in the online appendix). This diversity makes it possible to test for differences in migratory responses to climate anomalies depending on affected individuals' place of residence.

Third, Mali is characterized by high migration rates, both internal and international. As of 2010, which marks the end of the period studied in this paper, 1,013,760 Malians representing 6.7 per cent of the population were living abroad, mainly in neighboring countries but also in France, Spain and other parts of the world. According to INSTAT

(2012), internal migrants represented 16 per cent of the population in 2009.[1] In this context, it is interesting to see whether and to what extent climate anomalies in Mali have contributed to shaping migration patterns. A local-level case study conducted in Mali's Senegal River valley, in the Western part of the country, found that the overall level of migration during the 1983–1985 droughts actually stayed constant. However, migration patterns changed, with less migration from Mali to international destinations, and more rural-urban moves, especially among women and children (Findley, 1994). Whether this happened at a broader level is a question that needs to be investigated. Finally, the availability of census microdata also makes Mali an advantageous context for studying climate effects on migration at a highly disaggregated level.

This article contributes to a growing literature that investigates the link between climate variability and migration which has been recently reviewed by Cattaneo *et al.* (2019). Existing studies can be broadly categorized according to their level of analysis.[2] Cross-country analyses rely on large panels of countries and generally study decennial averages of net emigration flows or urbanization rates (used as a proxy for internal migration rates) over 30- or 40-year periods. Overall, their conclusions on the direction and magnitude of the influence of climate or environmental change are contrasted and range from a limited or rather indirect role (as in Naudé, 2010) to significant impacts (see, e.g., Barrios *et al.*, 2006; Marchiori *et al.*, 2012).[3] In addition, migration response to weather anomalies is not uniform across countries: shortages in rainfall have increased urbanization rates on the Sub-Saharan continent but not elsewhere (Barrios *et al.*, 2006); and increases in temperatures have accelerated international migration in middle-income countries but not in poorer ones which could be explained by binding liquidity constraints (Cattaneo and Peri, 2016).

Other authors have investigated the link between climate variables and migration using multi-country bilateral (dyadic) migration data, which not only increase the sample size but also allow for the control of country-pair specific factors in an augmented gravity model (see, e.g., Cai, 2016; Missirian and Schlenker, 2017; Wesselbaum and Aburn, 2019). Most of them find a significant influence of weather anomalies on migration flows, with agriculture (Cai, 2016) and conflict (Burke *et al.*, 2015) being some of the channels explaining the link between the two. One limitation of the above analyses is that they rely on aggregated variables and neglect within-country heterogeneity. As underlined by recent research, climate effects on migration are complex and contingent upon a number of factors at macro-, meso- and micro-scales. This may result in significant between-group or between-region heterogeneity within a given country that is worth investigating if one wants to design effective social protection policies *vis-à-vis* climate impacts.

Micro or local studies are in this perspective a nice complement to cross-country studies in that they generally allow some of the factors and contextual effects playing a role in

[1]A migrant is defined here as someone whose place of residence at the time of the census is different from his place of residence at birth, regardless of intervening migrations. This definition corresponds to what demographers call lifetime migration.

[2]Studies also differ in the way they measure climate change: some use deviations of temperature and/or rainfall from long-term trends; others use the frequency of natural disasters caused by climate change (floods, hurricanes, etc.).

[3]As argued by Berlemann *et al.*, 2021), a factor which explains this mixed picture is the method used to derive migration flows from migrant stock data.

the migration-environment association to be taken into account.[4] Overall, most of them confirm the influence of environmental and climate change on migration. But they also find that the contribution of environmental or climatic variables in the explanation of migration is sometimes lower than other variables, such as population density (Van der Geest *et al.*, 2010) or literacy and economic activity rates (Henry *et al.*, 2003). They also find differences in climate effects according to affected individuals' sex and age (Findley, 1994; Gray and Mueller, 2012). The limitation of these micro-studies is that they are generally based on household surveys covering a limited number of households and communities, which restrains the diversity of observed climatic conditions. Moreover, because they rely on panel data with a short time dimension, they generally fail to identify long-term trends in migration patterns and only focus on short-term or temporary displacements.

In order to overcome these limitations, this paper uses population data taken from the three latest population and housing censuses conducted in Mali in 1987, 1998 and 2009. We rely on population increment between censuses at the level of each Malian locality ($n = 11,000$) to infer net migration rates, and combine these data with climate data in order to assess the influence of weather anomalies on migration patterns. We also use the migration module included in the 2009 census to compute international migration rates at this level of disaggregation. While other papers have relied on exhaustive census data to analyze the climate-migration nexus (see, e.g., Joseph and Wodon, 2013; Strobl and Valfort, 2013; Iqbal and Roy, 2015; Dallmann and Millock, 2017), none of them has been able to compute a dataset with net migration rates and international migration rates at such a highly-disaggregated level,[5] either because they had access to only one census or because they could not construct a panel of localities.[6]

In addition, because we have three censuses and two intercensal periods, we are able to control for spatial and temporal unobserved effects which may confound the results. Overall, we find that dry events that have unevenly affected the regions of Mali have had the effect of increasing migration from rural to urban areas. This is true for both men and women, regardless of the age group considered. Climate shocks also had an impact on international mobility. The effect of drought episodes on mobility, however, differs according to the localities and the capacity of rural households to adapt to climatic constraints: it fades in localities characterized by more diversified crops and receiving more rainfall on average. Based upon our empirical analysis, we also forward a tentative estimate of the number of environmental migrants in Mali between 1987 and 2009, as well as projections of future environmentally-driven migration based on UN population forecasts and future climate scenarios for the end of the 21st century.

The rest of the paper is organized as follows. Section 2 provides the conceptual framework and discusses the role of migration as a mechanism for coping with drought. The data and descriptive statistics are introduced in section 3. Section 4 presents the empirical strategy and benchmark results. In this section, we also test for differentiated climate effects along several dimensions including age, wealth, crop diversification

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[4]For recent African case studies, see, *e.g.*, Cattaneo and Massetti (2015) on Ghana; Kubik and Maurel (2016) on Tanzania; Gray and Mueller (2012) on Ethiopia; Lewin *et al.* (2012) on Malawi; Strobl and Valfort (2013) on Uganda. See also Borderon *et al.* (2019) for a recent survey.

[5]Feng *et al.* (2010) use state-level data ($n = 32$) in the case of Mexico and Iqbal and Roy (2015) use district-level data ($n = 64$) in the case of Bangladesh.

[6]In some countries, the names or the identifying codes of the localities changed from one census to another.

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and agro-ecological conditions. Section 5 discusses estimated volumes of past and future climate-driven migration and section 6 concludes.

## 2. Migration as a mechanism for coping with drought

Because of their dependence on rain-fed agricultural production, people in rural areas of developing countries are highly exposed to a range of types of shocks. Given the lack of well-functioning insurance and credit markets and the fragility or absence of social programs and services, they have developed various informal strategies for managing and coping with risk. These strategies are multi-faceted and can manifest themselves at two stages: *ex ante*, that is before shocks occur, in order to reduce their magnitude; and *ex post*, after shocks occur, in order to insulate consumption patterns from income variability (Morduch, 1995; Fafchamps, 2003).

Reducing exposure to risk can be achieved in various ways, most of which imply altering production choices: people may adopt and specialize in production techniques that are less dependent on rainfall (such as small-scale irrigation) or that are resistant to droughts and other environmental risk factors (growing pearl millet in Sahelian areas, for example); they may diversify their portfolio of income-generating activities by planting different crops or combining farm and non-farm activities; and so on. Even if all these strategies contribute to reducing risk, some risk may remain that must be dealt with *ex post*. People may dissave or borrow; they may liquidate part of their assets (through the selling of livestock or land); they may reduce or modify their food consumption or cut non-essential spending so as to keep their productive assets; they may alter household composition or intra-household distribution of food; and so forth. As a last option, people may well decide to rely on others, against a promise of future reciprocity. But this last strategy may be ineffective in times of drought when everybody is hit simultaneously.

Even though the above discussion made no specific mention of it, migration stands pretty much everywhere in this typology. Migration may be both an *ex ante* livelihood- and risk-diversification strategy and a way to deal with risk *ex post*, once a shock has occurred. It can also be thought of as a risk-sharing strategy, as migrants and their relatives who remain in the village generally agree in advance to help each other in case of troubles, as in a mutual insurance contract (Stark and Bloom, 1985).

In Sahelian countries, and in Mali in particular, local case studies suggest that both long-term rainfall conditions and short-term variations in rainfall influence temporary and permanent migrations (Findley, 1994; Manchuelle, 1997; de Haan *et al.*, 2002). Temporary moves usually involve only a few members of the household and represent a way to diversify incomes, both in non-drought years, during the dry season, and in periods of economic hardship (Gubert, 2002). Some migrations may also be planned with the specific goals of reducing the number of family members to be fed and thus household food requirements. Under strong cash constraints, for example, or in times of drought, young women may be encouraged to marry earlier than they might otherwise (which implies that they leave their parents' households to live with their husband's family), and children may be fostered out to other households living outside the village (see Akresh, 2009) in the case of Burkina Faso). Finally, some people are found to leave their village permanently in response to the risk of repeated droughts, in order to increase their preparedness for future hazards and thus their resilience, or after several consecutive years of bad harvest. Rather than a response to destitution or a disjuncture, migration seems in most cases to be a useful way through which households can further enhance their livelihood and food security.

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Another interesting result from the literature is that migration patterns are usually found to change in times of drought, with a shift towards more short-cycle, short-distance moves (Findley, 1994). Moreover, in communities affected by the same weather anomalies, people do not necessarily react in a similar way: households and individuals have their own ability to act, even though the extent to which they can exert it may vary depending on their social position (in terms of gender, generation, class or ethnicity, for example), and make their decisions depending on the opportunities that are offered to them and the various constraints they encounter (Carling, 2002; de Haan *et al.*, 2002; de Haas, 2014).

As regards migration destination choices, for example, two ingredients are found to be particularly important in the decision to move across borders: the first is resources, as it is costly to move long-distance; and the second is networks abroad, as newly-arrived migrants generally need support before they can make a living in their new country of residence. These two pre-requisites contribute to explaining why environmental stressors such as drought do not necessarily lead to long-distance and international migration and rather result in a shift towards short-distance moves: resources are scarce during droughts, so that people are limited in their ability to invest in long-distance migration. In that perspective, poverty exerts a constraint on international migration, which explains why the poorest people rarely move, and when they do, why they rarely move very far.

The lessons that can be drawn from these initial analyses is that the influence of weather anomalies on migration should differ according to affected individuals' sex and age as well as to affected households' wealth and "adaptive capacity" to endure climatic shocks locally. This translates into heterogeneity in migratory responses to climate events.

## 3. Data and descriptive statistics

We bring together high-frequency, geo-referenced climate and population data.

### *3.1 Climate anomalies: the SPEI*

As our main climate indicator, we use the standardized precipitation-evapotranspiration index (SPEI) from the high-resolution ($0.5^\circ \times 0.5^\circ$) gridded dataset developed by Vicente-Serrano *et al.* (2010). Several other objective drought indices have been developed and used, such as the Palmer Drought Severity Index or the Standard Precipitation Index, but the SPEI has several advantages over them. In particular, it allows for comparison of drought severity through time and space whereas the Palmer Drought Severity Index does not, and considers both the role of temperature and precipitation variability, while the Standard Precipitation Index only considers the latter (Vicente-Serrano *et al.*, 2010).

As explained by Vicente-Serrano *et al.* (2010), taking into account temperature in addition to precipitation is crucial since the impact of rainfall on the growing cycle of a plant also depends on the ability of the soil to retain water. This is captured by "potential evapotranspiration", which in turn depends on numerous parameters including surface temperature, air humidity, latitude, solar radiation and wind speed. The SPEI is calculated as the difference between monthly precipitation and the potential evapotranspiration, and has been shown to correlate better with hydrological and ecological variables than other drought indices in a variety of natural systems (Beguería *et al.*, 2014).

In terms of their interpretation, SPEI values represent standard deviations above or below historical SPEI values in a given location. This allows comparison of droughts across locations with very different climatology. To take a simple example, in absolute terms (millimeters of rain) a −1 drought in a Sahelian region will be very different from a −1 drought in a tropical forest region, but both situations are comparable because they represent the same degree of deviation from the normal conditions at each site, to which the natural vegetation of the area is adapted.

To account for different types of droughts, the SPEI is computed from different time scales. Short-time scales represent soil water content and discharge in headwaters, while medium-time scales refer to storage of water sources, and long-time scales illustrate variations in groundwater. To capture conditions that cause agricultural stress, we use the 12-month SPEI.[7]

The intensity of a drought is measured according to the value of the SPEI. SPEI values ranging from 0 to −0.99 correspond to a mild drought; from −1 to −1.49 to a moderate drought; from −1.5 to −1.99 to a severe drought, while an extreme drought corresponds to a SPEI value below −2. An excess of precipitation can be measured following exactly the same logic, beginning with a value of +1. The average SPEI values for Mali at a time scale spanning 12 months are displayed in figure A2 (online appendix). The figure shows large fluctuations over the 1967–2009 period for all Malian agro-ecological zones, with a dominance of dry events. The standardized anomalies of precipitation, evapotranspiration and temperature are particularly intense in the years 1973–1974, 1982–1984 and 2002, with SPEI values during the growing season corresponding to severe droughts. Outside these sub-periods, averaged SPEI values are mostly negative, with a few exceptions. Given these patterns, our empirical analysis will mainly focus on dry events since there is no clear sign of excess precipitation over the period under concern, at least at the aggregate level.[8]

For our empirical analysis, we create different variables to measure the number and magnitude of drought:

- *Number of dry years*: We define a binary variable (by locality) that takes the value 1 if the average monthly value of SPEI in a given year is below the average monthly value of SPEI computed from 1904 to the year of the survey by more than one standard deviation, and 0 otherwise. We then compute the number of dry years for each intercensal period.
- *Number of dry agricultural seasons*: We define a binary variable (by locality) that takes the value 1 if the average monthly value of SPEI during the agricultural season (from June to October) in a given year is below the average monthly value of SPEI from 1904 to the year of the survey by more than one standard deviation, and 0 otherwise. We then compute the number of dry agricultural seasons for each intercensal period.

Note that while these two variables will be mostly used in our regressions, we will also turn to other climate indicators, such as the number of *intense* dry years, translating into averaged SPEI values that are below the long-term average by more than 1.5 standard

[7]As a robustness check, we also use the 6-month SPEI.

[8]We nevertheless computed indicators such as the number of wet years in the intercensal periods at a disaggregated level to test the impact of wet events on migration flows, but as expected, these were never significant.

deviations, the number of dry years in respectively the first five years of the intercensal period and the last five years, and so on.[9] Figure A3 in the online appendix displays the number of dry agricultural seasons for each intercensal period and each Malian municipality. As is made clear from the comparison of the different periods, the 1977–1987 period was on average much dryer than the two subsequent ones. As a result, drought frequency is lower in the 1990s and even more so in the 2000s, which correspond to our two periods of analysis.

### 3.2 Measuring migration through the Malian population censuses

District-level migration data is not available from any secondary source or population register. We thus estimate net migration rates using three rounds of population censuses (1987, 1998 and 2009) and international emigration rates using the 2009 census.[10] The method used to compute our migration indicators by age cohort and sex, together with an assessment of their strengths and weaknesses, are detailed in online appendix B.

## 4. Empirical strategy and results

### 4.1 Empirical strategy

We first estimate regressions of the number of dry years on migration, using standardized net migration rates for different age-cohorts (net migration rates are standardized using their across-locality mean and standard deviation in order to make comparisons between regression coefficients across models easier).[11] All regressions are panel regressions with locality and period fixed-effects. Since we expect climate to have differentiated effects on rural and urban localities, we systematically interact our drought variable with a dummy taking the value 1 if the locality is urban. Equations whose estimation results are shown in tables 1 and A3 (online appendix) are of the following type:

$$NMR_{j,a,[t-11,t]} = \beta_0 + \beta_1 \sum_{i=0}^{11} drought_{j,t-i} + \beta_2 \sum_{i=0}^{11} drought_{j,t-i} * Urban + \delta_j + \delta_t + \epsilon_{j,t}. \quad (1)$$

$NMR_{j,a,[t-11,t]}$ is inter-census net migration rate at the locality level, where $j$, $a$ and $t$ refer to age-cohort, locality and inter-census period, respectively. $\sum_{i=0}^{11} drought_{j,t-i}$ is the number of dry years (or dry agricultural seasons) over the intercensal period; *Urban* is a dummy taking the value one if the locality is classified as urban in the census, zero otherwise; $\delta_j$ and $\delta_t$ are locality and period fixed effects respectively and $\epsilon_{j,t}$ is an error term. The locality fixed effects reduce the potential of omitted variable bias driving the estimated coefficients on our shock variable. Their inclusion in the model is particularly important given limitations in data availability, which restrict us from including variables that may be correlated both with climate and migration. The inclusion of period

[9] We also used other weather variables such as temperature and precipitation, but found out that the predictive power of our model was maximized when using negative SPEI shocks.

[10] We thank the Malian Statistical Institute for making the microdata available to us, and for helping with the construction of the panel of localities.

[11] Values of standard deviations are nevertheless provided in some tables so the results can be converted to actual migration rates.

**Table 1.** Drought effects on standardized net migration rates

| | Men aged 20-69 | Women aged 20-69 |
|---|---|---|
| Specification 1 | | |
| Nb. shocks from t-11 to t (June-Oct) | −0.013<br>(0.002) | −0.011<br>(0.002) |
| Urban × shocks from t-11 to t (June-Oct) | 0.009<br>(0.005) | 0.012<br>(0.003) |
| Specification 2 | | |
| Nb. shocks from t-11 to t | −0.014<br>(0.002) | −0.010<br>(0.002) |
| Urban × shocks from t-11 to t | 0.011<br>(0.005) | 0.012<br>(0.002) |
| Specification 3 | | |
| Nb. shocks from t-11 to t | −0.015<br>(0.002) | −0.011<br>(0.002) |
| Consecutive shocks | 0.004<br>(0.002) | 0.002<br>(0.003) |
| Urban × shocks from t-11 to t | 0.011<br>(0.005) | 0.012<br>(0.002) |
| Specification 4 | | |
| Nb. shocks from t-11 to t-5 | −0.011<br>(0.006) | −0.003<br>(0.008) |
| Urban × shocks from t-11 to t-5 | 0.015<br>(0.008) | 0.014<br>(0.005) |
| Std. Dev. | 2.740 | 2.894 |
| Village F.E | × | × |
| Period F.E | × | × |
| Observations | 18552 | 18553 |

Sample: Census from 1987, 1998 and 2009. Notes: Standard errors in parentheses corrected for serial correlation over one period and for spatial correlation up to a distance cutoff at 500 km. Std. Dev. corresponds to the standard deviation of net migration rates.

fixed effects allows us to control for path dependency of localities with historically and structurally high rates of emigration for reasons that may be climate-related or not.

We estimate equation (1) following the procedure of Hsiang (2010) based on Conley (1999) to adjust standard errors for both spatial and serial correlation.[12] In some specifications, we will also include a full set of region-by-period fixed effects, to adjust for all factors that are common across localities within a region by period, such as agricultural prices. District-by-period fixed effects, or even municipality-by-period fixed effects would have been even more appropriate, but a concern with the use of these interacted terms is that they absorb a significant amount of weather variance.

[12]Parameters are estimated by OLS, and standard errors are corrected accounting for serial correlation over one period and for spatial correlation up to a distance cutoff set at 500 km. We are thankful to Isabelle Chort and Maëlys de la Rupelle for sharing the amended version of the code in Hsiang (2010).

To illustrate this, table A1 (in the online appendix) summarizes regressions of SPEI values on various sets of fixed effects (period fixed effects only; locality plus period fixed effects; locality plus period plus district-by-period fixed effects and locality plus period plus municipality-by-period fixed effects[13] ) and how much variation they absorb. On the first line are reported the R-square values of the different regressions. As suggested by the figures, district-by-period and municipality-by-period fixed effects absorb almost all variation. As a result, introducing these interaction terms in equation (1) means that the identification of climate effects would rest on very slim margins. This is also true for region-by-period fixed effects, but to a lesser extent.

As an alternative, we adopt the Interactive Fixed Effect estimator, a flexible linear factor model developed by Bai (2009), and discussed by Totty (2017). Contrary to the OLS estimate that assumes an idiosyncratic error term, the factor model allows the error term to be composed of unobserved common factors correlated with the regressors:

$$\epsilon_{j,t} = \lambda_j' F_t + \mu_{j,t}. \tag{2}$$

$F_t$ is a vector of time-specific common shocks, and $\lambda_j$ are village-specific factor loadings that capture specific responses to the common shocks. The main advantages of this model is that no specific form of the unobserved heterogeneity is imposed, and the model still performs in the absence of common factors. In order to assess the impact of droughts on international migration, we use the following model specification:

$$IMR_{j,t} = \beta_0 + \beta_1 \sum_{i=1}^{5} drought_{j,t-i} + \delta_j + \delta_t + \epsilon_{j,t}. \tag{3}$$

$IMR_{j,t}$ is (standardized) international migration rate at the locality level where $j$ and $t$ refer to locality and year, respectively; $\sum_{i=5}^{5} drought_{j,t-i}$ is the number of dry years (or dry agricultural seasons) in the last five years; $\delta_j$ and $\delta_t$ are locality and year fixed effects respectively, and $\epsilon_{j,t}$ is an error term.

### 4.2 Benchmark results

Regression results are displayed in tables 1, 2, A3 and 3. Table 1 presents the main estimation results of equation (1) for men and women aged 20–69 using alternative drought measures. In all regressions, the results show that the number of droughts has an impact on standardized net migration rates, with significant differences between rural and urban localities. Focusing on the first drought measure, which considers the number of dry episodes during the agricultural season (from June to October) over each intercensal period, the results indicate that one additional dry agricultural season leads to a 0.013 standard deviation (SD) decrease in net migration rate in rural localities for men aged 20–69. The results for women are roughly similar, with an estimated 0.011 SD decrease in net migration rate for this sub-sample. The effects of drought episodes are much less pronounced in urban localities for both men and women, since the sum of the two coefficients is not significantly different from zero. These results are roughly the same when one uses alternative drought measures. Results further indicate that the occurrence of

[13]The different administrative divisions of Mali are as follows: regions; districts (*cercles*); municipalities (*communes*) and localities.

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**Table 2.** Drought effects on standardized in-, out- and net migration rates

| | Net Migration rate | In-migration rate | Out-migration rate |
|---|---|---|---|
| | | Men aged 20-69 | |
| Nb. shocks from t-11 to t | −0.014<br>(0.002) | −0.009<br>(0.006) | 0.013<br>(0.001) |
| Urban*Nb. shocks from t-11 to t | 0.011<br>(0.005) | −0.012<br>(0.010) | −0.015<br>(0.004) |
| Std. Dev. | 2.740 | 0.630 | 2.585 |
| Observations | 18,552 | 18552 | 18552 |
| | | Women aged 20-69 | |
| Nb. shocks from t-11 to t | −0.010<br>(0.002) | 0.001<br>(0.007) | 0.010<br>(0.002) |
| Urban*Nb. shocks from t-11 to t | 0.012<br>(0.002) | −0.011<br>(0.007) | −0.013<br>(0.002) |
| Std. Dev. | 2.894 | 0.296 | 2.830 |
| Observations | 18553 | 18553 | 18553 |
| Village F.E | × | × | × |
| Period F.E | × | × | × |
| District*Period F.E | × | × | × |

Sample: Census from 1987, 1998 and 2009. Notes: Standard errors in parentheses corrected for serial correlation over one period and for spatial correlation up to a distance cutoff at 500 km. Std. Dev. corresponds to the standard deviation of net migration rates.

drought episodes during at least two consecutive years does not have any additional effect on net migration rates, as suggested by the non-significance of the dummy variable *Consecutive shocks*.

Table 2 presents additional results using in- and out-migration rates in addition to net migration rates. The advantage of these alternative dependent variables is that they shed light on the underlying mechanism behind the negative impact of droughts on net migration rates. The results show that the reduction in net migration is driven by droughts encouraging people to leave their (rural) locality, and not by droughts making a (rural) locality less attractive as a migration destination.[14] Overall, this first set of results suggests that when a given area is hit by dry episodes, this translates into a change in migration patterns in the localities situated in this area: rural localities experience an increase in emigration flows, so that net migration rates decrease, while no such impact is found in urban localities.

The effect of droughts on net migration rate in rural localities is still robust after the introduction of region-by-period fixed effects (column (2) in table A2, online appendix), but becomes insignificant after the introduction of district-by-period fixed effects (column (3) in table A2). This is not surprising since these interaction terms capture most of the remaining variation. To account for unobserved heterogeneity across villages, we also apply the more flexible Interactive Fixed Effect model for a single factor, and we find

[14]Due to space limitations, all the other results presented in the paper are based on regressions using net migration rates as the dependent variable. The extensive results on in-, out- and net migration can be provided upon request.

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that the estimates (column (4) in table A2) are similar to the benchmark results (column (1) in table A2). We deduce from this comparison that the bias induced by unobserved common factors is negligible.

We next assess the extent to which the effects of droughts vary across different demographic groups. Table A3 presents the results of estimating equation (1) for men and women for different age-cohorts. The same patterns can be observed in rural localities: overall, dry episodes significantly increase out-migration rates which translates into a decrease in net migration rates for both men and women. The estimated change in net migration rate following one additional dry agricultural season is particularly strong for younger men aged 20–29.[15] We also find that the older the age-cohorts, the smaller the size of the effect. In the case of women, the SD decrease in net migration rate is the strongest for the cohort aged 30–39 (it is equal to 0.012) and ranges between 0.005 and 0.011 for the other cohorts. Unlike men for whom the impact of weather shocks on migration is found to decrease with age, no clear pattern emerges for women.

In urban localities, the results are less clear-cut, making their interpretation uneasy. In the male sub-sample, droughts are indeed found to decrease out-migration which translates into an increase in net migration rates for the older age-cohorts only. The same impact is observed in the female sub-sample whatever the age-cohort (except the youngest one). Table A4 in the online appendix presents the results obtained on the same sub-samples, after including region-by-period fixed effects. As already mentioned, introducing these interaction terms means that the identification of climate effects rests on very slim margins. The number of droughts is thus only significant for the sample of younger men.

Lastly we assess the impact of droughts on (standardized) international migration rates. Given the small occurrence of international moves at the local level in a given year, we are not able to disaggregate international migration rates by age. However, we disaggregate them by main region of destination, in order to take distance as a proxy for migration costs into account.

We consider four groups of countries that are mutually exclusive: (1) neighboring countries, that is countries which share a border with Mali; (2) African countries which do not share a border with Mali; (3) OECD countries excluding France; and (4) France.[16] Results on total migration rates and migration rates disaggregated by sex are shown in tables 3 and A5 (online appendix) respectively. Overall, the number of droughts in the last five years is found to increase international migration rates, whether one considers destination countries all together or specific ones, except OECD countries. In column (1) of table 3 which focuses on total outmigration flows, one additional dry agricultural season leads to a 0.045 SD increase in international migration rate. This increase is much higher when one concentrates on migration outflows to neighboring countries (+0.090 standard deviation, column (2)) but lower when the focus is on outflows to non-neighboring African countries (+0.023 SD, column (3)) and France (+0.019 SD).

With regards OECD countries (column (4)), drought frequency is not always significant, and when it is, it has a negative sign, which suggests that one additional dry agricultural season actually reduces migration outflows to these countries, with an estimated SD decrease in migration rate of 0.04. This could be the sign that when hit by a

[15] As a reminder, this cohort is composed of male individuals who were 9–18 years old in the 1987 or 1998 census, and hence 20–29 years old in the following censuses.

[16] For historical reasons, France is, within developed countries, the first country of destination for Malian migrants.

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**Table 3.** Drought effects on standardized international migration rates

| | (1) Total | (2) Bordering | (3) Africa | (4) OECD | (5) France |
|---|---|---|---|---|---|
| Specification 1 | | | | | |
| Nb. of droughts last 5 years (June-Oct) | 0.0450<br>(0.0090) | 0.0904<br>(0.0146) | 0.0227<br>(0.0082) | −0.0052<br>(0.0101) | 0.0193<br>(0.0085) |
| Specification 2 | | | | | |
| Nb. of droughts last 5 years | 0.0488<br>(0.0148) | 0.0910<br>(0.0152) | 0.0339<br>(0.0164) | −0.0419<br>(0.0103) | 0.0197<br>(0.0075) |
| Specification 3 | | | | | |
| Nb. of intense droughts last 5 years (June-Oct) | 0.0591<br>(0.0163) | 0.1352<br>(0.0206) | 0.0385<br>(0.0167) | −0.0419<br>(0.0167) | 0.0112<br>(0.0129) |
| Std. Dev. | 0.0418 | 0.00963 | 0.0347 | 0.00714 | 0.00955 |
| Village F.E. | × | × | × | × | × |
| Years F.E. | × | × | × | × | × |
| Observations | 59550 | 59550 | 59550 | 59550 | 59550 |
| Number of villages | 9925 | 9925 | 9925 | 9925 | 9925 |

Sample: Census from 2009. Notes: Standard errors are clustered at the district of origin and are reported in parentheses. Std. Dev. corresponds to the standard deviation of net migration rates.

shock, households lose the resources needed to fund long-distance moves. Since strong network effects are at play in migration to France, financial constraints may be less of an issue in this specific case. The coefficients associated with the number of *intense* dry agricultural seasons are even bigger in size: one additional intense dry agricultural season results in a 0.06 SD increase in international migration rates. Migration outflows towards neighboring countries in particular are found to be strongly responsive, as emigration rates towards this set of destinations more than double when a dry episode occurs. The same comments apply when the sample is disaggregated by sex (table A5). Female international migration rates are about ten times lower than male rates, but they also increase in times of drought, especially toward neighboring countries. All in all, this set of results suggests that rainfall conditions influence both internal and international migration. In times of hardship resulting from poor climatic conditions, people have a higher average propensity to migrate, particularly so towards short-distant, neighborliness countries. There might nevertheless be between-group or between-region heterogeneity in climate effects, which is the focus of the next section.

### *4.3 Testing for differentiated climate effects*

We push forward the previous analyses in order to test for the existence of between-group and/or between-region heterogeneity in climate effects. To this end, we use alternative model specifications that include interaction terms between our drought variable and factors expected to potentially mediate climate effects on migration rates. By so doing, we aim at providing insights into the mechanisms linking climate and migration.

We first assess to what extent the agro-ecological context matters in the drought-migration relationship. Since differences in the agro-ecological context create marked differences in the forms and intensity of agriculture, we expect variation in drought

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effects according to whether individuals' beginning-of-period residence was in localities situated in the Desert, the Sahelian or the Sudanese zone. Our prior is that more favorable agro-ecological conditions are associated with a greater availability of effective *in situ* or on-farm adaptation strategies that may prevent households from using migration as a mechanism for coping with drought. In other terms, because the set of options available to households residing in these areas is likely to be larger, we expect climate effects on migration to be lower.

Regression results are displayed in table A6 (online appendix). Given the mechanism we have in mind, we have excluded urban localities from our sample. Results show that the number of droughts has a significantly different impact on (standardized) net migration rate depending on the agro-ecological zone. The impact is the strongest in arid areas and the smallest in semi-arid areas. The size of climate effects on migration in the arid zone suggests that in this area, certain thresholds or "tipping points" may be reached, so that people living there have little choice left but to move when SPEI values deviate from their "normal" values. Similar results are obtained with international migration rates (table A7 in the online appendix). Columns (1) to (5) show indeed that the estimated coefficients of the drought variable are larger for arid areas than for semi-arid and semi-humid ones, for migration towards neighboring and OECD countries.

In order to get additional insights on the mechanisms linking climate and migration, we test whether crop diversification plays a role. To this end, we use an alternative model specification where the number of droughts is interacted with a crop diversification index ranked in quintiles. Crop diversification is measured here by the Gini-Simpson index. It is defined as $D_i = 1 - \sum_{i=1}^{j} s_i^2$ where $s$ is the share of farmland allocated to a particular crop category and $i$ indicates one of the $j$ possible crops grown by farmers. $D_i$ ranges between 0 and 1. The higher the index, the more diversified the land uses. To construct this index, we exploit the EarthStat dataset of croplands on a 10 km $\times$ 10 km latitude/longitude grid[17] that informs about the share of farmland allocated to the main Malian crops in the year 2000 (yam, cotton, fonio, groundnut, maize, millet, rice, sorghum and tobacco).

Regression results are displayed in table A8 in the online appendix. They show that in localities where crop diversification is the highest, one additional dry agricultural season has a negligible impact on (standardized) net migration rates, while the reverse holds true in localities where it is the lowest.[18] Planting different crops could hence be a way to reduce exposure to shocks and make farmers less vulnerable to dry events. However, only detailed data on agricultural incomes could tell whether this interpretation is the correct one, and we unfortunately do not have such data.

Finally, we assess whether individuals' response to a drought is wealth-dependent. Households' wealth may impact the drought-migration link in different, contrasted ways. On the one hand, wealthy households may be more able to maintain their level of consumption when hit by a shock than households already close to their subsistence level. They may indeed sell part of their assets and manage to smooth their consumption even if their incomes have dropped sharply. By contrast, poorer households may be forced to move to cope with the effects of drought. On the other hand, individuals at the

[17] See http://www.earthstat.org/harvested-area-yield-175-crops/.

[18] As suggested by a referee, we checked that our results were not driven by a correlation between population size and diversification by re-running the same regression on the sub-sample of localities with below-median population size and above-median population size. The regression produced the same results in both cases.

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bottom of the income distribution may be unable to migrate in the event of a shock for lack of resources, and end up being involuntarily immobile. Clearly, understanding how response patterns are distributed is crucial if one aims at designing effective social protection policies against climatic shocks. We thus interact the number of droughts with a wealth index ranked in quintiles and re-run our regressions on both net migration rates and international migration rates.

Our wealth index is a composite indicator computed from households' dwelling characteristics and asset ownership reported in the census.[19] We first performed a principal component analysis to get a wealth index for each household that we averaged at the localitygo level. Results are provided in tables A9 and A10 (online appendix). Climate effects are found to strongly vary by locality wealth. They are the strongest for poorer localities, and progressively diminish for localities of the top quintiles. Net immigration rates in localities in the fourth and fifth wealth quintiles are even found to increase with the number of dry years. No such clear pattern emerges with international migration rates (table A10): interacted terms are generally not significant, with a few exceptions: interestingly, international migration towards non-neighboring African countries is found to increase with drought frequency only in the richest localities, which may indicate that poverty is a constraint on long-distance migration within the African continent. However, the reverse holds true for migration towards OECD countries, which is found to decline with drought frequency in the richest localities. So further investigation is required to understand the mechanisms at play.

## 5. Projecting future net migration

As a last exercise, we predict potential migration scenarios under different climatic conditions using our estimates in tables 1 and 3. To this end, we use forecast values of SPEI from 2018 through 2077, to get a sense of how drought events in the future will affect migration, all else being equal and under the (strong) assumption that the responsiveness of migration to SPEI remains constant in the future. Clearly, the relationship between future climatic events and migration may change due to shifts in the demographic, economic and social contexts, as well as many uncertainties. Nevertheless, we believe historical evidence provides insights on possible future climate-driven migration and informs current policy discussions. We first describe the data and then present the results.

### *5.1 SPEI and population projections*

For our forecast exercise, we use corrected cell-level projections of daily accumulated precipitation and daily mean, minimum and maximum near-surface air temperature from the IPSL-CM5A-LR Atmosphere Ocean General Circulation Model, used in the CMIP5 exercises for the IPCC projection (see Famien *et al.*, 2018 for more details). The method for calculating evapotranspiration is based on the Hargreaves equation and uses mean, minimum and maximum daily air temperature as well as extraterrestrial solar radiation. We consider two alternative climate scenarios: the RCP 2.6 (also known as the "friendly-climate scenario") and the RCP 8.5 (the "pessimistic climate scenario").

[19]In addition to collecting population data, censuses include questions about housing characteristics such as material of walls, roof or floor, number of household members per room, access to utilities, e.g., type of water or sewage service.

Average projected drought frequencies over 2018 through 2077 are reported in table A11 (online appendix). Based on predicted SPEI values, it is expected that the number of droughts will significantly increase in both scenarios.

### 5.2 Projected migration outflows

Regressing unstandardized net migration rates on our drought index shows that one additional drought reduces net migration rate in rural localities by 3.5 and 3.2 percentage points for men and women, respectively. In order to see what these estimates imply for migrant outflows, we use the following formula based on equation (1):

$$\frac{\beta_2}{\overline{NMR_{j,a,[t-11,t]}}} * \frac{\sum_{j=1}^{n,rural} NM_{j,a,1998} * droughts_{j,[t-11,t]}}{11} \tag{4}$$

where the first term corresponds to the change in percentage of the average net migration rate, which equals −25.9 and −21.7 per cent for men and women respectively. In order to get an estimate of the volume of additional (net) migration outflows due to the number of dry years over the 1998–2009 period, we first multiply the number of droughts recorded in each locality over the 1998–2009 period by our estimate of the marginal effect of drought on the (net) migrant population measured at the locality level in 1998. As shown by column (7) of table A12 (online appendix), the number of droughts ranged from 0–9 depending on the locality, with a mean of 2.82 over the 1998–2009 period. By summing up these numbers, we then obtain an estimate of the number of additional migrants due to drought episodes for all Malian rural localities over the period 1998–2009. By dividing this number by 11, we finally get the number of additional "drought-induced" migrants in one year.

Based on these computations, we find that the drought episodes that hit Mali between 1998–2009 resulted in an additional net outflow of 7138 male and 6285 female rural migrants per year (figure A4 in the online appendix). We then replicate the exercise using the predicted number of droughts under the "friendly climate scenario" and the "pessimistic climate scenario" (see table A11) over successive 20-year-long time spans. The results are provided in figure A4. In both scenarios, the annual net outflow of "drought-induced" migrants is found to increase as a result of the predicted increase in the number of drought episodes. For the 2058–2078 period, it ranges from 21,409 and 38501 when we consider men and women altogether.

To go one step further, we use the population projections of the United Nations to account for the fact that the Malian population will grow in the next decades (table A13, online appendix).[20] By so doing, predicted net outflows of "drought-induced" migrants are found to significantly increase: we get an estimated number of 135291 additional (net) migrants in the most pessimistic scenario for the 2058–2077 period. Projected numbers are hence strongly dependent upon the chosen scenario and can be quite large.

In order to get estimates of the number of additional international migrants due to past drought episodes and expected in the next coming decades, we adopt a similar approach. We take the estimated marginal effect of drought from the international

[20]These projections are only available at the national level, so we need to rest on the assumption that population growth will be similar across regions and localities.

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migration specification – equation (3) – and apply the following formula:

$$\frac{\beta_1}{\overline{IMR_{j,t}}} \frac{\sum_{j=1}^{n} droughts_{j,[t-5,t]} * IM_{j,2004}}{5}.$$

Results are provided in table A14 (online appendix). Focusing on column (1), we find that the drought episodes that hit Mali during the 2000s resulted in about 2300 additional international migrants per year over the 2004–2009 period. This figure increases up to 24603 for the 2058–2078 period, when we consider the most pessimistic climate scenario and take population growth into account. This suggests that drought episodes mostly translate into an increase in internal migration flows. In any case, the estimated increase in the number of migrants as a result of potentially dryer decades is significant but not massive.

## 6. Conclusion

In this paper, we combine population census and climate data to estimate the volume of migration induced by droughts in Mali. In comparison to most previous studies, we are able to analyze the long-term effects of climate events on migration decisions at a highly disaggregated scale. The use of the three latest population and housing censuses allows us to compute population increments and to infer net migration rates at the level of each Malian locality. We also exploit the 2009 census that records the number of departures abroad that took place each year between 2004 and 2009 from each Malian locality, to analyze the impact of climate variability on international migration. In both approaches, we are able to account for very short-distance migration, which is often neglected in the literature. In order to identify the most vulnerable localities, we test whether the effect of climate events varies with the agro-ecological environment and with the level of village wealth. To get insights on potential adaptation mechanisms, we also explore whether the effect of climate events is weakened in more diversified areas. Finally, we make some predictions of future migration patterns in Mali based on our regression estimates.

Our results show that climate events increase migration from rural areas for both men and women, regardless of their age. Between 1998 and 2009, droughts episodes translated into an additional net outflow of 7134 male and 6281 female rural migrants of active age per year. The effect varies with the capacity of rural households to adapt to climatic constraints. It fades in localities characterized by more diversified crops and in those located in the Sudano-Sahelian and Sudano-Guinean zones that are less arid. Richer villages also appear to be less vulnerable to climate shocks.

Droughts episodes are also found to increase the number of international departures. From 2004 to 2009, the total volume of additional international moves induced by droughts is estimated at 2,000. The analysis by destination countries informs, however, that droughts tend to exacerbate international moves mostly toward neighboring countries, probably due to the cost of longer-distance moves.

Using our estimates, we finally show that the number of migrants will significantly increase in the coming decades due to the combined effect of increased population and more frequent weather extremes. Projections suggest that in the pessimistic climate scenario, the number of additional migrants of active age from rural areas could be as high as 130000 per year in the 2058–2078 period, once population growth is taken into account. This number is far bigger than the one obtained for the decade 2000–2010, but remains manageable, provided all movers do not converge towards the same destination region.

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If they do, their arrival will certainly affect both the economy and the environment in the receiving areas, which will call for effective policy responses to insure a sustainable development. With regard to international mobility, the estimated volume of additional migrants is also found to increase but not massively. As said before, these projections need to be viewed with caution as they are based on an *all else equal* assumption that is unlikely to hold, but they tend to temper a little the very alarmist messages conveyed by the discourse on climate migration. In any case, further empirically-grounded research is needed on this topic, and our hope is that the increasing availability of high-resolution data will facilitate this.

**Supplementary material.** The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X22000183.

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