IS MIGRATION DROUGHT-INDUCED IN MALI? AN EMPIRICAL ANALYSIS USING PANEL DATA ON MALIAN LOCALITIES OVER THE 1987-2009 PERIOD

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Is migration drought-induced in Mali?

An empirical analysis using panel data on Malian localities over the 1987-2009 period*

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Abstract

This paper combines population census data and climate data to estimate the volume of migrations induced by the drought events that have hit Mali since the late 1980s. The results show that the droughts 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. Between 1998 and 2009, droughts translate into an additional net outflow of 7,134 male and 6,281 female rural migrants per year. The effect of drought episodes, however, differs according to localities and rural households' capacity 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 receive more rainfall on average. Climate shocks also had an impact on international mobility: over the 2004-2009 period, around 2,000 additional departures per year can be attributed to the dry episodes that hit Mali during the 2000s. We forecast that, under different climate scenarios and population growth projection, internal and international mobility induced by droughts events will substantially grow in the next decades.

Keywords: Climate change, Migration, Mali.

JEL Codes: Q54, Q15, F22, O55.

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I 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 *e.g.*, there were marked population shifts from the arid zones bordering the Sahara towards the cities of the Sahel, which grew by 6-10 percent during this period (Gervais (1987) and Ouedraogo (1988) cited by Findley (1994)). More recently, in 2011, the Horn of Africa (Ethiopia, Kenya and Somalia) was hit by one of its worst drought-related food crises which triggered large-scale internal and cross-border displacements (Bhattacharjee, 2012).

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. 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[1] 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 are notoriously difficult to provide. The same holds true for estimates of the volume of climate- and environmentally-induced migration at the world level. 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 (Stern (2007) and Myers (2002)).

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 labour migration is a central element in the livelihoods of many rural households and hence 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 and exploit population and climate data to conduct a geographically dis-

[1] *"Climate change will create world's biggest refugee crisis"* (The Guardian, Nov 2, 2017); *"Le réchauffement climatique va accentuer la pression migratoire aux porte de l'Europe"* (Le Monde, Dec 22, 2017); *"La amenaza de las migraciones climàticas"* (El Pais, March 24, 2018)

aggregated 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 1990 and 2000. Conducting such an analysis is helpful to understand how the climate has contributed to shape 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% of its population is engaged in this sector of activity, which accounts for more than 35% of gross domestic product (FAO, 2017). With only 8.9% of cultivated land having irrigation facilities, agriculture production is dominated by small-scale, rainfed subsistence agriculture (see Figure A.1 taken in Giannini et al. (2017) in Appendix). Climate anomalies recorded in Mali in the past 20 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 agroecological zones, referred to as the Desert, the Sahelian and the Sudanese 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 A.2 in Appendix). This diversity makes it possible to test for difference 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% of the population were living abroad, mainly in neighbouring countries but also in France, Spain and other parts of the world (IOM, 2013). According to INSTAT (2012), internal migrants represented 16% of the population in 2009[2]. In this context, it is interesting to see whether and to what extent climate anomalies in Mali have contributed to shape 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.

[2]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.

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. Existing studies can be broadly categorised according to their level of analysis[3]. Cross-country analyses rely on large panel of countries and generally study decennial averages of net emigration flows or urbanisation rates (used as a proxy for internal migration rates) over 30- or 40-year period (Barrios, Bertinelli, and Strobl (2006); Naudé (2010); Marchiori, Maystadt, and Schumacher (2012); Drabo and Mbaye (2015); Cattaneo and Peri (2016); Mbaye (2017)). 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, for *e.g.*, Barrios, Bertinelli, and Strobl (2006) and Marchiori, Maystadt, and Schumacher (2012)). In addition, migration response to weather anomalies is not uniform across countries: shortages in rainfall have increased urbanisation rates on the Sub-Saharan continent but not elsewhere (Barrios, Bertinelli, and Strobl, 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 controlling for country-pair specific factors in an augmented gravity model (Afifi and Warner (2008); Reuveny and Moore (2009); (Alexeev, Good, and Reuveny, 2011); Coniglio and Pesce (2015); Beine and Parsons (2015); Backhaus, Martinez-Zarzoso, and Muris (2015); Cai et al. (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 et al., 2016) and conflict (Burke, Hsiang, and Miguel, 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-

[3]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.)

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 taking into account some of the factors and contextual effects playing a role in the migration-environment association[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, Vrieling, and Dietz (2010)) or literacy and economic activity rates (Henry, Boyle, and Lambin (2003)). They also find differences in climate effects according to affected individuals's sex and age (Dillon, Mueller, and Salau (2011); Findley (1994); Gray and Mueller (2012)). The limitations 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 anomomalies 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 analyse the climate-migration nexus (Henry, Boyle, and Lambin (2003);Van der Geest, Vrieling, and Dietz (2010); Feng, Krueger, and Oppenheimer (2010); Feng, Oppenheimer, and Schlenker (2012); Joseph and Wodon (2013); Strobl and Valfort (2013); Iqbal and Roy (2015); Dallmann and Millock (2017); and Gittard (2018)), 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

[4]For African case studies, see for *e.g.* Van der Geest, Vrieling, and Dietz (2010) and Cattaneo and Massetti (2015) on Ghana; Henry, Boyle, and Lambin (2003) and Henry, Schoumaker, and Beauchemin (2004) on Burkina Faso; Kubik and Maurel (2016) on Tanzania; Dillon, Mueller, and Salau (2011) and Cattaneo and Massetti (2015) on Nigeria; Gray and Mueller (2012) on Ethiopia; Lewin, Fisher, and Weber (2012) on Malawi; Gittard (2018) on Kenya; Strobl and Valfort (2013) on Uganda and Findley (1994) on Mali. See also Borderon et al. (2019) for a recent survey.

[5]Feng, Krueger, and Oppenheimer (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.

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 in those located in the Sudano-Sahelian and Sudano-Guinean zones that receive 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 evironmentally 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 II 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 III. Section IV 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 and agroecological conditions. Section V discusses estimated volumes of past and future climate-driven migration. Section VI concludes.

II Migration as a mechanism for coping with drought

Because of their dependence on rain-fed agriculture 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 implying altering production choices: people may adopt and specialize in production techniques that are less dependent on rainfalls (such as small-

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

scale irrigation) or that are resistant to droughts and other environmental risk factors (growing pearl millet in Sahelian areas for *e.g.*); they may diversify their portfolio of income-generating activities by planting different crops or combining farm and non-farm activities; etc. Even if all these strategies contribute to reduce 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; etc. 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 of rainfall influence temporary and permanent migrations (Cekan (1992); Findley (1994); Manchuelle (1997); De Haan, Brock, and Coulibaly (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 *e.g.*, 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. 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 agency, 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 *e.g.*), and make their decisions depending on the opportunities that are offered to them and the various constraints they encounter (De Haan, Brock, and Coulibaly (2002); Carling (2002); De Haas (2014)). With regards migration destination choices, for examples, 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 explain 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 scare 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's sex and age as well as to affected households' wealth and "adaptative capacity" to endure climatic shocks locally.

III Data and descriptive statistics

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

III.1 Climate anomalies: the SPEI

As our main climate indicator, we use the Standardized Precipitation-Evapotranspiration Index (SPEI) from the high-resolution (0.5x0.5 degree) gridded dataset developed by Vicente-Serrano, Beguería, and López-Moreno (2010). Several other objective drought indices have been developed and used, such as the Palmer Drought Severity Index (PDSI) or the Standard Precipitation Index (SPI), but the SPEI has several advantages over them. In particular, it allows for comparison of drought severity through time and space whereas the PDSI does not, and considers both the role of temperature and precipitation variability while the SPI only considers the latter (Vicente-Serrano, Beguería, and López-Moreno (2010); Beguería, Vicente-Serrano, and Angulo-Martínez (2010)). As explained by Vicente-Serrano, Beguería, and López-Moreno (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 comparing 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 (Beguería, Vicente-Serrano, and Angulo-Martínez, 2010).

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 A.3. The figure shows large fluctuations over the 1967−2009 period for all Malian agroecological zones, with a dominance of dry events. The standardized anomalies of precipitation, evapotraspiration and temperature are particularly intense in years 1973-1974, 1982-1984 and 2002, with SPEI values during the growing season corresponding to severe droughts. Outside these sub-periods, averaged

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

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 frequency and magnitude of drought:

- *Frequency 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 frequency of dry years for each intercensal period.

- *Frequency 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 frequency 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 frequency of *intense* dry years, translating into averaged SPEI values that are below the long-term average by more than 1.5 standard deviation, the frequency of dry years in respectively the first five years of the intercensal period and the last five years, etc. Figure A.4 displays the frequency 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 2000s, which correspond to our two periods of analysis.

III.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).[9]

Measuring net migration rates at the locality level

[8] We nevertheless computed indicators such as the frequency 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.

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

Since Malian censuses do not have direct questions on migration (except a question on international migration in the 2009 census), we follow Iqbal and Roy (2015) and adopt the indirect method of estimating net migration described in UN (1970). The basic idea of this method, so called the residual approach, is that the population increment between any two dates for any given geographic area is the result of natural increase (births minus deaths) and net migratory movements. Given the population of an area at two points in time and an estimate of natural increase during the interval, we can calculate the number that would be expected at the end of the interval in the absence of migration. Then net change due to migration equals to the difference between observed and expected numbers of population at the end of the interval.

We use probability of survival to estimate the expected population. The net migration is then defined as:

$$NM_{j,a,[t,t+n]} = p_{j,a+n,t+n} - S.\ p_{j,a,t} \tag{1}$$

where $NM_{j,a,[t,t+n]}$ is the net migration of survivors among persons aged a at the first census in a given area (they will be aged $a+n$ at the second census); $p_{j,a,t}$ is the population in the jth area in a particular age group a in the census year t; $p_{j,x+n,t+n}$ is the corresponding population n years older and S is the survival ratio. Given that 11 years separate two censuses in Mali, we calculate the net migration rate (NMR) between two census periods t and $t+11$ using the following formula:

$$NMR_{j,a,[t,t+11]} = \frac{NM_{j,a,[t,t+11]}}{p_{j,a,t}} \tag{2}$$

The estimate of net migration derived by Equation 2 measures the combined effect of both internal and external migration. It should be considered as a lower bound estimate of total migration flows because it does not record short-term movements that may have taken place between censuses. As a result, it should be interpreted more as an indicator of long-term or permanent migration.

For our empirical analysis, we compute net migration rates at the locality level for various age-groups. To this end, we first compute age specific population data for each Malian locality using the two censuses of 1987 and 1998. We choose the following age-groups: 9−58, 9−18, 19−28,..., 49−58. We exclude the youngest age-group (0−8) because its size evolves over time with births, and we prefer to get rid of this source of variation for simplification purposes. We also exclude the oldest age-groups (70 years old and more) for reasons that are provided below. We then associate these data with age specific population data computed on the same age-groups eleven years later using the censuses of 1998 and 2009: 20−69, 20−29, 30−39, 40−49, 50−59, 60−69. We finally use the ten year forward survival probability for each of our chosen age-groups. Ideally, we would like these probabilities to be district-wise specific, but they are not available. Therefore, we use country-wide survival ratios for all localities for all age-groups (see Table A.1). By so doing, we rely on the assumption of mortality equality accross localities. While this is obviously a strong assumption, especially in a country such as Mali where the general mortality level is high, this is only a problem for our analysis if mortality rates are seriously impacted by extreme climatic events. By using a survival ratio estimated at the country level in a drought-affected locality, we are indeed under-estimating (resp. over-estimating) the number of deaths in the intercensal period (resp. the number of survivors), and hence under-estimating the locality's net intercensal migration (defined as the difference between the number of immigrants and the number of emigrants over the intercensal period). In order to reduce this source of bias in our analysis of the effect of climate factors on migration, we exclude two groups of population that are known to be especially vulnerable to drought events: the children and the elderly (see, *e.g.*, Kudamatsu, Persson, and Strömberg (2012) for evidence). This does not mean that drought cannot affect the health of other categories of population: it surely can in a variety of ways including through threats to food and water security. But we rest on the assumption that this potential impact on health does not translate into significant change in mortality rates for them. In order to test the validity of this assumption, we use the data on the number of deaths in the previous 12 months contained in the censuses. We compute mortality rates in the past 12 months for all age-groups for all localities and regress these mortality rates on various specifications of our shock variables. We find no significant effect of drought episodes on mortality rates (see results in Table A.2).

As new localities were created and some existing ones were merged over the 1987-2009 period, we discovered some inconsistencies among censuses. Those localities created after 1987 were indeed found to have a null population in year 1987 and a population of several dozens or hundreds of individuals in the following censuses, while the opposite was observed for those localities which were merged. This resulted in completely unrealistic net migration rates between censuses. We hence decided to drop these 717 localities, as well as the surrounding ones[10].

[10] We may still have some inconsistencies in the data, due to measurement errors in population size at the locality

We also found out that the level of disaggregation adopted in our analyses was inappropriate for urban conurbations. Urban conurbations are indeed composed of several urban localities. People may move from one urban locality to another one, while staying in the same urban conurbation. We have opted to focus on migration between "independent" urban or rural localities, that is localities which do not belong to a same urban conurbation. To this end, we aggregated 342 localities which are part of a same urban conurbation.[11]

Figures 1 and 2 display net migration rates at the locality level for men aged 20-69 for each intercensal period. On all map layers, the size of the circles is proportional to the measured migration rates. In order to keep the maps readable, we consider urban and rural localities separately. Both samples include localities with negative net migration rates (meaning that they recorded bigger number of emigrants than immigrants) and localities with positive net migration rates. Since our sample of urban localities is quite heterogenous as we mix urban localities and urban conurbations, it is not possible to see whether there are differentiated migration patterns between them, but a quick exploration of the data suggest that positive net migration rates do not only concern urban conurbations.

Measuring international emigrant flows

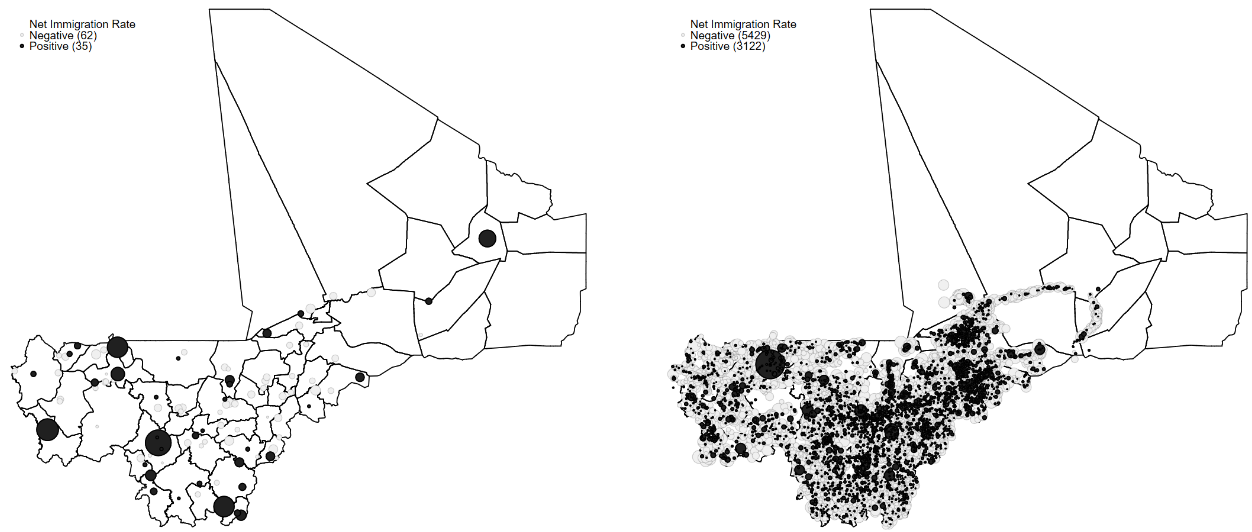
The 2009 population census is the first Malian census containing an emigration module, in which the head or other reference member of a household is asked to name (former) household members who have left the country to live abroad in the last 5 years. Figure 3 depicts the number of international emigrants by locality over the 2004-2009 period. Even though the number of departures by locality is higher in urban localities, most rural localities face international emigration. After identifying the emigrants, the module gathers a limited amount of relevant information on each emigrant: age, sex, year and month of departure, destination country and reason for migration. From this module, it is possible to compute figures on the number of international emigrants who left Mali over the course of the 2004-2009 period, at various levels of disaggregation (region, district, locality, household, region x year, district x year and so on). There are however a number of issues in measuring

level, especially when we disaggregate population size by sex and age cohort (since age may be measured with errors). However, as far as measurement errors are random with respect to our main variable of interest, this should not bias our estimates although they will be less precise.

[11] As an example, Kayes, the main city of Mali's first region is composed of six localities. We merged those six localities, and hence consider the city of Kayes as one single urban locality in our analysis. For an in-depth discussion on the urbanization process in Mali and the methodological challenges it poses for the construction of a panel of localities, see Bernard, Mesplé-Somps, and Spielvogel (2017).

Figure 1: Net migration rates from 1987 to 1998 among men aged 20-69

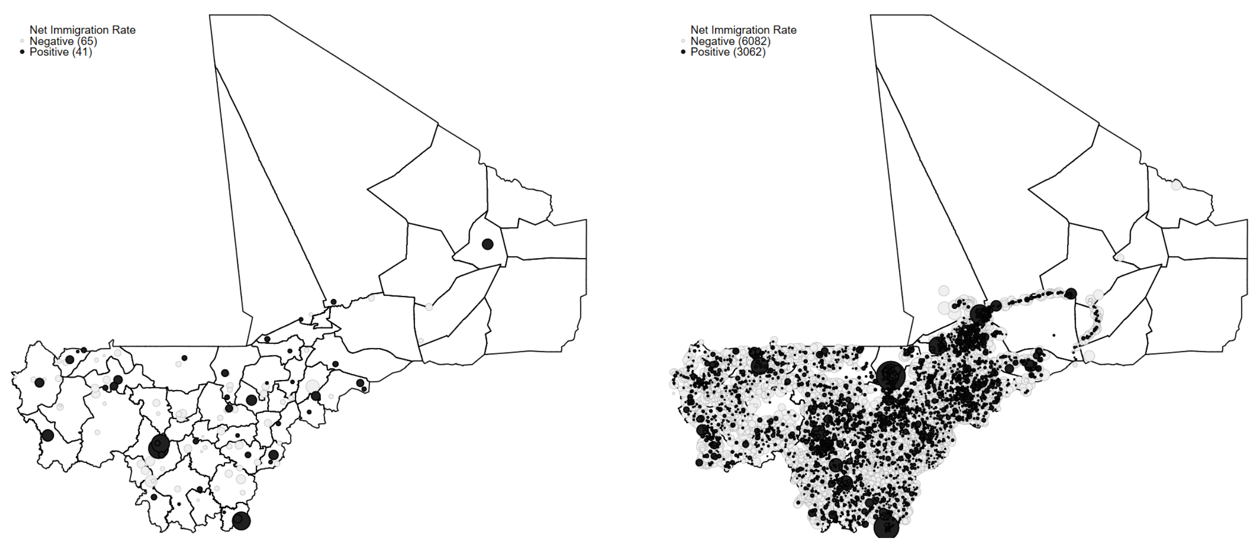
(a) Urban localities (b) Rural localities



Sources: Census from 1987 and 1998.

Figure 2: Net migration rates from 1998 to 2009 among men aged 20-69

(a) Urban localities (b) Rural localities



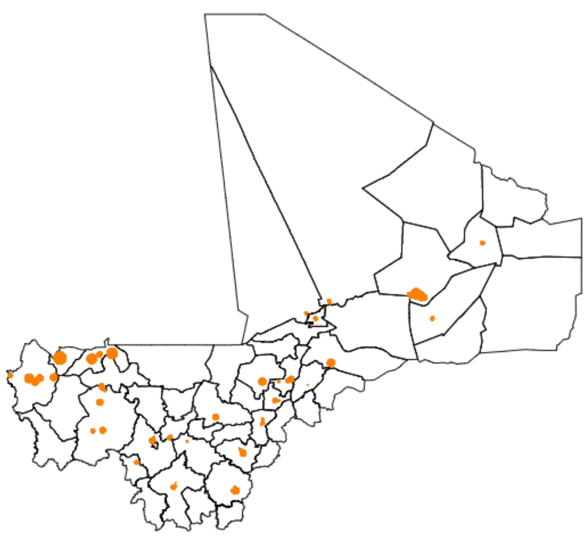
Sources: Census from 1998 and 2009.

international emigration in population censuses, and the Malian census is no exception. First, in cases when the entire household emigrated or all the left-behind died, there is nobody left behind to report the emigration. Second, even when there is someone staying in the country to report on those who left, persons who left a long time ago may end up being omitted from the count. In our case, the maximum period between the time the emigrant left and the time of enumeration (5 years) is not too long, so that emigration events should be recalled with accuracy. Third, there is a possibility of double counting an emigrant if the person who left belonged to more than one household in the country of enumeration. Even though the resulting biases go in both directions, it is generally considered that figures on emigration flows based on census data are lower-bound estimates. Something that could be specific to Mali is a downward bias in the estimated number of female emigrants since females who have left the country to live abroad on the occasion of their wedding may be considered as not belonging to their origin household anymore and as not yet part of their husband's family. Female emigration is hence likely to be under-estimated. In the empirical analysis that follows, we will use emigration rate at the locality level disaggregated by year and country of destination, and by sex.

Figure 3: International Emigration Flows from 2004 to 2009

(a) Urban localities

(b) Rural localities



Sources: Census from 2009.

IV Empirical strategy and results

IV.1 Empirical strategy

We first estimate regressions of the frequency of shocks on migration, using net migration rates for different age-cohorts. 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 frequency variable with a dummy taking the value 1 if the locality is urban. Equations whose estimation results are shown in Tables 1 and 2 are of the following type:

$$NMR_{j,a,[t-11,t]} = \beta_0 + \beta_1 Urban + \beta_2 \sum_{t-k}^{t} drought_{j,t-k} + \beta_3 \sum_{t-k}^{t} drought_{j,t-k} * Urban + \delta_j + \delta_t + \epsilon_{j,t} \quad (3)$$

$NMR_{j,a,[t-11,t]}$ 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. *Urban* is a dummy taking the value one if the locality is classified as urban in the census, zero otherwise; $\sum_{t-k}^{t} drought_{j,t-k}$ is the frequency of dry years (or dry agricultural seasons) over the intercensal period; δ_j and δ_t are locality and period fixed effects respectively and $\epsilon_{j,t}$ is a classical 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 fixed effects allows to control for path dependency of localities with historically and structurally high rates of emigration for reasons that may be climated-related or not. We estimate Equation 3 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 district-by-period fixed effects, to adjust for all factors that are common across localities within a district by period, such as agricultural prices. However, a concern with the use of district-by-period fixed effects is that they absorb a significant amount of weather variance. To illustrate this, Table A.3 summarizes regressions of SPEI values on various sets of fixed effects (period fixed effects; locality plus period fixed effects; locality plus period plus district-by-period fixed effects and locality plus

[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 500km. We are thankful to Isabelle Chort and Maëlys de la Rupelle for sharing the amended version of the code in Hsiang (2010).

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 3 means that the identification of climate effects rests on very slim margins.

In order to assess the impact of drought frequency on international migration, we use the following model specification:

$$IMR_{j,t} = \beta_0 + \beta_1 \sum_{i=1}^{5} drought_{j,t-i} + \delta_j + \delta_t + \epsilon_{j,t} \tag{4}$$

$IMR_{j,t}$ is 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 frequency of dry years (or dry agricultural seasons) in the last 5 years; δ_j and δ_t are locality and year fixed effects respectively and $\epsilon_{j,t}$ is a classical error term. Because the occurrence of international moves at the locality level in a given year is quite low, we are not able to disaggregate the data by sex or age-cohort.

IV.2 Benchmark results

Regression results are displayed in Tables 1, 2 and 3. Table 1 presents the main estimation results of Equation 3 for men and women aged 20-69 using alternative measures of drought frequency. In all regressions, the results show that drought frequency has an impact on 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 decreases net migration rate in rural localities by 3.5 percentage points, which corresponds to a decrease of 25.9% for men aged 20-69. The results for women are roughly similar, with an estimated decrease in net migration rate of 21.7%. The effects of drought episodes are much less pronounced in urban localities for men: one additional dry agricultural season translates into a 6.7% decrease in net migration rate. In the case of women, net migration rate is even found to increase by 2% in urban

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

localities. These results are roughly the same when one uses alternative drought measures. Results further indicate that the occurrence of 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*. Overall, these results suggest 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 either an increase in emigration flows or a decrease in immigration flows (or both), so that net migration rates decrease, while the opposite trend is observed in urban localities due notably to changing migration patterns among women.

Table 1: Drought effects on net migration rates

	Men aged 20-69	Women aged 20-69
Nb. droughts from t-11 to t (june-oct)	-0.035***	-0.032***
	(0.007)	(0.005)
Urban× Nb. droughts from t-11 to t (june-oct)	0.026*	0.035***
	(0.015)	(0.008)
Nb. droughts from t-11 to t	-0.039***	-0.029***
	(0.005)	(0.005)
Urban× Nb. droughts from t-11 to t	0.031**	0.036***
	(0.013)	(0.007)
Nb. droughts from t-11 to t	-0.041***	-0.031***
	(0.005)	(0.006)
Consecutive× Nb. droughts from t-11 to t	0.010	0.007
	(0.007)	(0.009)
Urban× Nb. droughts from t-11 to t	0.031**	0.036***
	(0.013)	(0.007)
Nb. droughts from t-11 to t-5	-0.029*	-0.008
	(0.016)	(0.024)
Urban× Nb. droughts from t-11 to t-5	0.043**	0.040***
	(0.021)	(0.015)
Village F.E	×	×
Period F.E	×	×
Observations	18,550	18,551

Sample: Census from 1987, 1998 and 2009. Note: Standard errors in parentheses corrected for serial correlation over one period and for spatial correlation up to a distance cutoff at 500 km. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

We next assess the extent to which the effects of drought frequency vary across different demographic groups. Table 2 presents the results of estimating Equation 3 for men and women for different age-cohorts. The same patterns can be observed: overall, dry episodes during the agricultural season significantly decrease net migration rates for both men and women in rural localities and increase net migration rates for both groups in urban localities. The estimated change in net migration rate following one additional dry agricultural season is particularly strong for younger men aged 20-29[14]. With an average net migration rate for this sub-population at the locality level equals to -3.94%, the size of the estimated coefficient means that for this sub-population, one additional dry agricultural season in the inter-census period results in a (negative) net migration rate that is in absolute value more than twice higher. For the older age-cohorts, the size of the effect is smaller, resulting in a percentage decrease in net migration rate ranging from 2% for the cohort of males aged 50-59 years old to 10% for the cohort of males aged 30-39 years old. In the case of women, the percentage decrease in net migration rate is the strongest for the cohort aged 30-39 (it is equal to 15.2%) and ranges between 3.4% and 7.4% 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. With a few exceptions, net migration rates in urban localities are found to increase with the frequency of dry episodes whatever the sub-sample. This confirms that dry events tend to accelerate rural-urban migration, which may suggest that the effects of weather shocks on migration mainly work through the agricultural channel.[15]

We finally assess the impact of drought frequency on 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 4 groups of countries that are mutually exclusive: (1) neighbouring countries, that is countries which share a border with Mali; (2) African countries, that is countries located in the African continent, but which do not share a border with Mali; (3) OECD countries excluding France; and France[16]. Results on total migration rates and migration rates disaggregated by sex are shown in Tables 3

[14] 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.

[15] Table A.4 in Appendix presents the results obtained on the same sub-samples, after including district-by-period fixed effects. As already mentioned, introducing these interaction terms means that the identification of climate effects rests on very slim margins. Drought frequency is thus only significant for the sample of younger men.

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

and 4 respectively. Overall, drought frequency in the last 5 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 results in an increase in international migration rate by 0.19 percentage point, which corresponds to a 15.3 percentage increase. This percentage increase is much higher when one concentrates on migration outflows to neighbouring countries (+81.8%, column 2) and France (+28.6%, column 5), but lower when the focus is on outflows to non-neighbouring African countries (+8.9%, column 3). 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 percentage decrease in migration rate of 30%. This could be the sign that when hit by a 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 frequency of *intense* dry agricultural seasons are even bigger in size: one additional intense dry agricultural season results in a 20.2 percentage 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 4). Female international migration rates are about ten times lower than male rates, but they react similarly and in quite the same proportions to drought. All in all, this set of results suggests that rainfall conditions influence both internal and international migration. With regards international migration, the magnitude of the effect varies by country or region of destination, which is likely to be due to some cost considerations. In times of hardship resulting from poor climatic conditions, people have a higher average propensity to migrate, particularly so towards short-distant, neighboring countries. There might nevertheless be between-group or between-region heterogeneity in climate effects, which is the focus of the next section.

IV.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 frequency 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 effects according to whether individuals' beginning-of-period residence was in localities situated in the Desert or arid zone, in the Sahelian or semi-arid zone, or in the Sudanese zone. Our prior is that in rural localities, the more favorable agro-ecological conditions found in the Sudanese zone and, to a lesser extent, in the Sahelian one are likely to be 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 5. Given the mechanism we have in mind, we have excluded urban localities from our sample. Results show that drought frequency has a significantly different impact on net migration rate depending on the agroecological zone. The impact is the strongest in arid areas located in the Northern part of the country, where one additional dry agricultural season results in a percentage decrease in net migration rates of 68.6 and 50.8 for men and women respectively. It is the smallest in semi-arid areas, where the corresponding percentage decrease equals to 5.9 and 12.2. 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 6). Column (1) shows indeed that the estimated coefficient of the drought frequency variable is between 1.7 and 2.5 larger for arid areas than for semi-arid and semi-humid ones. This implies that one additional dry episode during the agricultural season translates into more additional migration outflows from the former than from the latter (+27.4% vs. 11.3% and 16.1% respectively). 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 drought frequency 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 land allocations are. To construct this index, we exploit the EarthStat dataset of croplands on a 10 km x 10 km latitude/longitude grid[17] that informs about the share of farmland allocated to the main Malian crops in year 2000 (yam, cotton, fonio, groundnut, maize, millet, rice, sorghum and tobacco).

Regression results are displayed in Table 7. They show that in localities where crop diversification is the highest, one additional dry agricultural season has a negligible impact on net migration rates, while the reverse holds true in localities where it is the lowest. 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.

We finally 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 closed 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 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 drought frequency 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.[18]. We first transformed all the variables into a dichotomous version, and

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

[18] 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, etc.

performed a Principal Component Analysis (PCA) to get a wealth index for each household. We then computed an average wealth index at the locality level. Results are provided in Tables 8 and 9. As suggested by Table 8, climate effects 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 drought frequency. No such clear pattern emerges with international migration rates (Table 9): interacted terms are generally not significant, with a few exceptions: interestingly, international migration towards non-neighbouring 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.

Table 2: Drought effects on net migration rates

	Men	Women
	20-29	
Nb. droughts from t-11 to t (june-oct)	-0.042***	-0.013*
	(0.008)	(0.007)
Urban×Nb. shocks from t-10 to t (june-oct)	0.005	0.013
	(0.014)	(0.017)
Observations	18,531	18,523
	30-39	
Nb. shocks from t-10 to t (june-oct)	-0.033***	-0.019***
	(0.009)	(0.004)
Urban×Nb. shocks from t-10 to t (june-oct)	0.034	0.037***
	(0.027)	(0.013)
Observations	18,497	18,525
	40-49	
Nb. shocks from t-10 to t (june-oct)	-0.017***	-0.011***
	(0.005)	(0.004)
Urban×Nb. shocks from t-10 to t (june-oct)	0.031*	0.024**
	(0.019)	(0.010)
Observations	18,491	18,516
	50-59	
Nb. shocks from t-10 to t (june-oct)	-0.003	-0.012***
	(0.006)	(0.004)
Urban×Nb. shocks from t-10 to t (june-oct)	0.024*	0.024**
	(0.013)	(0.012)
Observations	18,455	18,450
	60-69	
Nb. shocks from t-10 to t (june-oct)	-0.006***	-0.006
	(0.002)	(0.004)
Urban×Nb. shocks from t-10 to t (june-oct)	0.013	0.020
	(0.014)	(0.014)
Observations	18,384	18,330
Village F.E	×	×
Period F.E	×	×

Sample: Census from 1987, 1998 and 2009. Note: Standard errors in parentheses corrected for serial correlation over one period and for spatial correlation up to a distance cutoff at 500 km. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

Table 3: Drought effects on international migration rates

	(1) Total	(2) Bordering	(3) Africa	(4) OECD	(5) France
$\overline{IM_{j,t}}$	0.0124	0.0011	0.0090	0.0010	0.0007
Nb. of droughts last 5 years (June-oct)	0.0019***	0.0009***	0.0008***	-0.0000	0.0002**
	(0.0004)	(0.0001)	(0.0003)	(0.0001)	(0.0001)
Nb. of droughts last 5 years	0.0020***	0.0009***	0.0012**	-0.0003***	0.0002***
	(0.0006)	(0.0001)	(0.0006)	(0.0001)	(0.0001)
Nb. of intense droughts last 5 years (June-oct)	0.0025***	0.0013***	0.0013**	-0.0003**	0.0001
	(0.0007)	(0.0002)	(0.0006)	(0.0001)	(0.0001)
Observations	59,214	59,214	59,214	59,214	59,214
Number of villages	9,869	9,869	9,869	9,869	9,869
Village F.E.	×	×	×	×	×
Years F.E.	×	×	×	×	×

Sample: Census from 2009. Note: Standard errors are clustered at the district of origin and are reported in parentheses. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

Table 4: Drought effects on international migration rates

	(1) Total	(2) Bordering	(3) Africa	(4) OECD	(5) France
			Men		
$\overline{IM_{j,t}}$	0.0110	0.0009	0.0080	0.0010	0.0007
Nb. of droughts last 5 years (June-oct)	0.0016***	0.0007***	0.0007***	-0.0000	0.0001*
	(0.0004)	(0.0001)	(0.0003)	(0.0001)	(0.0001)
			Women		
$\overline{IM_{j,t}}$	0.0012	.00013	.0009	.00003	0.0001
Nb. of droughts last 5 years (June-oct)	0.0003***	0.0001***	0.0001	0.0000	0.0000*
	(0.0001)	(0.0000)	(0.0001)	(0.0000)	(0.0000)
Observations	59,214	59,214	59,214	59,214	59,214
Number of villages	9,869	9,869	9,869	9,869	9,869
Village F.E.	×	×	×	×	×
Years F.E.	×	×	×	×	×

Sample: Census from 2009. Note: Standard errors are clustered at the district of origin and are reported in parentheses. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

Table 5: Drought effects on net migration rate by agro-ecological zone (ref: arid zone)

	Men aged 20-69	Women aged 20-69
Nb. droughts from t-11 to t(june-oct)	-0.093***	-0.075***
	(0.015)	(0.014)
Nb. droughts *semi-arid	0.085***	0.057***
	(0.013)	(0.014)
Nb. droughts *semi-humid	0.037**	0.047***
	(0.018)	(0.013)
Village F.E	×	×
Period F.E	×	×
Observations	18,336	18,337

Sample: Rural localities. Census from 1987, 1998 and 2009. Note: Standard errors in parentheses corrected for serial correlation over one period and for spatial correlation up to a distance cutoff at 500 km. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

Table 6: Drought effects on international migration rates by agro-ecological zone (ref: arid zone)

	(1)	(2)	(3)	(4)	(5)
	total	Bordering	Africa	OECD	France
$\overline{IM_{j,t}}$	0.0124	0.0011	0.0090	0.0010	0.0007
Nb. droughts from t-5 to t (June-oct)	0.0043**	0.0027***	0.0012	0.0002	0.0002
	(0.0017)	(0.0007)	(0.0013)	(0.0002)	(0.0003)
Nb. droughts from t-5 to t (June-oct)×semi-arid	-0.0023	-0.0016***	-0.0007	-0.0003*	0.0000
	(0.0016)	(0.0006)	(0.0013)	(0.0002)	(0.0003)
Nb. droughts from t-5 to t (June-oct)×semi-humid	-0.0008	-0.0015***	0.0008	-0.0003*	0.0002
	(0.0016)	(0.0006)	(0.0013)	(0.0002)	(0.0003)
Observations	37,266	37,266	37,266	37,266	37,266
Number of villages	6,211	6,211	6,211	6,211	6,211
Village F.E.	×	×	×	×	×
Years F.E.	×	×	×	×	×

Sample: Census from 2009. Note: Standard errors are clustered at the district of origin and are reported in parentheses. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

Table 7: Drought effects on net migration rate by quintile of crop diversification index

	Men aged 20-69	Women aged 20-69
Nb. shocks from t-11 to t (june-oct)	-0.050***	-0.039***
	(0.008)	(0.008)
shock*diversification 2	-0.023	0.003
	(0.029)	(0.025)
shock*diversification 3	0.045***	0.001
	(0.011)	(0.016)
shock*diversification 4	0.009	0.008
	(0.015)	(0.014)
shock*diversification 5 (high)	0.052***	0.035***
	(0.011)	(0.010)
Village F.E	×	×
Period F.E	×	×
Observations	18,204	18,205

Sample: Rural localities. Census from 1987, 1998 and 2009. Note: Standard errors in parentheses corrected for serial correlation over one period and for spatial correlation up to a distance cutoff at 500 km. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

Table 8: Drought effects on net migration rates by wealth (ref: poorer localities)

	Men aged 20-69	Women aged 20-69
Nb. droughts from t-10 to t (june-oct)	-0.219***	-0.239***
	(0.015)	(0.017)
Nb. droughts*wealth 2	0.134***	0.162***
	(0.013)	(0.015)
Nb. droughts*wealth 3	0.188***	0.202***
	(0.015)	(0.015)
Nb. droughts*wealth 4	0.240***	0.267***
	(0.018)	(0.018)
Nb. droughts*wealth 5 (rich)	0.291***	0.331***
	(0.019)	(0.025)
Village F.E	×	×
Period F.E	×	×
Observations	18,336	18,337

Sample: Rural localities. Census from 1987, 1998 and 2009. Note: Standard errors in parentheses corrected for serial correlation over one period and for spatial correlation up to a distance cutoff at 500 km. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

Table 9: Drought effects on international migration rates by wealth (ref: poorer localities)

	(1)	(2)	(3)	(4)	(5)
	total	Bordering	Africa	OECD	France
$\overline{IM_{j,t}}$	0.0124	0.0011	0.0090	0.0010	0.0007
Nb. droughts last 5 years	0.0016**	0.0010***	0.0005	0.0001	0.0001
	(0.0007)	(0.0002)	(0.0006)	(0.0001)	(0.0002)
Nb. droughts*wealth 2	0.0011	0.0002	0.0006	-0.0000	0.0002
	(0.0009)	(0.0003)	(0.0007)	(0.0001)	(0.0001)
Nb. droughts*wealth 3	-0.0004	-0.0002	-0.0003	-0.0002	0.0002
	(0.0008)	(0.0002)	(0.0007)	(0.0001)	(0.0001)
Nb. droughts*wealth 4	-0.0002	-0.0003	0.0000	-0.0000	0.0001
	(0.0009)	(0.0002)	(0.0008)	(0.0001)	(0.0001)
Nb. droughts*wealth 5 (rich)	0.0007	-0.0002	0.0013*	-0.0004**	-0.0001
	(0.0009)	(0.0002)	(0.0007)	(0.0001)	(0.0002)
Observations	59,214	59,214	59,214	59,214	59,214
Number of villages	9,869	9,869	9,869	9,869	9,869
Village F.E.	×	×	×	×	×
Period F.E.	×	×	×	×	×

Sample: Census from 2009. Note: Standard errors are clustered at the district of origin and are reported in parentheses. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

V Projecting future net outmigration

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 context 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.

V.1 SPEI and population projections

For our forecast exercise, we use cell-level projections of daily accumulated precipitation; daily mean, minimum and maximum near-surface air temperature; daily mean surface downdwelling shortwave radiation and daily mean wind speed elaborated by Famien et al. (2018) to construct a projected version of our SPEI-based indicators[19]. 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"). Average projected drought frequencies over 2018 through 2077 are reported in Table 10. Based on predicted SPEI values, it is expected that the number of droughts will significantly increase in both scenarios.

Table 10: Number of droughts computed from observed and predicted SPEI

	Mean	Var	Min	Max
Simulated (RCP 2.6) nb. shocks from 2018 to 2037	1.652	3.000	0	13
Simulated (RCP 8.5) nb. shocks from 2018 to 2037	5.242	4.686	0	20
Simulated (RCP 2.6) nb. shocks from 2038 to 2057	8.124	3.465	1	20
Simulated (RCP 8.5) nb. shocks from 2038 to 2057	6.260	4.641	0	20
Simulated (RCP 2.6) nb. shocks from 2058 to 2077	5.400	4.528	0	18
Simulated (RCP 8.5) nb. shocks from 2058 to 2077	10.034	4.607	0	20

Sources: observed SPEI and predicted SPEI (data from the IPSLCM-5A-LR model).

[19] 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.

V.2 Projected migration outflows

Table 1 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 3:

$$\frac{\beta_2}{\overline{NMR_{j,a,[t-11,t]}}} * \frac{\sum_{j=1}^{n,rural} NM_{j,a,1998} * droughts_{j,[t-11,t]}}{11} \tag{5}$$

where the first term corresponds to the change in percentage of the average net migration rate, which equals -25.9% and -21.7% for men and women respectively. In order to get an estimate of the volume of additional (net) migration outflows due to drought frequency 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 effet of drought on the (net) migrant population measured at the locality level in 1998. As shown by column (7) of Table 11, the number of droughts ranged from 0 to 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 1998-2009. By dividing this number by 11, we finally get the number of additional "drought-induced" migrants in one year.

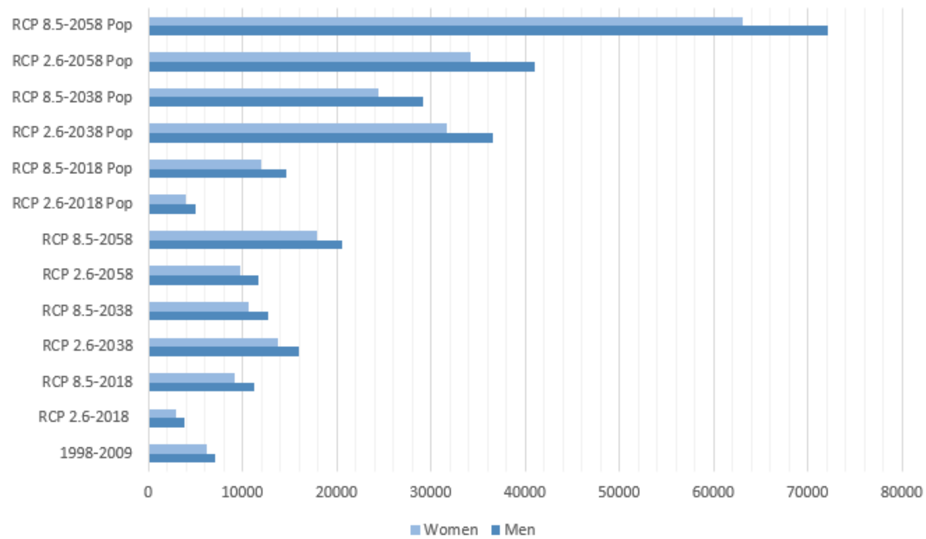
Table 11: Number of droughts and volume of net migration at the locality level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Men			Women		
	$\hat{\beta}_2$	$\overline{NMR_{j,[t-11,t]}}$	$NM_{j,[t-11,t]}$	$\hat{\beta}_2$	$\overline{NMR_{j,[t-11,t]}}$	$NM_{j,[t-11,t]}$	$droughts_{j,[1998,2009]}$
Mean	-0.035	0.082	-8.620	-0.032	0.102	-9.917	2.822
Min	.	-0.951	-5,374	.	-0.950	-6,514	0
Max	.	143.083	101,887	.	205.085	50,899	9

Sample: Census from 1987, 1998 and 2009.

Based on these computations, we find that the drought episodes that hit Mali between 1998 and 2009 resulted in an additional net outflow of 7,134 male and 6,281 female rural migrants per year(Figure 4). In order to predict the evolution of the number of drought-induced migrants in the next decades, we replicate the exercise using the predicted number of droughts under the "friendly climate scenario" and the "pessimistic climate scenario" (see Table 10). To smooth potential mea-

Figure 4: Estimated drought-induced net migration from rural areas for men and women aged 20-69



surement errors in climate projections, we use quite large time spans: from 2018 to 2037, from 2038 to 2057, and from 2058 to 2077. The results are provided in Figure 4. 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 21,396 and 38,477 when we consider men and women alltogether.

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 12).[20] By so doing, predicted net outflows of "drought-induced" migrants are found to significantly increase: we get an estimated number of 135,209 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 migration specification (Equation 4)

[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.

Table 12: Population Projection in Mali

Year	Men	Women
2009	7,313,414	7,293,186
2018	9,541,743	9,565,974
2038	16,637,405	16,834,048
2058	25,523,544	25,798,982

United Nations, DESA.

and apply the following formula:

$$\frac{\beta_1}{\overline{IMR_{j,t}}} \frac{\sum_{j=1}^{n} \ droughts_{j,[t-5,t]} * IM_{j,2004}}{5} \tag{6}$$

Results are provided in Table 13. Focusing on Column (1) which provides estimates on total international outflows, we find that the drought episodes that hit Mali during the 2000s resulted in about 2,000 additional international migrants per year over the 2004-2009 period. This figure increases up to 10,000 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 translates 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.

Of course, one has to be very cautious with such extrapolations. There are indeed strong uncertainties with regards the deviation of average annual temperatures and precipitations from their long-run historical mean that may occur in the next coming decades. And there are strong uncertainties too with regards the impacts of climatic variables if their deviation is outside a given range. Our results should hence be considered as only indicative of what happened in recent years and of what could possibly happen in the next coming decades.

Table 13: Projections of international outflows

Climate scenarios	(1) Total	(2) Bordering	(3) Africa	(4) OECD	(5) France
Observed 2004-2009	2,032***	1,524***	494.5	-450.3**	531.3**
	(620.6)	(267.5)	(400.9)	(202.9)	(263.8)
2018-2038					
RCP 2.6	2,043***	803.0***	716.7**	-580.1**	1,044**
	(653.6)	(291.0)	(284.2)	(266.0)	(511.2)
RCP 8.5	3,908***	3,667***	725.0	-1,032**	1,691**
	(1,258)	(650.7)	(696.0)	(469.4)	(836.7)
RCP 2.6 +pop increase	2,642***	2,458***	447.9	-763.9**	1,352**
	(850.7)	(436.2)	(430.0)	(347.5)	(668.9)
RCP 8.5 +pop increase	5,111***	4,796***	948.3	-1,350**	2,212**
	(1,646)	(851.2)	(910.3)	(613.9)	(1,094)
2038-2058					
RCP 2.6	4,352***	3,736***	861.4	-1,103**	1,614**
	(1,401)	(662.9)	(826.9)	(501.6)	(798.9)
RCP 8.5	4,816***	4,281***	942.8	-1,194**	1,846**
	(1,550)	(759.7)	(905.1)	(543.3)	(913.5)
RCP 2.6 +pop increase	9,975***	8,562***	1,974	-2,527**	3,700**
	(3,211)	(1,519)	(1,895)	(1,150)	(1,831)
RCP 8.5 +pop increase	11,037***	9,811***	2,161	-2,737**	4,231**
	(3,554)	(1,741)	(2,074)	(1,245)	(2,094)
2058-2078					
RCP 2.6	4,352***	3,736***	861.4	-1,103**	1,614**
	(1,401)	(662.9)	(826.9)	(501.6)	(798.9)
RCP 8.5	6,131***	5,447***	1,304	-1,279**	1,907**
	(1,974)	(966.6)	(1,252)	(581.9)	(943.7)
RCP 2.6 +pop increase	10,078***	7,714***	5,125**	-3,847**	5,730**
	(3,225)	(2,796)	(2,032)	(1,764)	(2,807)
RCP 8.5 +pop increase	9,975***	13,127***	3,027	-3,874**	5,673**
	(3,211)	(2,330)	(2,906)	(1,763)	(2,807)
Observations	48,660	48,660	48,660	48,660	48,660

Sample: Census from 2009. Note: Standard errors are clustered by village and are reported in parentheses. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

VI Conclusion

In this paper, we combine population census and climate data to estimate the volume of migration induced by droughts in Mali. As a Sahelian country, Mali has been hit by several drought episodes since the end of the 1970s and will be strongly affected by climate change which will translate into more frequent heat waves in the future. Mali thus constitutes an interesting case to investigate the impact of climate events on migration intensity and patterns. In comparison to most previous studies, we are able to analyse 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 analyse 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. We finally 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 7,134 male and 6,281 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 neighbouring 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 next coming decades due to the combined effect of an 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 130,000 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 2000 decade, but remains manageable, provided all movers do not converge towards the same destination region. 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 regards international mobility, the estimated volume of additional migrants is also found to increase but not massively. As said before, these projections need to be taken 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.

References

Afifi, Tamer and Koko Warner. 2008. "The impact of environmental degradation on migration flows across countries." .

Akresh, Richard. 2009. "Flexibility of household structure child fostering decisions in Burkina Faso." *Journal of Human Resources* 44 (4):976–997.

Alexeev, A, DH Good, and R Reuveny. 2011. "Climate Change, Weather Disasters, and International Migration." In *EAERE 18th Annual Conference, Special session on Environmentally Induced Migration, Rome*, vol. 1.

Backhaus, Andreas, Inmaculada Martinez-Zarzoso, and Chris Muris. 2015. "Do climate variations explain bilateral migration? A gravity model analysis." *IZA Journal of Migration* 4 (1):3.

Barrios, Salvador, Luisito Bertinelli, and Eric Strobl. 2006. "Climatic change and rural–urban migration: The case of sub-Saharan Africa." *Journal of Urban Economics* 60 (3):357–371.

Beguería, Santiago, Sergio M Vicente-Serrano, and Marta Angulo-Martínez. 2010. "A multiscalar global drought dataset: the SPEIbase: a new gridded product for the analysis of drought variability and impacts." *Bulletin of the American Meteorological Society* 91 (10):1351–1356.

Beguería, Santiago, Sergio M Vicente-Serrano, Fergus Reig, and Borja Latorre. 2014. "Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring." *International Journal of Climatology* 34 (10):3001–3023.

Beine, Michel and Christopher Parsons. 2015. "Climatic factors as determinants of international migration." *The Scandinavian Journal of Economics* 117 (2):723–767.

Bernard, Claire, Sandrine Mesplé-Somps, and Gilles Spielvogel. 2017. "Taille des villes, urbanisation et spécialisations économiques: Une analyse sur micro-données exhaustives des 10 000 localités maliennes." .

Bhattacharjee, Abhijit. 2012. "IASC Real Time Evaluation (IASC RTE) of the Humanitarian Response to the Horn of Africa Drought Crisis 2011: Regional Mechanisms and Support during the Response." *New York: IASC* .

Borderon, Marion, Patrick Sakdapolrak, Raya Muttarak, Endale Kebede, Raffaella Pagogna, and Eva Sporer. 2019. "A systematic review of empirical evidence on migration influenced by environmental change in Africa." *Demographic Research* 41 (18):491–544.

Burke, Marshall, Solomon M Hsiang, and Edward Miguel. 2015. "Climate and conflict." *Annu. Rev. Econ.* 7 (1):577–617.

Cai, Ruohong, Shuaizhang Feng, Michael Oppenheimer, and Mariola Pytlikova. 2016. "Climate variability and international migration: The importance of the agricultural linkage." *Journal of Environmental Economics and Management* 79:135–151.

Carling, Jorgen. 2002. "Migration in the age of involuntary immobility: theoretical reflections and Cape Verdean experiences." *Journal of ethnic and migration studies* 28 (1):5–42.

Cattaneo, Cristina and Emanuele Massetti. 2015. "Migration and climate change in rural Africa." .

Cattaneo, Cristina and Giovanni Peri. 2016. "The migration response to increasing temperatures." *Journal of Development Economics* 122:127–146.

Cekan, Jindra. 1992. "Seasonal coping strategies in central Mali: five villages during the "soudure"." .

Coniglio, Nicola D and Giovanni Pesce. 2015. "Climate variability and international migration: an empirical analysis." *Environment and Development Economics* 20 (4):434–468.

Conley, Timothy G. 1999. "GMM estimation with cross sectional dependence." *Journal of econometrics* 92 (1):1–45.

Dallmann, Ingrid and Katrin Millock. 2017. "Climate variability and inter-state migration in india." *CESifo Economic Studies* 63 (4):560–594.

De Haan, Arjan. 1999. "Livelihoods and poverty: The role of migration-a critical review of the migration literature." *The journal of development studies* 36 (2):1–47.

De Haan, Arjan, Karen Brock, and Ngolo Coulibaly. 2002. "Migration, livelihoods and institutions: contrasting patterns of migration in Mali." *Journal of Development Studies* 38 (5):37–58.

De Haas, Hein. 2014. *Migration theory: Quo vadis?* International Migration Institute, University of Oxford.

Dell, Melissa, Benjamin F Jones, and Benjamin A Olken. 2014. "What do we learn from the weather? The new climate-economy literature." *Journal of Economic Literature* 52 (3):740–98.

Dillon, Andrew, Valerie Mueller, and Sheu Salau. 2011. "Migratory responses to agricultural risk in northern Nigeria." *American Journal of Agricultural Economics* 93 (4):1048–1061.

Drabo, Alassane and Linguère Mously Mbaye. 2015. "Natural disasters, migration and education: an empirical analysis in developing countries." *Environment and Development Economics* 20 (6):767–796.

Fafchamps, Marcel. 2003. *Rural poverty, risk and development.* Edward Elgar Publishing.

Famien, Adjoua Moise, Serge Janicot, Abe Delfin Ochou, Mathieu Vrac, Dimitri Defrance, Benjamin Sultan, and Thomas Noel. 2018. "A bias-corrected CMIP5 dataset for Africa using the CDF-t method: a contribution to agricultural impact studies." .

FAO. 2017. "Mali: Country fact sheet on food and agriculture policy trends."

Feng, Shuaizhang, Alan B Krueger, and Michael Oppenheimer. 2010. "Linkages among climate change, crop yields and Mexico–US cross-border migration." *Proceedings of the National Academy of Sciences* 107 (32):14257–14262.

Feng, Shuaizhang, Michael Oppenheimer, and Wolfram Schlenker. 2012. "Climate change, crop yields, and internal migration in the United States." Tech. rep., National Bureau of Economic Research.

Findley, Sally E. 1994. "Does drought increase migration? A study of migration from rural Mali during the 1983–1985 drought." *International Migration Review* 28 (3):539–553.

Gervais, R. 1987. "Pour une Problématique démographique des catastrophes dites naturelles: L'exemple du Niger 1969–1974." *Demographie et Sous-Developpement dans le Tiers-monde. Eds. Gauvreau, D., Gregory, J., Kempeneers, M., and Piche, V. Montreal: McGill University* .

Giannini, Alessandra, P Krishna Krishnamurthy, Remi Cousin, Naouar Labidi, and Richard J Choularton. 2017. "Climate risk and food security in Mali: A historical perspective on adaptation." *Earth's Future* 5 (2):144–157.

Gittard, Mélanie. 2018. "Climate Change, Migration and Population: Evidence from a Micro-Analysis using Census Data in Kenya." Tech. rep., Paris School of Economics.

Gray, Clark and Valerie Mueller. 2012. "Drought and population mobility in rural Ethiopia." *World development* 40 (1):134–145.

Gubert, Flore. 2002. "Do migrants insure those who stay behind? Evidence from the Kayes area (Western Mali)." *Oxford Development Studies* 30 (3):267–287.

Henry, Sabine, Paul Boyle, and Eric F Lambin. 2003. "Modelling inter-provincial migration in Burkina Faso, West Africa: the role of socio-demographic and environmental factors." *Applied Geography* 23 (2-3):115–136.

Henry, Sabine, Bruno Schoumaker, and Cris Beauchemin. 2004. "The impact of rainfall on the first out-migration: A multi-level event-history analysis in Burkina Faso." *Population and environment* 25 (5):423–460.

Hsiang, Solomon M. 2010. "Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America." *Proceedings of the National Academy of sciences* 107 (35):15367–15372.

INSTAT. 2012. "4ème Recensement General De La Population Et De l?habitat Du Mali (Rgph-2009)." *Analyse des résultats définitifs. Theme: Migration* .

IOM. 2013. "The Mali migration crisis at a glance."

Iqbal, Kazi and Paritosh K Roy. 2015. "Climate change, agriculture and migration: Evidence from Bangladesh." *Climate Change Economics* 6 (02):1550006.

Joseph, George and Quentin Wodon. 2013. "Is Internal Migration in Yemen Driven by Climate or Socio-economic Factors?" *Review of International Economics* 21 (2):295–310.

Kubik, Zaneta and Mathilde Maurel. 2016. "Weather shocks, agricultural production and migration: Evidence from Tanzania." *The Journal of Development Studies* 52 (5):665–680.

Kudamatsu, Masayuki, Torsten Persson, and David Strömberg. 2012. "Weather and infant mortality in Africa." .

Lewin, Paul A, Monica Fisher, and Bruce Weber. 2012. "Do rainfall conditions push or pull rural migrants: evidence from Malawi." *Agricultural Economics* 43 (2):191–204.

Manchuelle, François. 1997. *Willing migrants: Soninke labor diasporas, 1848-1960*. James Currey Publishers.

Marchiori, Luca, Jean-François Maystadt, and Ingmar Schumacher. 2012. "The impact of weather anomalies on migration in sub-Saharan Africa." *Journal of Environmental Economics and Management* 63 (3):355–374.

Mbaye, Linguère Mously. 2017. "Climate change, natural disasters, and migration." *IZA World of Labor* .

Missirian, Anouch and Wolfram Schlenker. 2017. "Asylum applications and migration flows." *American Economic Review* 107 (5):436–40.

Morduch, Jonathan. 1995. "Income smoothing and consumption smoothing." *Journal of Economic Perspectives* 9 (3):103–114.

Myers, Norman. 1997. "Environmental refugees." *Population and environment* 19 (2):167–182.

———. 2002. "Environmental refugees: a growing phenomenon of the 21st century." *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences* 357 (1420):609–613.

Naudé, Wim. 2010. "The determinants of migration from Sub-Saharan African countries." *Journal of African Economies* 19 (3):330–356.

Ouedraogo, Dieudonne. 1988. "Sécheresse et Population." In *Conference des Planificateurs et des Demographes CEA, Addis-Ababa, March.*

Reuveny, Rafael and Will H Moore. 2009. "Does environmental degradation influence migration? Emigration to developed countries in the late 1980s and 1990s." *Social Science Quarterly* 90 (3):461–479.

Stark, Oded and David E Bloom. 1985. "The new economics of labor migration." *The American Economic Review* 75 (2):173–178.

Stern, Nicholas Herbert. 2007. *The economics of climate change: the Stern review.* cambridge University press.

Strobl, Eric and Marie-Anne Valfort. 2013. "The effect of weather-induced internal migration on local labor markets. Evidence from Uganda." *The World Bank Economic Review* 29 (2):385–412.

UN. 1970. "Manual VI: Methods of measuring internal migration, Manuals on Methods of Estimating Population, Vol.6. New York: United Nations." *Population Studies* .

Van der Geest, Kees, Anton Vrieling, and Ton Dietz. 2010. "Migration and environment in Ghana: a cross-district analysis of human mobility and vegetation dynamics." *Environment and Urbanization* 22 (1):107–123.

Vicente-Serrano, Sergio M, Santiago Beguería, and Juan I López-Moreno. 2010. "A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index." *Journal of climate* 23 (7):1696–1718.

Wesselbaum, Dennis and Amelia Aburn. 2019. "Gone with the wind: International migration." *Global and Planetary Change* 178:96–109.

Figure A.1: Rainfall and agricultural production in Mali

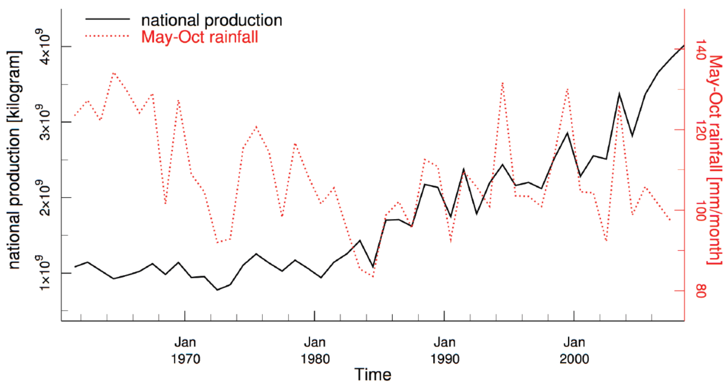


Table A.1: Probability of surviving over the next 10 years (%)

Age-groups	10-20	20-30	30-40	40-50	50-60	60-70
	95.57	94.23	92.79	88.73	77.13	51.57

Sources: DESA, Population Division, United Nation. Notes: These probabilities are computed from the 2000-2010 period.

Table A.2: Drought effects on mortality rates

	(1)	(2)	(3)	(4)	(5)	(6)
		Men			Women	
Nb. shocks from t-5 to t	-0.000			-0.000		
	(0.000)			(0.000)		
Nb. shocks from t-11 to t-1 (june-oct)		0.000			-0.000	
		(0.000)			(0.000)	
Nb. shocks from t-10 to t			0.000			-0.000
			(0.000)			(0.000)
Observations	13,149	13,149	13,149	13,771	13,771	13,771
Number of villages	8615	8615	8615	8832	8832	8832
Village F.E	×	×	×	×	×	×
Year F.E	×	×	×	×	×	×

Sample: Census from 1987, 1998 and 2009. Note: Standard errors in parentheses corrected for serial correlation over one period and for spatial correlation up to a distance cutoff at 500 km. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%. We control by the size of age cohorts (10-19, 20-29, 30-39, 40-49, and 50-59) by village.

Figure A.2: Agro-ecological zones in Mali

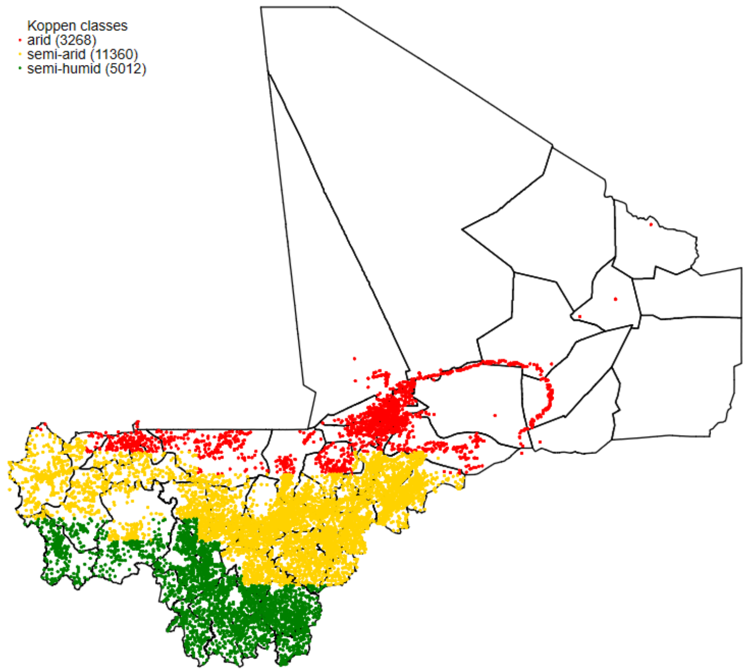


Figure A.3: Evolution of the SPEI during the agricultural season (June-October) in Mali by agro-ecological zone

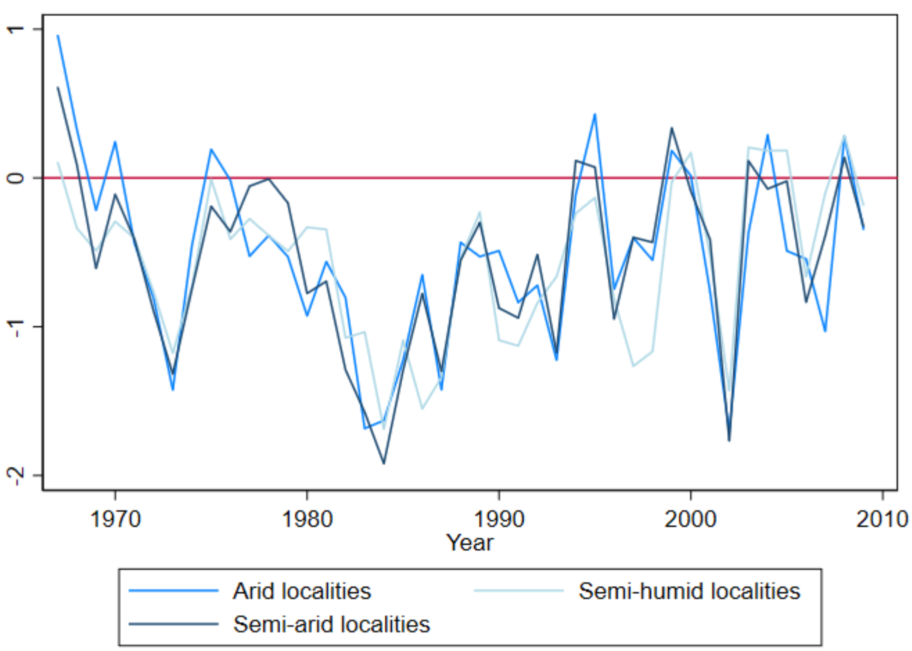
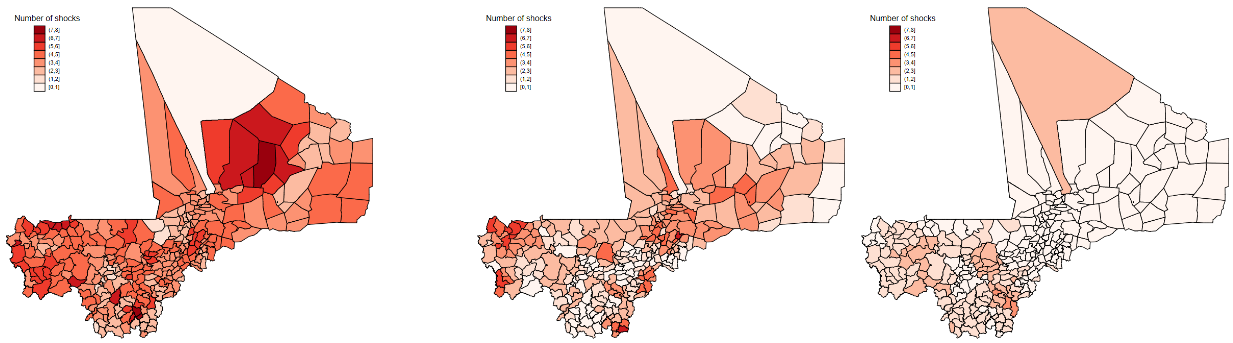


Figure A.4: Frequency of droughts in Mali



1977-1987 period   1988-1998 period   1999-2009 period

Table A.3: SPEI Variation under Various Sets of Fixed Effects

	R-squared			
	0.29	0.63	0.81	0.93
Period F.E	×	×	×	×
Locality F.E		×	×	×
District×Period F.E			×	
Municipality×Period F.E				×

Sample: Census from 1987, 1998 and 2009.

Table A.4: Drought effects on net migration rates

	Men	Women
	20-29	
Nb. shocks from t-10 to t (june-oct)	-0.0430**	-0.0179
	(0.0215)	(0.0181)
Urban*Nb. shocks from t-5 to t (june-oct)	0.0130	0.0159
	(0.0307)	(0.0350)
Observations	18,531	18,523
	30-39	
Nb. shocks from t-10 to t (june-oct)	0.00634	-0.0104
	(0.0207)	(0.0139)
Urban*Nb. shocks from t-5 to t (june-oct)	0.0501	0.0417
	(0.0587)	(0.0271)
Observations	18,497	18,525
	40-49	
Nb. shocks from t-10 to t (june-oct)	0.00297	-0.00134
	(0.0158)	(0.0114)
Urban*Nb. shocks from t-5 to t (june-oct)	0.0382	0.0263
	(0.0361)	(0.0215)
Observations	18,491	18,516
	50-59	
Nb. shocks from t-10 to t (june-oct)	0.0130	-0.00305
	(0.0165)	(0.0151)
Urban*Nb. shocks from t-5 to t (june-oct)	0.0249	0.0287
	(0.0260)	(0.0212)
Observations	18,455	18,450
	60-69	
Nb. shocks from t-10 to t (june-oct)	-0.00417	-0.00840
	(0.0139)	(0.0143)
Urban*Nb. shocks from t-5 to t (june-oct)	0.0180	0.0260
	(0.0235)	(0.0257)
Observations	18,384	18,330
Village F.E	×	×
Period F.E	×	×
District*Period F.E	×	×

Sample: Census from 1987, 1998 and 2009. Note: Standard errors in parentheses corrected for serial correlation over one period and for spatial correlation up to a distance cutoff at 500 km. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

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