Challenging the Climate-Migration Narrative: New evidence from Senegal*

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Abstract

Development policies promoting in situ adaptation to the adverse impacts of climate change have gained popularity as a means to reduce migratory pressures. This study investigates the influence of climate anomalies on internal migration patterns in Senegal, where millions rely on rain-fed agriculture for their livelihoods. Using comprehensive data from the 2013 Senegalese census, covering migration histories of 13 million individuals, and incorporating fine-grained drought exposure data, we assess mobility responses to climate variability. Estimating a panel gravity model of internal migration flows among 426 municipalities, we show that drought exposure resulted in reduced long-run migration rates in rural areas and to urban destinations, potentially slowing down urbanization. Conversely, wet growing seasons were associated with higher migration. Agricultural output was particularly vulnerable to fluctuations in the Standardized Precipitation-Evapotranspiration Index (SPEI) over the studied period. Our results indicate severe financial constraints that limit costly migratory moves for individuals dependent on agricultural income. Expensive migration to geographically and ethnically distant destinations especially decreased following droughts, while strong network ties offset these negative effects. These findings challenge prevailing climate-migration narratives and highlight the need for special consideration of the needs of those trapped in poverty. (*JEL* F22, O15, Q51, Q54, R23)

Keywords: Climate change; Internal Migration; Urbanisation; SPEI; Drought.

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1 Introduction

Overwhelming scientific evidence documents the gradual change of climatic conditions and increasing variability related to higher frequency of extreme weather events worldwide. One important consequence of these changes is the disruption of long established agricultural production systems, and therewith livelihood systems, especially in rural low income areas (Pörtner et al., 2022). Coping and adaptation strategies to climatic challenges traditionally include crop diversification, technological adaptation, livelihood diversification, and *migration* (Black et al., 2011).

International migration has taken much space in the public discourse surrounding the challenges of addressing global climate change. However, resettlement to other countries is costly and remains the exception rather than the rule in most regions. The majority of migratory movements are expected to occur within the borders of a country (Clement et al., 2021). Rural to urban migration has been suggested as important margin of adjustment to declining agricultural productivity and increasing unpredictability of agricultural conditions. Migration can be considered as a direct reaction to declining yields and few opportunities within agriculture (Barrios et al., 2006), or indirectly as an adaptation mechanism at the household level to secure income from remittances and diversify economic risk in an increasingly unpredictable environment (Rapoport and Docquier, 2006).

On the other side, migration entails a range of physical and mental costs, including the expenses associated with transportation, securing new housing and employment, and reestablishing social connections at the destination. This process requires some initial investment, which can be a challenging hurdle for individuals with resources near subsistence levels. In such cases, a decrease in income exacerbates their financial constraints, potentially reducing the capacity of poor rural households to send members to urban areas for purposes such as income diversification, education investment, occupational upgrading and ultimately trap people into poverty (Cattaneo and Peri, 2016; Nawrotzki and DeWaard, 2018). Further, migration decisions and outcomes are influenced by a complex combination of demographic, economic, social, political, environmental and other drivers and circumstances interacting at multiple scales (Black et al., 2011; Boas et al., 2019; Pörtner et al., 2022). Against this context, estimates about future climate related migratory pressures are at best vague. Current World Bank (WB) estimates range from 44 to 216 million internally displaced individuals in the the six analysed regions by 2050 (Clement et al., 2021).

By combining rich micro data containing migration histories of over 13 million individuals sourced from the exhaustive Senegalese population census, and novel fine-grained data on local drought conditions, this papers aims to improve the understanding of the climate migration nexus. The article contributes to the growing literature on climate change induced mobility. We draw a differentiated picture of drought related migration in Senegal between 2003-2013 across different demographic groups, drought intensities, framing conditions, and distinguishing urban and rural communities. We estimate an augmented gravity model of internal migration on a highly disaggregated level of 426 municipality, featuring a large battery of fixed effects.

Approximately 55–62% of the sub-Saharan workforce is employed in agriculture, and 95% of cropland relies on rainfall for irrigation (Pörtner et al., 2022). The high projected population growth is likely to further exacerbating the already-existing strain on livelihood systems (Lutz et al., 2019). With an estimated amount of internal climate migrants of up to 85.7 million by 2050, constituting 4.2% of the total population, the World Bank considers Sub-Saharan Africa at especially high risk. This underscores the significance of Senegal, as politically stable economic economic hub and gateway to the Atlantic for the Sahel region, as a pertinent case study.

Our findings are at odds with the popular narrative of climate induced migration and call for a careful evaluation of impacts on a case by case basis. We show that droughts in rural localities are associated with lower emigration rates, while we do not find a significant effect in urban communities. The negative effects are stronger for more costly migration moves, proxied by either geographic or ethnic distance between localities. On the other hand, the presence of large migrant networks at destination may partially offset the immobilizing effects of droughts. This result is robust to a large set of alternative modelling choices and climate measures. This revealed *climate immobility* is in line with recent findings on *trapped populations* (Marchetta et al., 2021; Nawrotzki and DeWaard, 2018; Cattaneo and Peri, 2016). In line with a mechanism of cost-constrained migration in the presence of income shocks, we find that periods with favorable agricultural conditions were associated with increased long-run migration from rural localities. Further, considering past drought exposure, we find evidence for inter-temporal substitution of migration decisions to periods without droughts. In terms of heterogeneity across population groups, we find that the effects are driven by men in the second half of their work life, while women show significantly less response to drought in their mobility choices. Further, immobilizing effects are especially experienced by individuals without formal school education, which are likely less mobile and more involved in agricultural activities. We interpret these findings as evidence for the presence of significant migration costs of internal mobility in Senegal. Labor mobility is an important building block of the Senegalese society. In the presence of negative income shocks due to unfavorable agricultural conditions, potential plans to relocate may be postponed or abandoned if the liquidity necessary for such a move cannot be accumulated. A magnification of this effect may be linked to the increased need for labor in the rural origin household during unfavourable agricultural conditions.

The remainder of the paper is organized as follows. Section 2 reviews the literature on climate and internal migration. Section 3 presents the context of the study. The presentation of the data follows in Section 4. In Section 5 we discuss identification challenges of the impact of climate shocks and the empirical strategy. In Section 6 we present baseline results. Section 7 underscores the role of cost constraints and presents further evidence for the mechanism at play. In particular we analyse the impact of distance and networks, inter-temporal substitution patterns and shock intensity. In Section 8 we present robustness checks based on alternative empirical specifications and estimators, as well as different measures of climate shocks. Section 9 concludes.

2 Literature

While the large and growing number of publications on migration and climate change testify to great importance of the topic, research has not yet converged towards clear conclusions. Environmental factors interact with a complex array of contextual factors, as well as individual and household characteristics in shaping migratory responses. Further, studies largely differ in terms of empirical strategy, measurement of migration, measurement of climate and climate related events and geographic scope (Beine and Jeusette, 2021; Borderon et al., 2019; Berlemann and Steinhardt, 2017, for recent overviews of the empirical evidence).

Rural to urban migration has been identified as a major consequence of increasing fluctuations in climatic conditions. The cost associated with international migration and the limited alleviation of adverse climatic effects through migration to other rural regions within the country, render internal migration to urban areas within the country as a potentially more effective means of adaptation for a considerable number of individuals. Due to the lack of comprehensive data on internal migration in the cross-country setting, a series of papers analyzed the link between climate events and rural to urban migration using urbanization rates as proxy. Barrios et al. (2006) analyze the link between average rainfall and urbanization rates in Sub-Saharan Africa and find positive effects. Marchiori et al. (2012) show that standardized temperature and precipitation anomalies have affected migration in sub-Saharan Africa especially in those countries that are dependent on agriculture. Further, this work indicates that weather induced rural to urban migration, by exerting downward pressure on urban wages, may in turn generate international migration from urban areas. In contrast, extending the sample to 137 countries, Beine and Parsons (2015) find no effect of rainfall shortages, but suggest a slightly negative effect of excess temperatures on urbanisation. Cattaneo and Peri (2016) find that high temperatures increase urbanization rates in middle income countries, but have reduced mobility in poorer countries.

The lack of convincing or converging conclusions of these analyses comes in part from urbanization rate being a very bad proxy for net migration in favor of urban areas. Past the first stage of urban transition inception, migration is no longer the driver of urbanization in low and middle income countries (Menashe-Oren and Bocquier, 2021). Natural growth, boosted by a bulge at reproductive age and lower mortality in urban areas, is the main driver of urbanization.

A more micro based strand of the literature has produced a series of case-studies, overcoming some of the challenges related to the measurement of internal migration. Many factors, reaching from the socioeconomic structure, over environmental and geographic conditions to cultural norms, and the complex inter-plays between all of the above, may give rise to largely heterogeneous responses across countries. Studies focusing on one specific country allow for a deeper understanding of the climate-migration nexus, where cross-country analysis may fail to properly account for these heterogeneities. Quantitative, context specific studies have been implemented for a number of African countries[1].

Closely related to our approach, a series of papers has used retrospective census questions to estimate augmented gravity models of inter-provincial migration. Gravity models with bilateral data allow for the inclusion of various fixed effects and are very robust to unobserved heterogeneity across migration corridors. Dallmann and Millock (2017) look at bilateral migration rates across 31 Indian states. They find that droughts, measured by negative deviations in the standard-

[1] See for example, on Burkina Faso (Henry et al., 2003, 2004), Ethiopia (Gray and Mueller, 2012), Ghana (Cattaneo and Massetti, 2015; Van der Geest et al., 2010), Kenya (Gittard, 2020), Madagascar (Marchetta et al., 2021), Malawi (Lewin et al., 2012), Mali (Defrance et al., 2022; Findley, 1994), Morocco (Nguyen and Wodon, 2014), Nigeria (Cattaneo and Massetti, 2015; Dillon et al., 2011), South Africa (Mastrorillo et al., 2016), Tanzania (Kubik and Maurel, 2016; Afifi et al., 2014), Uganda (Strobl and Valfort, 2015), Zambia (Nawrotzki and DeWaard, 2018).

ized precipitation index (SPI) at origin states increased inter-state migration. Similar results have been established for inter-provincial migration in South America (Thiede et al., 2016) and South Africa (Mastrorillo et al., 2016). A caveat of these studies is that they consider relatively coarse spatial units and miss migratory moves within regions. As migration costs generally increase with distance, much internal migration is expected to take place in the form of shorter distance rural-to-urban migration. Further, they rely on small sub-samples of the population limiting the potential to detect heterogeneous effects.

In absence of direct migration data on the geographically fine-grained level, Defrance et al. (2022) for Mali and Gittard (2020) for Kenya adopt an indirect method to deduce net migration rates from observed changes in local population for a large set of sub-localities. Both find evidence that that drought spells are related to increased net migration rates in rural areas. Focusing on net migration, these studies remain silent regarding differential effects on in- and out-migration rates.

While these findings fit well into the conventional narrative of climate change as push factor, other studies highlight the potential retention effect of negative weather shocks. Marchetta et al. (2021) use survey data of households in Madagascar and find a strong negative impact of drought on the decision of youth to migrate in the year after the adverse weather shock. Nawrotzki and DeWaard (2018) find similar results for inter-districts in Zambia. While adverse climate conditions increased out-migration rates in wealthy districts, the opposite is found in the poorest districts. Gray and Mueller (2012) deliver a differentiated picture of the effect of droughts on migration in Ethiopia. They find that work related migration of men increased, while marriage related migration of women decreased following local drought events. Regarding the potential of climate change to impact the urbanisation process within countries, former case studies are limited by either constraint or imprecise knowledge of migrants destination and/or migrants precise origin communities.

Various factors, including the socioeconomic structure, environmental and geographic conditions, cultural norms, and the interplay between these elements, may result in diverse responses to climate-related challenges. Cross-country analysis, though useful, may not accurately account for country-specific nuances. In a recent effort to generalize conclusions based on individual survey data from GALLUP, which covers a broad range of African countries, Bertoli et al. (2022) conducted a meta analysis of the link between internal and international migration intentions and local weather shocks. The examination of 51,000 different model specifications indicated strong inconsistencies in the significance, sign, and magnitude of the effect of weather shocks on migration intentions across countries. As a result, the authors conclude that there may not be a universal specification that governs weather-driven mobility decisions in a wide range of countries, even those within the same region. These findings emphasize the need for a more comprehensive theoretical understanding of the underlying mechanisms.

Our paper aims to shed further light on the mechanism that link climate fluctuations to migration. Overcoming many of the caveats of previous studies, we base our analysis on the exhaustive Senegalese population census of 2013, which encompasses migration histories for approximately 13 million individuals. Exploiting a specific feature of the Senegalese census, repeated retrospective questions regarding past residency 5 and 10 years prior, we build a short, coherent panel of medium to long-run migration over two 5-year intervals. By determining the origin and destination of migrating individuals, we can accurately monitor incoming and outgoing migration flows for each locality. This information also allows us to enrich our model with a comprehensive set of fixed effects, controlling for heterogeneity across dyadic migration corridors. Conducting the analysis based on a single census eliminates many challenges associated with harmonizing localities over time, resulting in a more precise geographical resolution compared to most comparable studies. This, in turn, allows us to draw more accurate conclusions regarding urbanization related effects and potential heterogeneity across different types of localities.

3 Migration as coping mechanism in Senegal

Senegal is particularly interesting for a case study on the link of climate variability and migration. It is usually considered amongst the climate change "hotspot" regions, those regions expected to be most severely impacted by changing climate (Müller et al., 2014; Turco et al., 2015; Taylor et al., 2017). Historically, climate change in Senegal has been linked to persistent drought in the 1970s and 1980s. Recent observations suggest a reversal towards higher precipitation; however, this increase has resulted from increasing rainfall intensity rather than frequency. Rainfall patterns thus have become increasingly erratic, contributing to an uncertain risk environment. The main staple crops (rice, millet, groundnuts, and sorghum) are highly sensitive to changes in rainfall patterns, resulting in significantly lower food production in years with irregular rainfall. 55% of the Senegalese population lived in rural areas in 2013. The major part of income for the predominant part of the Senegalese population comes from subsistence agriculture, cash crops, livestock rearing and daily agricultural labour, activities which are highly climate-sensitive (WFP, 2014). While a large share of the population is directly or indirectly dependent on agriculture, poverty is high, and technical and financial means to deal with these uprising climatic challenges are limited. Additionally, Senegal has consistently one of the highest population growth rates in the world, putting additional pressure on food security. In 2022, the United Nations population division estimated a growth rate of of 2.75%, adding over 447000 people to the population per year, explained by Senegal's high fertility rate of 4.65 births per woman (UN, 2022).

Most studies on the climate-migration nexus share the underlying assumption that climate-related migration essentially represents either a failure to mitigate climate change, and/or a failure of adaptation. Black et al. (2011) put this perspective into question, pointing out that migration can also be seen as a valid coping mechanism for increased stresses and shocks. Even in the absence of climatic stress, migration can be a desired outcome for many individuals. In this sense, mobility refers to both voluntary movement and involuntary or survival displacement. Thus it is as important to understand the incentives and outcomes for those who move, as it is to understand the same for those who choose not to, or who are unable to move despite being at risk. In other words, immobility is as important as mobility (Cundill et al., 2021).

Consistent with this view, it should be noted that rural communities in the Sahelian zone of West Africa have always managed their resources and livelihoods in the face of challenging and unpredictable environmental conditions. Senegal, a comparatively small country, spans over three different climatic zones, from tropical savannas in the south to partially deserted areas in the northern Sahel region. Different agro-ecological zones give rise to diversified agricultural activities and livelihood strategies that are well adapted to local conditions. Figure A1 in the appendix illustrates the distribution of main income means, reflected by different livelihood zones.

Mobility and flexibility regarding the various potential sources of economic income have been integral to Senegalese people's survival for centuries. Various ethnic groups used regional mobility to survive under harsh climatic conditions. Agricultural calendars usually revolved around the rainy season from June to October, which meant that agricultural workers had to engage in alternative economic activities to secure their livelihoods during the dry season. Against this backdrop, international migration to European countries was readily embraced in the 20^{th} century when new opportunities arose due to demographic challenges after World War II. While official recruitment policies ended with the oil crisis in 1973, Senegalese citizens could enter France visa free until 1986 (Maher, 2017).[2] Therefore, some form of circular or sequential migration across Senegalese regions, or to international destinations along well established routes was the norm rather than the exception for many Senegalese households. A popular Senegalese proverb states that *"he who does not travel will never know where it is best to live"* [adapted from (Ndiaye, 2014)]. [3]

It is clear then that climate anomalies can disrupt usual mobility patterns in a variety of ways. Ex-ante, it is not self-evident whether adverse climate conditions will promote or limit mobility. Anecdotal evidence suggests that entire rural communities which depend on rain-fed agriculture may be involuntarily displaced because they must seek alternative sources of income. On the other hand, established mobility patterns may be disrupted by negative income shocks. Tightening household budgets may lead to foregone opportunities for individual household members to invest in a better future through occupational upgrading in urbanized areas or through migration to destinations abroad. Further, rural households may need additional cheap labor to cope with increasingly unfavorable agricultural conditions. In order to design policies to mitigate the negative impacts of climate change, it is essential to take into account the wide heterogeneity of individual perspectives, life plans, and adaptive capacities across genders, education levels, age groups, etc. to identify the most vulnerable populations.

4 Data

We combine fine grained, comprehensive population data from the complete 2013 Senegalese census with a novel data set of remotely sensed drought exposure for the African continent to conduct our analysis.

4.1 Measuring Migration

Challenges Estimating models of migration is typically related to severe data constraints. By the very nature of migration, it is costly and sometimes impossible to follow individuals across

[2] Maher (2017) argue that making entry to France significantly more difficult, family reunification schemes reshaped what had been a form of circular migration to permanent resettlement in the subsequent period.

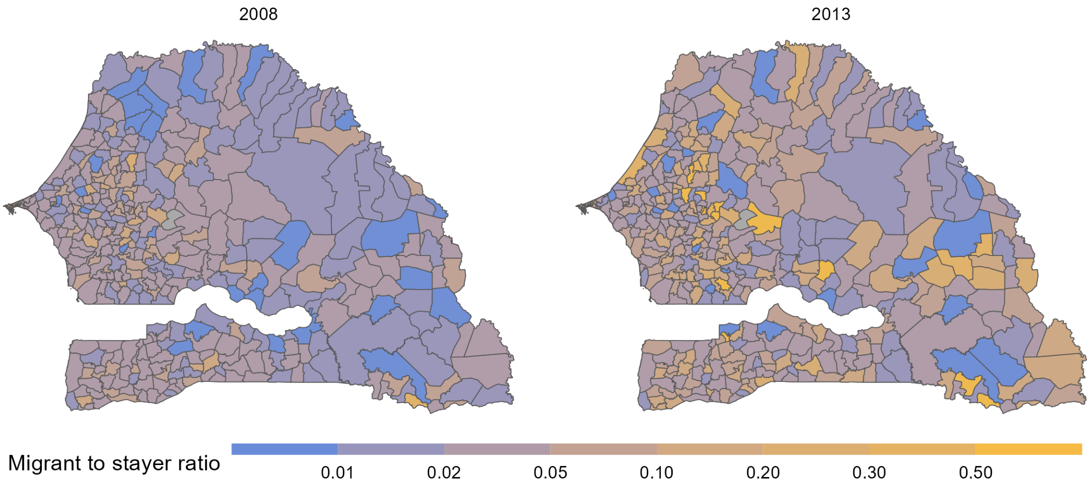
[3] Another proverb illustrating this attitude is: *"If you have a son, let him go. One day he will come back either with money or knowledge"*(Ndiaye, 2014).

space and time. The recent literature suggested different approaches to overcome these constraints. Some studies relied on survey data of individual migratory histories (Marchetta et al., 2021; Nawrotzki et al., 2015, i.e.). While superior in terms of measurement of migration, these papers usually rely on small samples to derive conclusions, leaving open questions regarding external validity of the results, and limiting the scope for heterogeneity analysis. In the absence of direct migration indicators, another strand of the literature relied on estimated net-migration rates, derived as population increments between two points in time corrected for birth and death (UN, 1970; Iqbal and Roy, 2015; Defrance et al., 2022; Gittard, 2020). This approach is valuable in overcoming data constraints, but may be prone to many sources of measurement error[4]. Additionally, it does not allow to differentiate between in- and out-migration, thus potentially missing crucial insights into heterogeneous mechanisms at hand. Similar to our approach, a handful of studies directly used migration-related items in censuses to derive measures of migration, usually consisting of questions related to individuals' previous place of residence, to reconstruct migration history at regular intervals. These studies draw on sub-samples of the full population and are generally limited in terms of spatial disaggregation. Often geographic units change over time making it difficult to obtain a coherent panel of places at a fine-grained level. Since repeated observations are essential in this context to control for unobserved geographic specificities, studies used large aggregate regions, such as federal states for which boundaries can be consistently tracked over time, as units of observations (Dallmann and Millock, 2017; Thiede et al., 2016; Mastrorillo et al., 2016). This approach misses potentially important migratory movements *within* the geographic unit, such as re-allocations from surrounding rural areas to the regional urban center, and risks to inappropriately measure exposure to locality specific climate shocks.

Our dataset allows us to overcome several of these shortcomings: (i) We derive direct and precise measures of incoming and outgoing migration using past and current residence of individuals; (ii) We draw on the full Senegalese population census, allowing for detailed heterogeneity analysis of different population groups and a high degree of external validity; (iii) Fine-grained spatial disaggregation (427 municipalities) allows precise mapping of individuals to climate shocks and surrounding geographic and socio-economic conditions; (iv) We construct a time-consistent panel of two waves of migration flows, allowing to control for unobserved location specific features at a fine-grained level.

[4]For example, if climate shocks have a direct impact on mortality and/or fertility, estimated net-migration rates in the presence of these shocks are likely biased.

Figure 1: Emigration rates by municipality



Note. Municipality level migration rates, expressed as migrant to stayer ratio for the periods 2003-2008 (left) and 2008-2013 (right). Rates reflect the number of individuals who left the municipality to another destination within national boundaries between t and $t-5$ divided by the number of individuals who stayed.

Methodology We draw on the full Senegalese population census of 2013, capturing migration histories of around 13 million individuals. The Senegalese census is unique in the sense that it allows us to derive two subsequent migration episodes with one census round. This ensures coherent encoding of places and allows us to conduct our analysis on a disaggregate level (n=427). In 2013, individuals were asked where they lived respectively five and ten years ago. Knowing their current place of residence, we then derive information on two five-year migratory episodes for each individual (see Figure 2). Current and past residence can be traced at the level of "communes", the smallest administrative divisions of Senegal. A commune is similar to a municipality or a townships and is governed by a mayor and a council. We match the census data to the GADM administrative division shapefiles 4.1 (available at www.gadm.org) to geo-reference 431 localities[5] [6]. We distinguish rural and urban localities based on their administrative status in 2013, as reported in the census.

Aggregating individual moves between localities, we obtain a short panel of migration flows

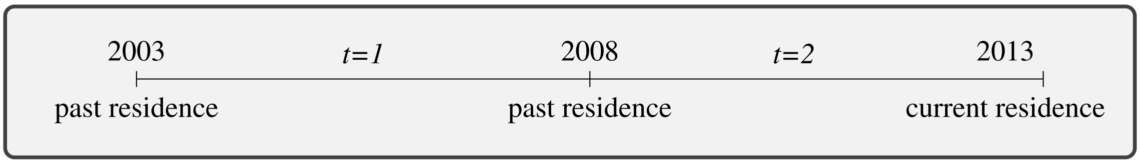
[5]The census itself uses a slightly different definition of administrative boundaries by considering some urban areas as separate localities. This leads to 554 localities in the raw census data. Using GIS methods we merge these urban localities to the surrounding municipality as indicated in the GADM boundary file. We consider the municipality as urban if it contains at least one urban locality.

[6]Due to severe data inconsistencies we aggregate the four municipalities belonging to the department of Guédiawaye to one entity, shrinking the number of places to 427.

between each pair of localities for 2003-2008 and 2008-2013[7]. We limit our baseline analysis to individuals aged 20 to 60 at the beginning of the migration period, capturing individuals that finalized their school education and are not retired yet. We show a detailed breakdown of effects across the entire life cycle in Section 6.2.

It is important to note that we do not capture temporary migratory movements within the five year periods, neither do we account for potential transitory locations before arriving at the final destination after 5 years. The derived measure represents the number of individuals who changed their place of residence from i at the beginning of the 5-year migration window to j at the end of the window. Temporary migration may occur if agricultural workers relocate during droughts, but come back as soon as climatic conditions normalize. Consequently, our migration indicator reflects long-term or permanent migration, rather than short-term responses to current conditions, which may well occur climate- or labor market-related.

Figure 2: Measuring internal migration in the population census



Note. Two five year migration episodes derived from survey questions of the Senegalese 2013 population census by comparing current and past residence municipalities. We make use of the following two survey items to derive repeated migratory outcomes for each individual over comparable time periods: *"Where did [NAME] reside 5(10) years ago?"*.

Stylized facts In the following, we derive several key facts about the internal migratory dynamics in Senegal that will be useful to put the later empirical findings into context. We consider the second period of migration between 2008 and 2013, allowing us to make full use of the information reported in the census and deepen the understanding of general migratory dynamics[8]. In total, we observe 905033 individuals in our sample, who changed their locality of residence during the 5 years between 2008 and 2013. This corresponds to an internal annual migration rate of 1.8%.

Figure 3 A gives a comprehensive picture of the migratory movements between regions. For

[7] We discard outlier observations with unrealistically high migration rates ($> 5\%$), and origin-destination pairs with extreme variations in migration flows across periods (top and bottom 1%), due to coding inconsistencies across time. Additionally, we exclude the municipality of Khelcom from the analysis as we find systematic coding errors in the raw census data. In total the excluded observations amount to 2.47% of the full data set.

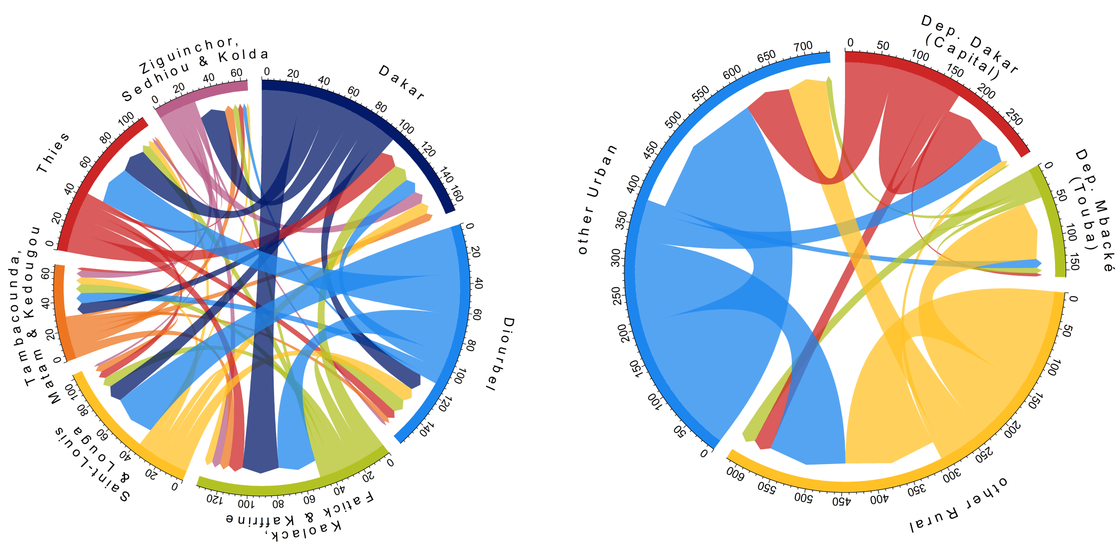
[8] Migration flows for the 2003 to 2008 period are deduced from the past residence 10 years ago. Key indicators, such as migration motives, are only reported for last migratory move, or at the time of the survey, such as education and marital status.

clarity of exposition we group adjacent smaller regions. The direction of the flow is indicated by the arrowhead. The size of the flow is indicated by the width of the arrow at its base in thousands[9]. Figure 3 B shows the same data, but distinguishes between urban and rural places. Additionally, we separately consider the departments of Dakar, seat of the capital Dakar, and Mbacké, seat of the second most populous city Touba, which is considered a holly city in Mouridism[10]. We expect significantly different dynamics at play for migration from/to those places. Arrows pointing back to the same locality reflect within migration, for example individuals that moved between rural localities. The differences between urban and rural areas are striking. The migration corridor that received the most attention in the literature, rural-to-urban migration, accounts only for a minor share of all migratory movements. Contrary to the widespread perception of the *rural exodus*, only 1% of all migration moves lead from rural localities to the capital and 6.7% to other urban areas, excluding Touba. Most of the out-migration from rural areas goes to other rural areas (15.8% of total migration) and to Touba (9.9%). At urban places, migration to Touba is rare, while a significant proportion moves to the capital (5.1%). The largest chunk, representing 22.9% of all moves consists of urban to urban migration.

Figure 3: Aggregate migration flows between 2008 and 2013

A. Regions

B. Locality types



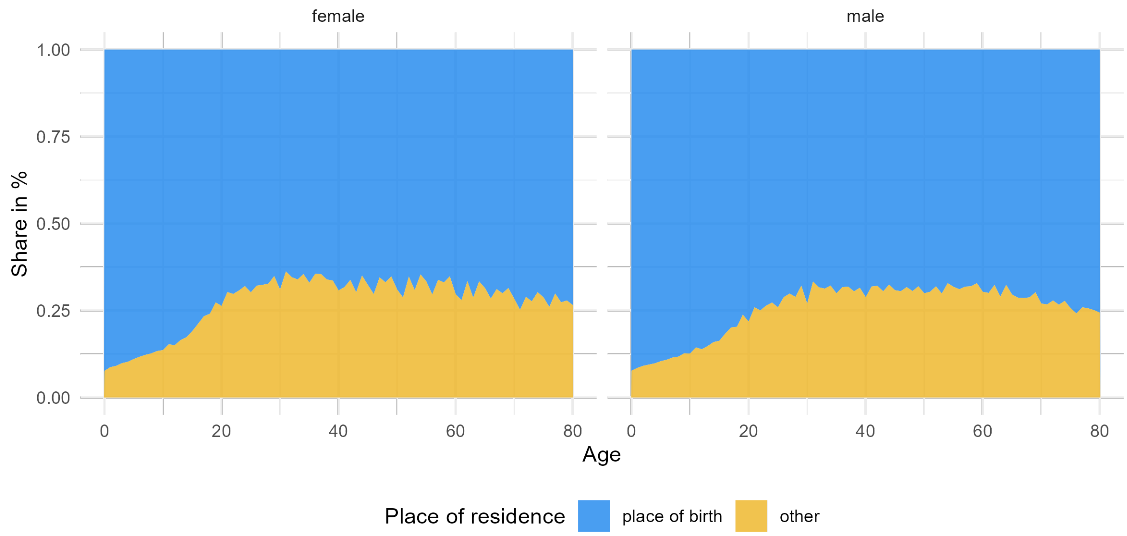
Note. Chord diagrams of migration flows during 2008-2013 in thousands. The direction of the flow is indicated by the arrowhead. The size of the flow is indicated by the width of the arrow at its base. Own calculations based on the full count 2013 Senegalese population census.

[9]We thank Guy J. Abel for making his R code to generate chord diagrams of migration flows publicly available.

[10]Mouridism is a branch of Sunni Islam indigenous to Senegal that has strong influence in all strata of society. The Mourids make up about 40% of the total population.

Figure 4 visualized average migration status over the life cycle. The stacked area chart shows the proportion of individuals residing in their birthplace in the year 2013, disaggregated by age and gender. A notable fraction, accounting for 8% of all individuals, relocates within the first year after birth. During young adulthood, mobility rates are relatively high, as individuals leave parental care, make educational choices and enter the labor market. As for individuals aged 60 or above, the likelihood of living in a municipality different from their birthplace slightly decreases, which may be indicative of the impact of return migration following retirement dominating the aggregate trend. Overall, females tend to be slightly more mobile than males, as women often join the husbands' households after marriage.

Figure 4: Share of internal migrants by age and gender

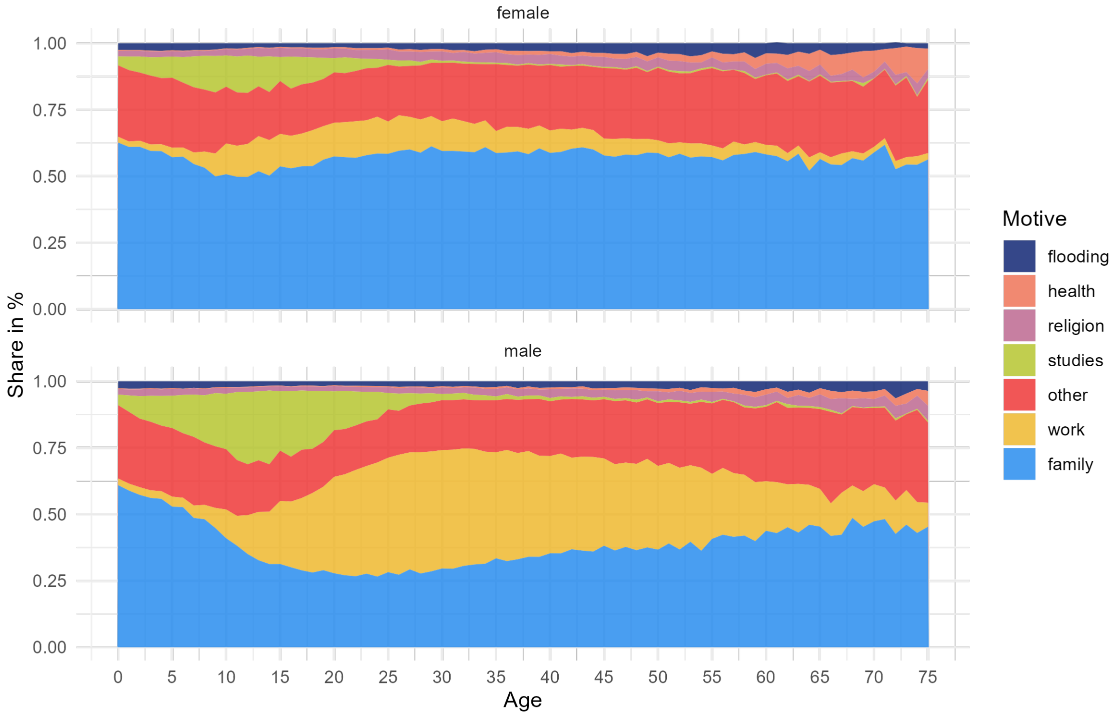


Note. Stacked area chart of migrant shares of the total population by gender and age in 2013. For each age group we calculate the share of individuals residing at a place different to their place of birth. Own calculations based on the full count 2013 Senegalese population census.

Next we evaluate the prevalence of specific migration motives across the life cycle. To this end, we examine reasons for the latest migration event, as self-reported in the census, across different age groups and gender. Figure 5 indicates that occupational reasons are the primary impetus for migration among working-age men. In contrast, women primarily cite familial reasons, reflecting the distinct social roles of women in Senegalese society. Specifically, women frequently relocate for marriage purposes, to accompany their husbands, or to attend to the needs of other family members, such as parents or in-laws. Nevertheless, while unfavorable labor market conditions may be the direct reason for men to reallocate, women are likely to be impacted indirectly.

In Figures A3 and A4 in the appendix, we continue to dissect migration flows by breaking down the composition of migrants by their reported motives for migration by gender, age group and migration corridor.

Figure 5: Migration motives over the life cycle

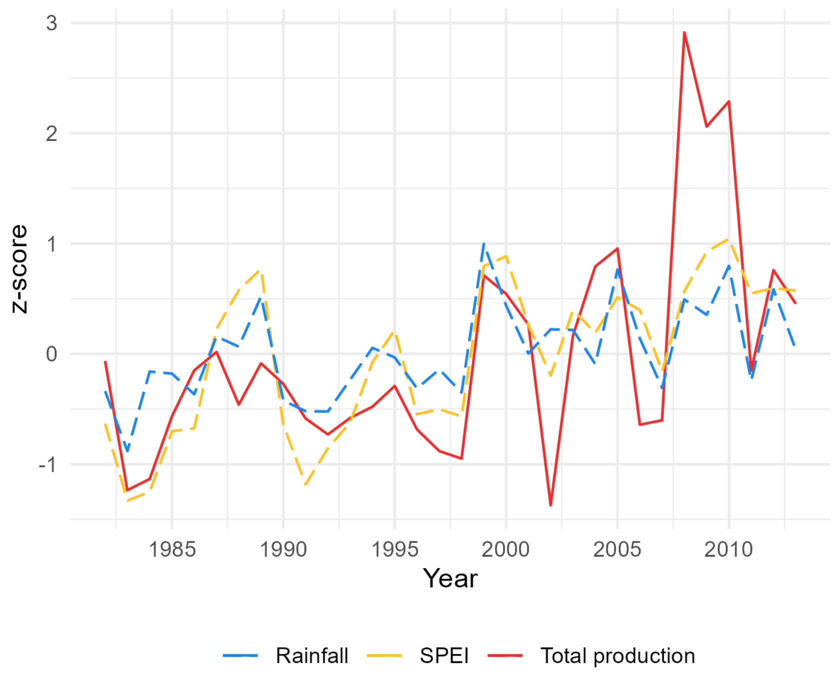


Note. Stacked area chart of migration motives as share of all migratory moves by gender and age during 2008 to 2013. Own calculations based on the full count 2013 Senegalese population census.

4.2 Climate Anomalies

Measurement Next we turn to the measurement of local climate shocks. The literature on climate variability and migration has traditionally focused on measures precipitation, and in some cases on extreme temperatures, to model climate anomalies. We opt for the Standardized Precipitation-Evapotranspiration Index (SPEI) as our preferred measure for climatic anomalies (Vicente-Serrano et al., 2010). Especially with regards to the impact on agriculture drought, effects are apparent after longer periods with shortage of precipitation. The time period between arrival of water inputs in form of precipitation and availability through ground moisture depends on temperature and the capacity of the soil to retain water (potential evapotranspiration). Climatologists therefore distinguish between meteorological droughts (precipitation deficiency) and agricultural droughts (soil moisture deficiency) (Wilhite and Glantz, 1985; Peng et al., 2020). While rainfall anomalies directly relate to meteorological droughts, they may be an insufficient indicator of agricultural droughts, which are expected to be the driver of climate-related productivity shocks in agriculture and, ultimately, mobility choices.

Figure 6: Agricultural output and growing conditions in Senegal 1983-2013



Note. Standardized rainfall and SPEI during growing season for the years 1983 to 2013 based on own calculations. Standardized yearly aggregate production value of the five main crops groundnut, rice, cassava, maize and sorghum in tons (FAO). Rainfall data stems from Funk et al. (2015). SPEI indicators are derived from Peng et al. (2020).

More recent analysis therefore relied on the SPEI to measure local drought exposure (Bertoli et al., 2022; Defrance et al., 2022). Vicente-Serrano et al. (2012) illustrate that this state-of-the-art index generally out-performs alternative drought measures in predicting crop yields. The SPEI is a recently developed multi-scalar drought index, considering the joint effects of precipitation and potential evapotranspiration, which in turn incorporates numerous parameters, including temperature, soil composition and vegetation, air pressure and the number of sun hours. The index is designed to allow for comparisons of droughts across time and space. It is therefore especially well suited to estimate a generalized model linking drought conditions across various locations and periods. SPEI values can be interpreted as standard deviations above or below the historic mean for the specific locality.

As a first straightforward visual check for the quality of our climate measure we plot standardized production value in tons, aggregated over the 5 main crops (groundnut, rice, cassava, maize and sorghum) along with average growing season SPEI and precipitation. Figure 6 shows that growing season SPEI and standardized rainfall correlate strongly with agricultural output. For a more rigorous test, we link agricultural production between 1983-2013 to climatic conditions and estimate the following equation:

$$ln(output_c^{year}) = \beta clim^{year} + \lambda Year + \mu_c + \epsilon_c^t \tag{1}$$

where $clim$ is the average growing season SPEI, or the standardized average growing season rainfall, respectively. We control for crop fixed effects and a linear time trend capturing general productivity gains. Table 1 reveals that the SPEI measure tends to slightly outperform pure rainfall in predicting agricultural yields. Controlling for linear time effects in column (2), we find that an increase in SPEI by 1 unit is associated with 26.7% higher agricultural production output at the aggregate level, significant at the 1% level[11].

This result demonstrates the significant susceptibility of Senegal's agricultural productive system to variations in rainfall. The agricultural sector in Senegal primarily relies on small-scale rain-fed subsistence farming without access to advanced irrigation systems. As anticipated, agricultural yields rise in response to increased rainfall and decline with higher temperatures (columns 3 to 6). Only the SPEI variable retains statistical significance in the statistical horse race conducted on column 7, further bolstering the validity of our modelling choice.

Defining anomalies We exploit the high resolution (around 5 km) SPEI dataset recently made available for Africa by Peng et al. (2020) to derive precise measures of drought exposure at the municipality level. This constitutes a significantly improved measurement of local conditions, compared to former studies building on the gridded SPEI data by Vicente-Serrano et al. (2010) with a resolution of 50km. Figure 7 shows the mean growing season SPEI for the years in our sample on grid-cell level. We follow the FAO assessment and consider the months from June to

[11] SPEI values are standardized deviations, thus an SPEI=1 (-1) implies that the growing season is one standard deviation wetter (drier) than the historic average.

Table 1: Climate variation and agricultural output

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
SPEI	0.4410**	0.2666***					0.3850*
	(0.1396)	(0.0517)					(0.1763)
std. rainfall			0.6228**	0.3569***			0.1077
			(0.1666)	(0.0411)			(0.0759)
std. temperature					-0.0857**	-0.1516***	-0.0018
					(0.0226)	(0.0253)	(0.0388)
Observations	160	160	160	160	160	160	160
R^2	0.72751	0.74883	0.70188	0.74750	0.61743	0.73496	0.72832
Within R^2	0.29296	0.34828	0.22646	0.34482	0.00732	0.31228	0.29506
Linear time-trend		✓		✓		✓	
Crop fixed effects	✓	✓	✓	✓	✓	✓	✓

Note. The dependent variable is the log production value in tons of the 5 main crops. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.

October as growing season.[12] Cells in red experienced growing seasons that were drier than the respective historic average in the year, while cells in blue had relatively wet growing seasons. We note considerable spatial and temporal variation in climatic conditions, which is a suitable setting for a case study of the effects of climate variability. Further, it is reassuring at this point that treatment is relatively well distributed over our two sampling periods from 2004 to 2008 and 2009 to 2013. Thus estimates are not merely driven by few cases. Rather most localities experienced significant variation in terms of drought exposure across periods and contribute to the identification of our parameters of interest.

Given the long time spans of migration periods constructed with the census data (5-year intervals), defining a relevant drought measure is a crucial task. We adopt two different approaches in our baseline estimations:

1. We calculate the number of dry months over the 5-year migration period. We encode a month as dry if the monthly SPEI value is at least 1 standard deviations smaller than its historic mean. We distinguish between month during the growing season, and the total number of month within the respective year.

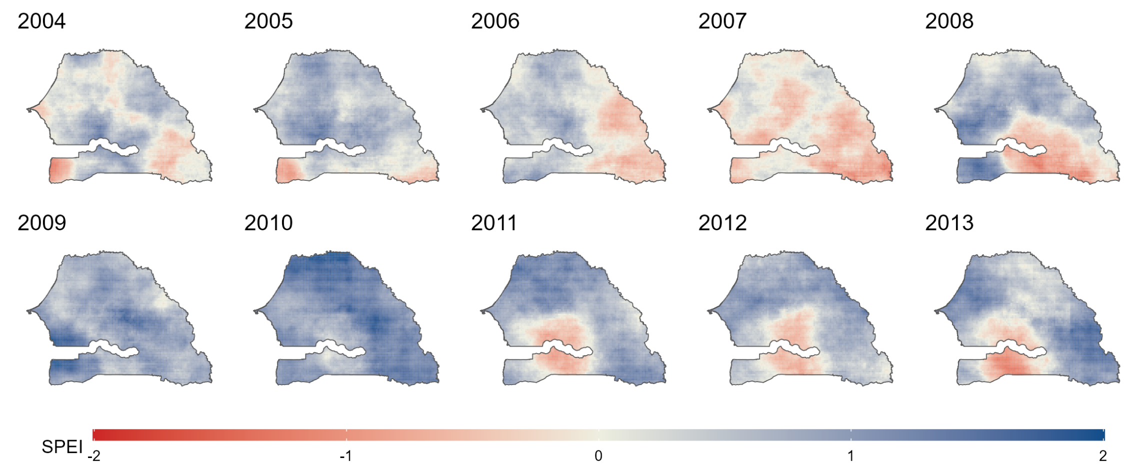
2. We calculate the number of dry growing seasons over the period. Therefore we compute the average SPEI value over the growing season for each year. We consider growing seasons

[12] See FAO country briefing for Senegal: https://www.fao.org/giews/countrybrief/country.jsp?code=SEN.

with an average SPEI smaller than -0.5 as dry.

In section 8.1 we present results for a broad set of alternative modelling choices, such as different SPEI scales, different thresholds in terms of deviation, rainfall and temperature deviations.

Figure 7: Average growing season SPEI from 2004 to 2013



Note. Yearly averaged growing season spei12 on grid cell level based on data from Peng et al. (2020) at a resolution of $5km^2$. Red (blue) cells have been drier (wetter) than the historic average during the growing season of the respective year.

5 Empirical approach

Our goal is to estimate the causal effect of droughts at origin on migration flows. Much of the literature on climate migration employed some variant of the gravity model, that is directly grounded in micro-economic theory (Beine et al., 2016). In this framework migration is modelled as aggregated flows of individuals between two locations.[13] The gravity approach makes full use of the data and is highly robust: By exploiting three sources of variation, origin, destination and time, the modelling choice allows to include a full battery of fixed effects addressing a broad set of potentially concerning confounders.

We map our tailored drought indicators to the 427 municipalities, and estimate the following equation that links bilateral aggregated migration flows between localities to weather shocks at the origin municipality:

[13] See Beine and Parsons (2015) for a detailed derivation of the gravity equation from the canonical random utility maximization model of individual choices.

(2) $$ln(\frac{mig^t_{ij}}{stay^t_{ii}}) = \beta \sum_{t-4}^{t} clim^t_i + \gamma \mathbf{X}^t_{ij} + \mu_i + \mu^t_j + \epsilon^t_{ij}$$

mig^t_{ij} is the number of migrants that have moved from origin municipality i to destination j over the 5-year migration period $[t, t-4]$, where t is either the year 2008 or 2013. $stay^t_{ii}$ represents the stock of individuals that do not move, so that $\frac{mig^t_{ij}}{stay^t_{ii}}$ is the bilateral migrant to stayer ratio, referred to as *migration rate* hereafter. $\sum^t_{t-4} clim^t_i$ is either the sum of dry growing seasons, or dry months during growing seasons over the 5-year migration period.

μ^t_j is a destination-year specific fixed effect, controlling for changes in the attractiveness of specific destinations, including droughts at destination[14]. It is important to note that μ^t_j also captures general time-specific effects. This may be mobility-related, i.e. increasing international migration opportunities, but also differences related to the census items used to calculate migration, such as measurement error and recall bias. μ_i captures all time consistent effect in the origin community. This includes geographic features, as well as labor market composition and path dependency of localities with structurally high rates of migration for historic reasons, which may be climate-related or not. The measurement of location-specific weather shocks modelled as standardized deviations from the local long-run mean, together with location-specific fixed effects, lends strong support to causal interpretation of our main parameter of interest β. Anticipation of residual variation in drought exposure is unlikely, and the treatment can arguably be considered random[15].

We enrich our battery of fixed effects by a vector of additional control variables $\mathbf{X}^t_{i,j}$. To account for the standard gravity forces shaping bilateral flows, we include the logarithm of distance measured in kilometers, and a contiguity dummy for each origin-destination pair. Additionally, we introduce two distinct indicators that aim to capture network-related effects, which are widely recognized as key factors in shaping migration flows (Beine et al., 2009). Firstly we control for migrant networks, measured as the number of individuals born in locality i and residing in j at the beginning of the migration period t. This measure thus captures the presence of direct contacts at potential migration destinations that may act as facilitator for subsequent migratory moves.

[14]Destination-time specific fixed effects also account for certain forms of multilateral resistance in the gravity framework (Feenstra, 2002).

[15]We address this issue in more depth in Section 7.3.

Secondly, to account for the complex ethnic and religious structure within the Senegalese society, we enrich our model by a measure of ethnic distance between two localities. The Senegalese census allows us to identify 26 distinct ethnic groups, distinguishing themselves through linguistic, religious and cultural particularities. In the spirit of the respective literature on ethnic networks and international trade (Felbermayr et al., 2010, for example), we compute the following index of bilateral ethnic distance between two localities:

$$ed^t_{i,j} = 1 - \sum_{n=1}^{N} s^t_{n,i} * s^t_{n,j} \quad (3)$$

where $s^t_{n,i(j)}$ is the share of ethnicity n in municipality $i(j)$ at time t. Hence, $\sum_{n=1}^{N} s^t_{n,i} * s^t_{n,j}$ represents the likelihood that two simultaneously drawn individuals residing in municipalities i and j have the same ethnicity. We then have $0 \leq ed_{i,j} \leq 1$. Ethnic distance is maximized with $ed_{i,j} = 1$ if no ethnicity simultaneously exists at both locations i and j, and $ed_{i,j} = 0$ if a single ethnicity n makes up the entire population at both localities.

In further robustness analysis we add measures of conflict at origin from ACLED, and night-light intensity at the beginning of the migratory period taken from the Earth Observation Group (Baugh et al., 2010) to account for shocks in economic development which may drive subsequent migration. Regarding conflicts, we are especially concerned that the occurrence of violent events in the Casamance region could drive migration and impact our estimates[16]. Nevertheless, because conflicts and economic development may well be outcomes of climate shocks itself, we opt for a parsimonious specification as baseline model to avoid over-controlling bias. Results are robust to the inclusion of these additional controls.

As standard in the migration literature, we estimate equation 2 using the Poisson-pseudo maximum likelihood estimator (PPML). Firstly, this allows for zeros in the dependent variable. Secondly, Silva and Tenreyro (2006) show that estimating the log-linearized equation 2 with OLS leads to biased estimates should any of the covariates be correlated with higher moments of the error term. Results for alternative estimators and modelling choices are presented as robustness checks in Section 8.2.

[16]Starting in 1990 a low-level insurgency spear-headed by the Movement of Democratic Forces of Casamance (MFDC) has led to sporadic violent clashes with government forces in the Casamance region in southern Senegal.

6 Results

6.1 Main findings

Regression results are displayed in tables 2 and 3. Table 2 presents the main estimation results of the gravity model introduced in equation 2. Resulting coefficients can be interpreted as semi-elasticities. As presented in Section 4.1, migration patterns differ strongly across urban and rural areas. We therefore separate the sample into rural and urban origin localities. As a first observation, the gravity model appears to be well specified and attains high goodness of fit levels in all specifications. As expected we consistently find negative effects of geographic distance between two places, reflecting the increasing costs of the migration move. The reverse holds for migrant networks which act as facilitator of migration and lower costs. We show that ethnic distance between two local communities has a highly significant migration hampering effect. For migration from urban areas (column 5), which are generally more diverse and open communities, this effect vanishes, while migrant networks from the same origin municipality remain highly significant. While often neglected in the "gravity-style" migration modelling, this result suggest that controlling for ethnic ties should be an important building block that impacts migration flows beyond the pure existence of migrant networks, especially in highly heterogeneous societies.

Columns 1 to 4 present results for rural localities. Turning to our preferred specification in column 1, we find that one additional dry agricultural season over the 5-year migration period decreases the bilateral migration rate by 12.35%, significant at the 5% level. The coefficient remains stable after controlling for conflicts and lagged economic activity, proxied by nightlight intensity variables (column 2). Column 4 confirms coherent results adopting an alternative drought measure: An additional dry month during the agricultural growing season decreases migration rates by 6.1%. Columns 3 and 5 reveal strong evidence for an agricultural channel at play: When considering all months of the year, as opposed to growing season months only as relevant treatment (column 4), the effect size sharply drops to less than one third (column 3). Column 5 shows that dry agricultural seasons have no significant effect on migration rates at urban localities, again suggesting an agricultural channel as key driver of the (im)mobility responses.

We next assess the impact of droughts through specific migration corridors. Leveraging the full potential of our unique data set containing highly desegregated origins and destinations of migratory moves, we repeat the analysis for sub-samples of specific origin-destination pairs. Table

Table 2: Baseline results

	rural localities				urban localities
	(1)	(2)	(3)	(4)	(5)
contiguity	-0.0448	-0.0449	-0.0449	-0.0450	0.1361
	(0.0769)	(0.0769)	(0.0770)	(0.0770)	(0.1065)
ln(distance)	-0.3594***	-0.3595***	-0.3595***	-0.3600***	-0.2482**
	(0.0640)	(0.0640)	(0.0640)	(0.0640)	(0.1043)
ethnic distance	-0.2569***	-0.2569***	-0.2561**	-0.2560**	0.0634
	(0.0997)	(0.0997)	(0.0998)	(0.1000)	(0.0759)
ln(network)	0.9530***	0.9530***	0.9531***	0.9528***	0.8049***
	(0.0229)	(0.0229)	(0.0228)	(0.0230)	(0.0484)
conflict		0.0306			
		(0.0438)			
nightlight		-0.0882			
		(0.0922)			
dry years (agri)	-0.1235**	-0.1261**			0.0631
	(0.0576)	(0.0576)			(0.0534)
dry months			-0.0194**		
			(0.0085)		
dry months (agri)				-0.0610***	
				(0.0236)	
R^2	0.68975	0.68982	0.69005	0.69016	0.84612
Pseudo R^2	0.66085	0.66086	0.66089	0.66099	0.88030
Observations	237,157	237,157	237,157	237,157	117,390
i fixed effects	✓	✓	✓	✓	✓
j-year fixed effects	✓	✓	✓	✓	✓

Note. Standard errors are clustered at the origin municipality level. ***,**,* mean that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%, respectively. The dependent variable is the bilateral migrant to stayer ratio. The estimation sample consists of all individuals aged 20 to 60 at the beginning of the migration period.

3 presents results from estimating equation 2 by sub-group. Columns 1 and 2 reveal coefficients coherent in size with our baseline specification when estimating the model only with observations of migration corridors from rural to rural (1) or rural to urban (2) localities. Nevertheless the estimates for rural-to-rural flows only, is not statistically significantly different from 0 at the 10% level. The significantly negative estimate for rural-to-urban flows suggests that this type of migratory movements is especially costly and may be omitted or postponed when exposed to droughts. Our result is at odds with former cross country analysis suggesting that climate change is likely to foster urbanisation (Beine and Parsons, 2017; Marchiori et al., 2012; Barrios et al., 2006). In fact, our results indicate that long run migration to urban areas is more of a luxury good than an emergency action. Against this context, climate change may ultimately slow down urbanisation.

In columns 3 and 4 we look at migration flows to the main destinations for internal migrants, Dakar and Touba. In column 5 we consider only migration corridors leading to municipalities in the Department of Dakar. To maintain a sufficiently large sample size after limiting the set of possible destinations, we consider flows from rural and urban localities alike. Surprisingly, we find no significant effects of droughts on migration flows to the capital Dakar. As indicated in Figure 3 in Section 4.1, direct migration to the capital is rare for individuals residing at rural localities, and likely out of reach for the poorer population. Migration to closer urban destinations may be the more attainable goal and reacts therefore stronger to adverse income shocks at the margin.

Touba is the second most populous city and the most popular migrant destination after Dakar. Limiting the set of destinations to municipalities within the Mbacké department, which encompasses the immediate vicinity of the holy city Touba, we observe an estimated coefficient that is roughly twice as large as our baseline. This indicates that migration to Touba, which is the single main destination for migrants from rural areas, reacts strongly to droughts at origin communities of potential migrants. Paradoxically, the lower cost of moving to Touba (as compared to Dakar, for example) could translate into higher reliance on agricultural income, and therefore be more sensitive to drought. Additionally, factors at the destination could also contribute to this heightened sensitivity. Touba has a very specific access to land management system, managed collegially by the cadres of a hierarchic religious institution (Ross and Guèye, 2021). Acquisition of building land follow the principle of effective use: “Recipients of a lot in Touba are given 2 years to build a house on it and begin inhabiting it, failing which the lot can be “repossessed” by the village head and reassigned to another homesteader. [...]. The first concrete act of inhabiting a lot requires that a perimeter wall be built" (Ross and Guèye, 2021, p68). This requirement may severely impede newcomers from rural areas affected by droughts.

Overall, these results suggest that, especially in rural areas, individuals may be trapped in the face of negative shocks to agricultural productivity. As highlighted in Section 2, migration is an important building block of Senegalese society. Climate-related anomalies likely impede structural migration dynamics and distort livelihood systems of which migration is traditionally a part. These results are consistent with findings on trapped populations in other countries (Marchetta et al., 2021; Nawrotzki and DeWaard, 2018). It is important to note that we look at long-term mobility responses measured at the end of a 5 year window. Thus, while short-term labour or "survival" migration may well occur in direct response to droughts, we show that the probability of long-run reallocation drops. This is likely due to negative long-run effects of droughts on household wealth. As demonstrated in Cattaneo and Peri (2016), even when migration to areas with more favorable climatic conditions or less climate dependent labor markets would be the optimal choice, associated initial costs of the re-allocation can be restrictively high. Against this context, tightening household budgets can render migration less likely in the presence of droughts and potentially lead to lock-in effects into poverty.

Table 3: Subsample analysis across different migration corridors

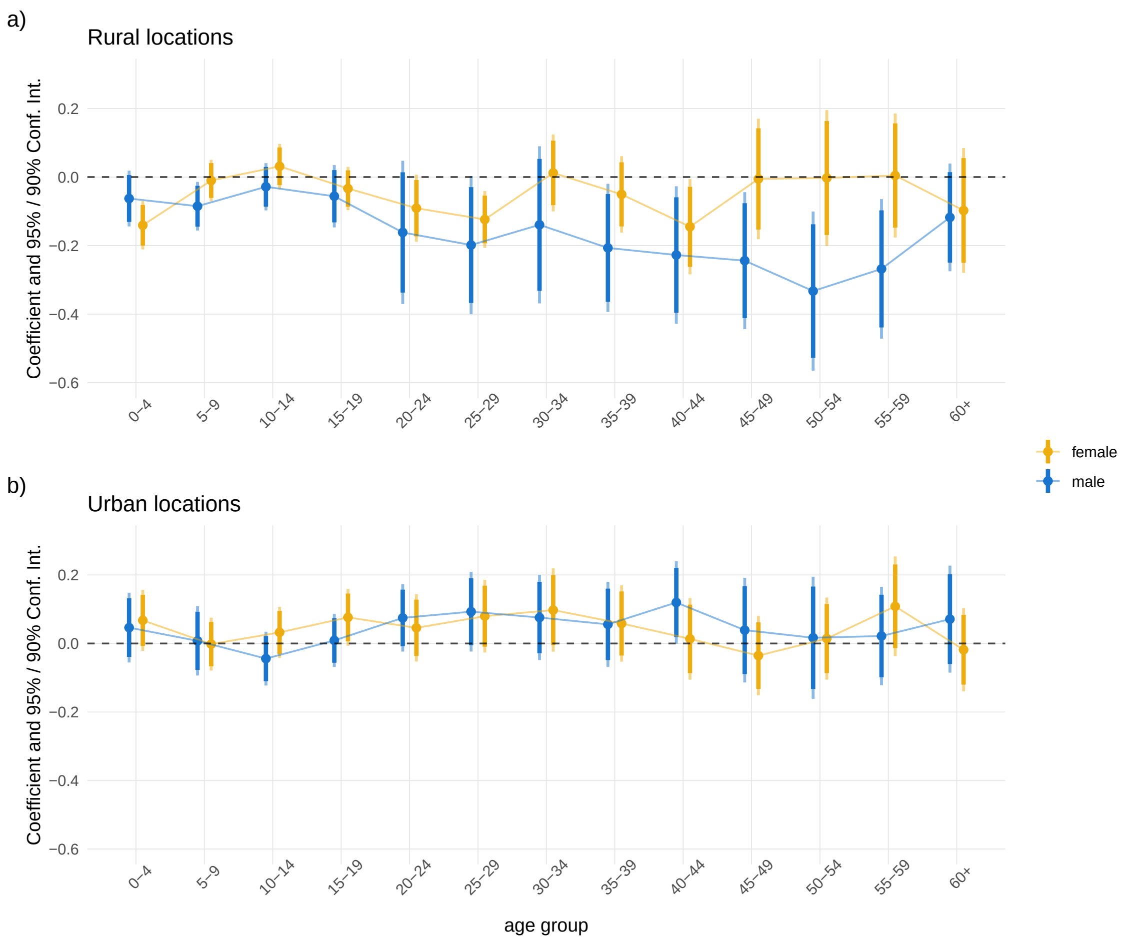
	rural to rural (1)	*rural to urban* (2)	*to Dakar* (3)	*to Touba* (4)
dry years (agri)	-0.0925	-0.1281**	-0.0356	-0.2583**
	(0.0598)	(0.0576)	(0.0256)	(0.1091)
R^2	0.65460	0.72321	0.94172	0.97898
Pseudo R^2	0.58054	0.68294	0.86966	0.94886
Observations	157,865	79,292	13,674	9,201
Controls	✓	✓	✓	✓
i fixed effects	✓	✓	✓	✓
j-year fixed effects	✓	✓	✓	✓

Note. Standard errors are clustered at the origin municipality level. ***,**,* mean that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%, respectively. The dependent variable is the bilateral migrant to stayer ratio. All specifications control for contiguity, geographic and ethnic distance, and migrant networks. The estimation sample consists of all individuals aged 20 to 60 at the beginning of the migration period.

6.2 Heterogeneity across demographic groups

We next assess the extent to which the effects of droughts vary across different demographic groups. Using comprehensive census data of the full population of more than 13 million individuals enables us to obtain precise understanding of heterogeneous responses over the life cycle of different sexes and education groups. We look at both dimensions in turn.

Figure 8: Heterogeneous effects of droughts on migration by gender, age cohort and locality type



Note. We perform repeated regressions over sub-samples by age cohort, gender and location type. All estimations include origin and destination times year fixed effects, and control for contiguity, geographic and ethnic distance, and migrant networks. Standard errors are clustered at the level of origin municipalities.

Life cycle analysis We firstly split our sample by age cohorts and gender, and run again separate estimations for rural and urban origin localities. We make full use of our generous data-set and run step-wise separate regressions for each 5 year age cohort. This allows for an unprecedentedly precise look on mobility responses to droughts over the life cycle. The age refers to the age at the beginning of the five year migration episode. We pool people aged 60 and older together into one cohort. Figure 8 visualizes the estimated drought coefficients for the 56 resulting sub-sample regressions. The empirical specification corresponds to our baseline model laid out in Equation 2 in Section 5. All models contain the full set of fixed effects and control variables.

We first turn to the results for rural locations displayed in Panel a. For the younger age cohorts until the age of 19, we find little evidence for a significant effect of droughts, irrespective of gender. This observation is indicative of the remarkable adaptability of Senegalese rural communities in their parenting and familial systems. The younger demographic cohorts are less likely to rely on agricultural labor and flexible familial arrangements enable parents to relocate while their children are left with extended family members, such as grandparents or aunts. The sole age bracket that displays a statistically significant coefficient is the 0-4 year age group, mirroring the estimate for women of child bearing age. Thus only the youngest kids are fully impacted by the mobility decisions of their mothers.

From the age of twenty onwards, droughts consistently interfere with individual mobility decisions until retirement. Our findings indicate that men experience a greater inhibitory effect on their mobility as compared to women. This observation aligns with Figure 5, which suggests that women's migration is primarily driven by family-related factors, while men's migration is predominantly influenced by work-related considerations. Thus, the influence of droughts on agricultural labor markets leads to a greater interference with work-related mobility decisions among men residing in rural areas.

An intriguing finding from our analysis is the magnification of the negative impact on male mobility during the latter phase of their professional life, between the ages of 45 and 59. During this stage, the decision to migrate must be taken against the background of a heightened level of family obligations and community involvements. Under challenging circumstances, the probability of men in this age group leaving their communities reduces considerably. Additionally, younger individuals have a longer duration of expected participation in the labor market, which implies that they can benefit more from relocation over their lifetime. Consequently, considering individual migration as a household decision, younger individuals may have a greater likelihood of accessing scarce family resources to finance the upfront migration costs. On the contrary, the effects vanish entirely for women of the same age cohorts. This likely reflects the earlier dropout from physically demanding agricultural labour. After retirement, droughts do not exhibit any significant impact on the mobility choices of either men or women.

Confirming our previous analysis, we find no evidence suggesting that droughts affect mobility decisions in urban areas at any age, as illustrated in Panel b.

Education Next, we examine the impact of drought on groups with different levels of education. We limit our analysis to rural areas and the population aged 20 to 60, and consider mobility responses of men and women separately. Then, we divide our samples into three groups based on their highest completed formal education: (i) those without any completed formal education, (ii) those with completed primary education and (iii) those with completed secondary education. We disregard individuals with tertiary education, as these represent a very small and particular group in rural Senegal. We observe the educational status of individuals only at the end of the second migration period in 2013. At the age of 20 the vast majority of individuals are likely to have completed secondary education at this point. Educational outcomes should therefore be unaffected by unforeseen shocks, avoiding issues related to reverse causality in our estimation.

Table 4 presents estimation results of our benchmark specification by education level. For the sub-sample of men without formal school education, one additional dry growing season is associated to 12.2% lower emigration rates. For the groups of individuals with primary education and secondary education, and for women across all education groups, droughts are not found to impact migration choices significantly. Low educated individuals are more likely to work in the agricultural sector and are rather impacted by climatic events, while individuals with higher education are not, or only little concerned by climate. We rationalise this finding as additional evidence for the agricultural channel at play. Taken together, the findings presented in this section help to further characterise the population that is mostly impacted by droughts.

Table 4: Subsample analysis by education

	male			female		
	no schooling (1)	*primary* (2)	*secondary* (3)	*no schooling* (4)	*primary* (5)	*secondary* (6)
dry years (agri)	-0.1219***	-0.0471	-0.0658	-0.0090	0.0222	-0.0597
	(0.0394)	(0.0438)	(0.0490)	(0.0252)	(0.0539)	(0.0988)
R^2	0.65503	0.31777	0.38445	0.78637	0.35118	0.34674
Pseudo R^2	0.55546	0.41952	0.43900	0.65778	0.46375	0.41028
Observations	227,908	119,998	147,784	231,264	108,636	59,857
Controls	✓	✓	✓	✓	✓	✓
i fixed effects	✓	✓	✓	✓	✓	✓
j-year fixed effects	✓	✓	✓	✓	✓	✓

Note. Sample of individuals aged 20 to 60 at the beginning of the migration episode. Rural origin localities only. Standard errors are clustered at the origin level. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%. The dependent variable is the bilateral migrant to stayer ratio. The estimation sample consists of all individuals aged 20 to 60 at the beginning of the migration period.

7 Additional evidence on the mechanism

7.1 The role of migration costs and non-linear effects

In Section 6.1, we demonstrated that exposure to droughts reduces the likelihood of medium- to long-run migration in rural areas. We interpret these findings in light of tightening household budgets, which make the initial costs of settling in more favorable localities unaffordable. Previous studies, such as (Cattaneo and Peri, 2016), have emphasized that climate shocks can render migration prohibitively expensive, particularly in impoverished societies with limited financial resources.

Against this backdrop, we test two hypotheses supported by the literature emphasizing the role of migration costs. Firstly, migration costs typically increase with the geographic distance between two localities. We expect that climate-related negative income shocks may disproportionately reduce migration to more distant destinations. Secondly, social networks have been found to facilitate migration by reducing migration costs to specific destinations closely connected to origin communities (Beine et al., 2009). We anticipate that the presence of social networks may partially counteract the decline in migration flows. We measure networks in two distinct ways. Firstly, we consider the number of individuals born in the origin municipality and already residing in the potential destination municipality, representing direct network ties between the two localities. Secondly, we employ our measure of ethnic distance, as presented in Section 5, to proxy for indirect networks based on individuals of the same ethnicity. These networks may ease integration into destination societies and reduce the costs associated with migration. We expect that migration to destinations with a high degree of ethnic distance will decrease more substantially compared to destinations with accessible large ethnic networks. To test these hypotheses, we introduce interaction terms into our model (Equation 2).

The results of this analysis are presented in Table 5. Column 1 reveals that bilateral geographic distance has a significantly negative moderating effect on the relationship between droughts and mobility. This implies that migration flows to destinations in close proximity may increase in response to drought, while migration to distant destinations becomes less likely. In column 2, we examine the moderating effects of ethnic distance. Consistently, we find that migration to destinations with significant ethnic differences from origin communities is especially reduced in the presence of adverse climate shocks. Column 3 shows that the presence of direct network ties, measured as the logarithm of the number of individuals in the potential destination municipality, has the potential to mitigate the inhibiting effects on mobility. Hence, migration to destinations with extremely close network ties may increase in response to droughts at the origin, while migration to destinations without these ties decreases.

Overall, these findings tell a compelling story about the role of migration costs in societies with limited financial resources. Migration can be an effective mechanism to cope with the negative impacts of adverse climatic conditions, particularly for rural communities dependent on agricultural income. Nevertheless, the results in this section emphasize that migration is only a viable option for individuals who can afford it. Special attention must be directed to those, who remain trapped in place.

7.2 Differentiated climate effects

We push forward the previous analysis by digging deeper into the factors that may tighten or loosen financial constraints, and in turn their impact migration propensities. Firstly, we assess the differential impact of more severe droughts. Intuitively, the negative effect of dry conditions on agricultural productivity, and therefore on household income, should depend on the severity of droughts in two ways: The potential of droughts to disturb household decisions, and hinder costly

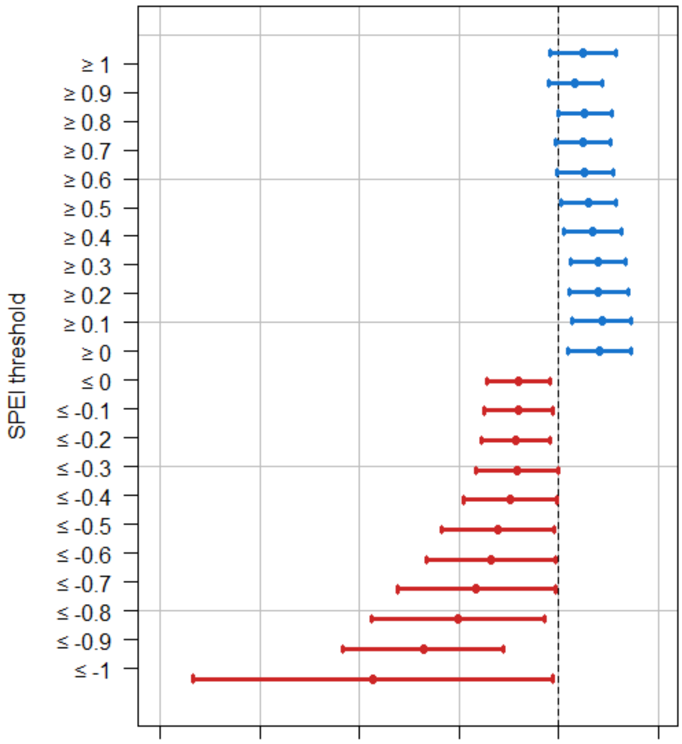
Table 5: Moderating effects of migration cost determinants

	geographic distance (1)	*ethnic distance* (2)	*network ties* (3)
contiguity	-0.0748	-0.0740	-0.0778
	(0.0763)	(0.0766)	(0.0762)
ln(distance)	-0.3617***	-0.3746***	-0.3743***
	(0.0727)	(0.0698)	(0.0701)
ln(ethnic distance)	-0.2778***	-0.2559**	-0.2794***
	(0.1016)	(0.1052)	(0.1023)
ln(network)	0.9620***	0.9630***	0.9559***
	(0.0232)	(0.0233)	(0.0231)
dry years (agri)	0.1854*	-0.0983***	-0.1332***
	(0.1051)	(0.0293)	(0.0349)
ln(distance) × dry years (agri)	-0.0534**		
	(0.0230)		
ln(ethnic distance) × dry years (agri)		-0.0876**	
		(0.0360)	
ln(network) × dry years (agri)			0.0314***
			(0.0106)
R^2	0.69830	0.69635	0.69748
Pseudo R^2	0.66248	0.66244	0.66250
Observations	235,538	235,538	235,538
i fixed effects	✓	✓	✓
j-year fixed effects	✓	✓	✓

Note. Standard errors are clustered at the origin municipality level. ***,**,* mean that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%, respectively. The dependent variable is the bilateral migrant to stayer ratio. The estimation sample consists of all individuals aged 20 to 60 at the beginning of the migration period.

migratory moves is likely increasing in drought severity. *(i) Planned migration may be postponed or abandoned altogether, if the shock to household wealth is sufficiently strong.* On the other hand, *(ii) extreme droughts may destruct rural livelihood systems and lead to forced displacements and survival migration, increasing migration rates.* Both effects jointly could give rise to a bell-shaped relationship between drought severity and migration rates.

Figure 9: Differentiated climate effects of positive and negative deviations in growing season SPEI by shock intensity



Note. The x-axis shows the estimated effect and 95% confidence interval of one additional dry (red) or wet (blue) year during the five year migration episode on migration rates. The y-axis indicates the threshold value used to define dry/wet years. All estimations include origin and destination times year fixed effects, and control for contiguity, geographic and ethnic distance, and migrant networks. Standard errors are clustered at the level of origin municipalities.

Secondly, we asses the role of extraordinary wet conditions on migration. The migration literature has so far has largely focused on droughts as negative income shocks. In the framework of cost constraint migration, favorable growing conditions may allow individual to save resources and enable subsequent migration. The impact of excess rainfall on expected crop yields is ambiguous. Excess rainfall can directly damage agricultural production by flooding farmland and delaying agricultural calendars, or indirectly by impacting crop health through restricted root growth, oxygen deficiency and nutrient loss (Li et al., 2019). While SPEI and SPI were developed to monitor droughts, they also have been used as flood indicators measuring excessive rainfall. Nevertheless, whether excessive rainfall leads to flooding heavily depends on the soil type and topology of the landscape (McKee et al., 1993). It is therefore extremely difficult to determine how much rain is too much. While below average precipitation is strictly harmful for agricultural output, an equal amount of excess rainfall could lead to diminished crop yields at one place, while generating favorable growing conditions at another place. Ex-ante we expect that small amounts of excessive rainfall have a strictly positive effect on agricultural productivity. For larger positive deviations the effect becomes ambiguous. Turning to the impact on migration, *(iii) we expect moderate positive deviations in SPEI (relatively wet growing seasons) to loosen household constraints and foster migration, while (iv) the effect of extremely wet growing seasons are likely location specific and could go in both directions.*

In order to test these hypotheses in turn, we recalculate our baseline climate measure using different threshold values to generate more fine-grained classifications of growing seasons according to their relative wetness. We focus on rural locations and run rolling regressions in increments of 0.1, defining growing seasons as dry if the average growing season spei12 $\leq \{0, -0.1, -0.2, ..., -1\}$, and as wet if spei12 $\geq \{0, 0.1, 0.2, ..., 1\}$, respectively. Figure 9 presents the result of this exercise. Climate indicators represent increasingly drier or wetter conditions. All models are similar to the baseline and include the full set of controls and fixed effects as presented in Table 2. The impact of positive deviation is plotted in blue, while indicators representing dry conditions are displayed in red. The results show that more severely dry growing seasons have a larger impact on migration rates. The estimated coefficients reach from -8.7%, considering all growing seasons drier than the historic average, to over four times this value with -37.4%, if we only classify growing season with an SPEI smaller than -1 as drought. Further, visual inspection of figure 9 suggests an exponential link between drought severeness and drought impact on migration. As exposure to extreme droughts is a rare event in our sample, we cannot formerly test this hypothesis. We do not find any evidence of a bell-shaped relationship between drought severity and migration rates. One limiting factor to our analysis is the scarcity of extremely dry events, defined as SPEI negative deviations of 2 standard deviations and more. Thus we cannot rule out that survival migration arises for the most extreme cases. Further, survival migration may arise in to short run, undetected by our implemented measurement of internal migration over episodes of five years.

Turning to positive deviations in growing season SPEI, we find that relatively wet growing seasons are associated with higher long-run migration rates: one additional growing season that has been wetter than the historic average ($spei \geq 0$) increases the long-run bilateral migration rate by 8.2%. This coefficient is strikingly similar in its absolute magnitude to its counterpart for relatively dry years ($spei \leq 0$). The revealed symmetry fits well into the context of cost constraint migration and represents additional support for the presumed mechanism at play. Assuming that positive deviations in our drought indicators represent years with favorable growing conditions, rather than disruptions, we can reverse the reasoning introduced in Section 6.1. More-than-usual rainfall during the past 5 years may then enable rural households to accumulate savings through increased agricultural productivity, which can eventually be used to cover the costs of long-run household re-allocations. While our findings do not represent conclusive evidence, we suspect that positive climatic events in the context of significant poverty have the potential to "free" trapped populations and increase mobility in the aggregate. Further investigation is required to better understand the precise mechanism at play that links excessive rainfall, agricultural productivity and long-run migration decisions in low-income areas in rural Africa.

7.3 Anticipation and inter-temporal substitution

Next, we address potential inter-temporal effects, i.e., the impact of future and past droughts on current migration patterns. The purpose of this exercise is twofold. Firstly, estimating the model with future drought exposure can be considered as a falsification exercise. If our econometric specification adequately controls for location specific features, including expectations, future events should have no impact on current decisions. Secondly, past droughts may have a long lasting impact on sourcing societies. This may be linked to inter-temporal substitution patterns, changes in local communities and labor markets, or updated expectations about the future. In the case of cost-constrained migration aspirations, droughts may force individuals to postpone mobility decisions. At the same, people may update their expectations about drought risks at their current place of residence and reinforce their desire to re-allocate as soon as the necessary resources become available. Thus, while droughts in recent years may decrease migration, they could reinforce migration in the subsequent periods. We address these two points in turn.

The main threat to identification of the climate shock in equation 2 may arise from potential serial correlation of climate shocks across time, together with unobserved factors driving migration at a certain locality. While we cannot rule out this form of endogeneity, we argue that residual correlation is unlikely after controlling for locality fixed effects and using a standardized measure of local climate shocks[17]. As a straightforward test for this assumption, we firstly estimate our model using the number of droughts over the 5-year period after the end of the migration window as *placebo treatment*. If locality specific trends would drive the results, we should expect similar coefficients for current and future droughts. Reassuringly, column 1 in table 6 shows no significant effect of future droughts. This backs up the causality of the effect of drought on migration flows.

Secondly, we turn to lagged treatment measures. From a theoretical perspective this is enlightening to understand potential inter-temporal displacement of migration decisions. A climate shock could simply lead to postponing migration moves instead of preventing them. In this case, we would expect a negative impact of contemporary, but a positive impact of past droughts. Table 6, column 3 lends some support to this mechanism. While droughts during the migration period are linked to lower emigration rates, droughts during the preceding 5 years tend to increase migration. Droughts more than 10 years before the end of the migration episode do not significantly impact current migration decisions (column 4).

One concern related to inter-temporal substitution arises from the relatively small units in terms of population in our gravity framework. If the number of potential migrants at a certain locality is limited, past droughts may determine the size of the pool of potential migrants in the subsequent period. Depending on the nature of correlation of climate shocks, this could lead to over or underestimation of contemporaneous shocks. In column 6 we therefore include climate shocks during the last three preceding periods along with current drought exposure into our model[18]. We find that the magnitude of the coefficient in t drops slightly when controlling for past droughts, but remains highly significant and negative.

[17]Indeed we can show that residual correlation in local droughts over time becomes insignificant once we difference out locality and year fixed effects. This lends additional support to the consideration of droughts as conditionally random events.

[18]We thus control for droughts over the last 20 years preceding the census year.

Table 6: Placebo treatment and long-run effects

Var: dry years (agri)	(1)	(2)	(3)	(4)	(5)
$t+1$	-0.1261				
	(0.0831)				
t		-0.1235**			-0.0658**
		(0.0576)			(0.0266)
$t-1$			0.1649**		0.1152*
			(0.0759)		(0.0641)
$t-2$				-0.0286	
				(0.0188)	
R^2	0.68612	0.68975	0.69024	0.69095	0.69016
Pseudo R^2	0.66070	0.66085	0.66090	0.66064	0.66094
Observations	237,157	237,157	237,157	237,157	237,157
Controls	✓	✓	✓	✓	✓
i fixed effects	✓	✓	✓	✓	✓
j-year fixed effects	✓	✓	✓	✓	✓

Note. Standard errors are clustered at the origin level. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%. The dependent variable is the bilateral migrant to stayer ratio $\frac{mig_{ijt}}{stay_{iit}}$. The estimation sample consists of all individuals aged 20 to 60 at the beginning of the migration period.

8 Robustness

8.1 Alternative measures of climate conditions

The literature on the climate migration nexus has adopted a broad set of different indicators. Different modelling approaches of climate shocks are likely one explanation of the heterogeneous set of conclusions the associated literature has produced. Justifying the precise respective choice has received surprisingly little attention in empirical work. A notable exception is Bertoli et al. (2022), who fall short on identifying a common specification of weather shocks that performs well across different countries. In this section we revisit our baseline estimates using a broad set of alternative modelling approaches to climate shocks. Modelling choices can be systematized around the following four dimensions:

1. *SPEI scale:* One strength of the SPEI as drought index is that it can be calculated over different time scales. This allows to identify different drought types. Commonly considered time scales reach from 1 to 48 months. Short time scales are mainly related to soil water content and river discharge in headwater areas, medium time scales are related to reservoir storages and discharge in the medium course of the rivers, and long time scales are depict

variations in groundwater storage (Vicente-Serrano et al., 2010). Therefore, different time scales are useful for monitoring drought conditions in different hydrological subsystems which may have heterogenous impacts on the livelihoods of those depending on them. We present baseline results for various time-scales $s \in \{1, 3, 6, 12, 24\}$.

2. *Threshold values:* To derive meaningful measures of droughts over multi-year periods, we convert continuous measures into binary drought indicators that respectively capture the number of drought months or dry growing seasons over five years. Naturally, the choice of the threshold value at which we consider a month/growing season dry is somewhat arbitrary and impacts the final treatment measure. McKee et al. (1993) suggest values from 0 to -0.99 for mild droughts; -1 to -1.49 for moderate droughts and -1.5 to -1.99 for severe droughts. In accordance with this classification, we incrementally set the threshold values to $\tau_{monthly} \in \{0, -1, -1.5\}$ in order to identify drought events of varying intensities. Extreme values tend to average out over the course of the growing season. When considering yearly mean values we therefore opt for lower threshold values $\tau_{yearly} \in \{0, -0.5\}$.

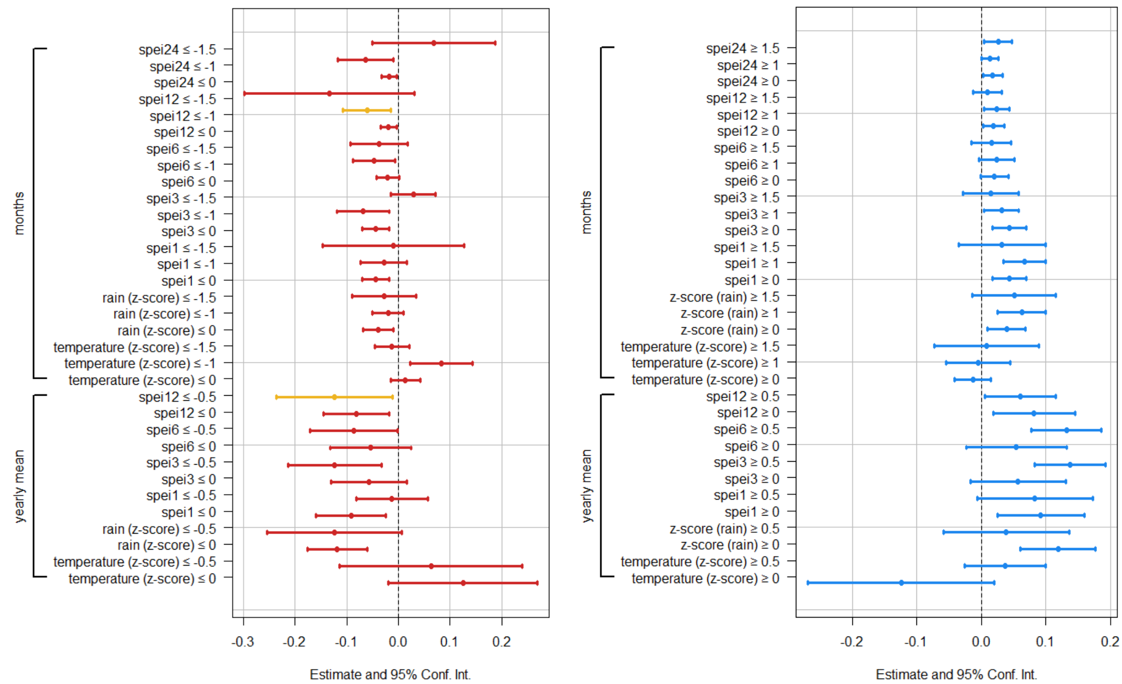
3. *Alternatives to SPEI:* While we argue that SPEI is the most suitable tool to consistently measure climate stress on temporally and geographically fine grained level, the literature has adopted alternative measures. To allow for maximal comparability of our results to the associated research, we show results for a set of alternative indicators. The most obvious choices are standardized rainfall and temperature deviations. We apply the same threshold values as introduced for the SPEI.

For clarity of exposition, Figures 10 A and 10 B graphically present the results of this exercise. All models are similar to our baseline specification laid out in Equation 2 in Section 5 and differ solely in the specification of the climate measure. Coefficients plotted in orange are our two benchmark indicators detailed in Section 6. Our general conclusions remain robust under a broad set of different modelling choices and are by no means a statistical artifact. Droughts are consistently associated with lower bilateral migration rates, while extraordinarily wet periods tend to increase migration over 5 years. As expected, the effect of extreme temperature anomalies is opposed to droughts. Colder periods put less stress on crops and tend to be associated with higher migration rates, while the findings for high temperature point to opposite.

The retention effect of severe droughts is generally stronger. An inherent trade-off between treatment strength and exposure must be taken into account by the modeler, as higher threshold values are capable of identifying more severe droughts, yet these occurrences are relatively infrequent. Consequently, while point estimates increase in magnitude in tandem with the severity of the events, the significance of these estimates decreases due to the limited number of places that are affected in our sample. Reinforcing these effects, extreme shocks also tend to create more variation in responses, as the potential margin of action to face these challenges is strongly context specific and varies across localities and individuals. This effect may be amplified due to the greater variability in responses that more severe droughts elicit, since the capacity to effectively respond to such challenges is heavily influenced by contextual factors that vary across both localities and individuals.

Figure 10: Robustness to alternative measures of weather shocks

A. Negative deviations B. Positive deviations



Note. The x-axis shows the estimated effect and 95% confidence interval of one additional dry (red) or wet (blue) year during the five year migration episode on migration rates. All climate indicators are standardized and can be interpreted as deviations from the historic, location specific mean. The y-axis indicates measure and the threshold value used to define dry/wet years. Our baseline specifications are highlighted in yellow. All estimations include origin and destination times year fixed effects, and control for contiguity, geographic and ethnic distance, and migrant networks. Standard errors are clustered at the level of origin municipalities.

8.2 Alternative model specifications

It is well acknowledged in the empirical migration literature that a high proportion of zero values in the data for bilateral flows may pose challenges to the estimation of equation 2 by OLS. First, the theoretically justified definition of the dependent variable in logs leads to the exclusion of all empty migration corridors, and therefore disregards much valuable information in our data[19] (Beine and Parsons, 2015). Secondly, as carefully laid out by Silva and Tenreyro (2006), log-linearization of the gravity model in the presence of heteroskedasticity introduces correlation between regressors and error term, and invalidates the key assumption for consistency of the OLS estimates. As suggested by Silva and Tenreyro (2006), and broadly adopted in the respective literature, we thus opted for the Poisson pseudo maximum likelihood (PPML) estimator in our baseline.

In table 7 we present several alternative modelling choices which have been implemented in the literature. Columns 1 and 2 show our baseline results as point of reference. In columns 3 and 4 we introduce a full set of origin-destination dummies into our model. This comes at the cost of a smaller sample size, as observations without within-variation are discarded in the estimation by maximum likelihood[20]. Although the number of observations sharply drops, estimated coefficients remain stable and significant at the 1% level. In columns 5 and 6 we results for the OLS estimation with bilateral fixed effect model. We add 1 to migration flows to avoid loosing the large share of zero observations. While it is well established in the literature that this approach leads to biased coefficients, our results hold qualitatively. Again we find that droughts are significantly and negatively associated with migration rates. Overall, results are largely consistent across alternative empirical strategies and modelling choices.

[19] 82% of observed bilateral flows in our data are zero.

[20] Consider bilateral flows from i to j which are zero in both observed periods. The log-likelihood maximizing estimates for the dyadic fixed effect of this corridor is reached at $\mu_{i,j} = -\infty$. Observations for these dyads are *statistically separated* and dropped from the estimation (Correia et al., 2019).

Table 7: Robustness to alternative model specifications

	Poisson				OLS	
	(1)	(2)	(3)	(4)	(5)	(6)
contiguity	-0.0448	-0.0450				
	(0.0769)	(0.0770)				
ln(distance)	-0.3594***	-0.3600***				
	(0.0640)	(0.0640)				
ethnic distance	-0.2569***	-0.2560**	-0.6244	-0.6056	0.5166	0.6056
	(0.0997)	(0.1000)	(1.080)	(1.064)	(0.6482)	(0.6485)
ln(network)	0.9530***	0.9528***	-0.5472***	-0.5548***	-0.5878***	-0.5893***
	(0.0229)	(0.0230)	(0.0503)	(0.0502)	(0.0466)	(0.0466)
dry years (agri)	-0.1235**		-0.1344***		-0.0296***	
	(0.0576)		(0.0173)		(0.0055)	
dry months (agri)		-0.0610***		-0.0670***		-0.0166***
		(0.0236)		(0.0067)		(0.0025)
R^2	0.68975	0.69016	0.93798	0.93826	0.75660	0.75662
Pseudo R^2	0.66085	0.66099	0.60875	0.60914	0.32132	0.32135
Observations	237,157	237,157	22,696	22,696	237,437	237,437
i fixed effects	✓	✓				
j-year fixed effects	✓	✓	✓	✓	✓	✓
i-j fixed effects			✓	✓	✓	✓

Note. Sample: rural origin localities. Standard errors are clustered at the origin level. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%. The dependent variable is $\frac{m_{ijt}}{stay_{iit}}$ for PPML, and $ln(\frac{m_{ijt}+1}{stay_{iit}})$ for OLS estimations. The estimation sample consists of all individuals aged 20 to 60 at the beginning of the migration period.

9 Conclusion

In this paper, we combine exhaustive population data of individual migration histories of 13 million individuals with novel data on climatic conditions on a highly disaggregated scale to estimate the impact of climate volatility on internal migration rates in Senegal. In comparison to most previous studies, we capture short and long distance internal migration alike, and distinguish between in- and out-migration on the level of highly disaggregated municipalities.

At odds with the popular narrative of climate induced migration, we provide robust evidence that droughts have lowered mobility in rural Senegal between 2003 and 2013 in the medium to long run. Effects are driven by low educated men at rural localities, who are disproportionately occupied in the agricultural sector. We explain these findings with significant costs of long-run migration in the presence of liquidity constraints. Finding accommodation or employment far from the community of residence is costly in terms of money, time, and mental capacity. Climate related negative income shocks, through a drop in agricultural productivity, may render relocation then prohibitively costly, while years with favorable growing conditions free up resources for subsequent migration. Coherently, we show that especially costly migration to urban centers and geographically and ethnically distant destinations drops following droughts, while the presence of large, migration facilitating networks may offset the negative effects. Further, we find evidence for inter-temporal substitution in mobility decisions: migration may be postponed following a negative shock in recent years, leading to higher migration rates after concerned communities have recovered.

The notion that climate change results in the displacement of populations has been widely promoted and is appealingly intuitive. Putting our findings into perspective of global climate change and long-term deteriorating climatic conditions raises concerns about the potential of rural communities to recover from repeated droughts and may lead to lock-in effects into poverty. Our study, based on the case of Senegal, serves as a compelling example demonstrating that adverse climate conditions in poor rural Africa may not spawn migration, but rather impede it. Especially in societies in which migration has historically been an important building block to improve living conditions, immobility is problematic in itself and may lead to ever-deeper cycles of poverty and vulnerability, putting trapped populations at risk of humanitarian emergencies. For these individuals, climate change may not be related to displacement, but to missed opportunities, and possibly to confinement to a state of poverty.

It is crucial for policymakers to be cognizant of these more concealed costs of climate change: The absence of displaced populations must not be confounded with the absence of adverse impacts on livelihoods. Consequently, any assessment of the impacts of climate challenges should place equal emphasis on the well-being of both those who have been displaced and those who have not.

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APPENDIX
Supplementary material to *Challenging the Climate-Migration Narrative: New evidence from Senegal*

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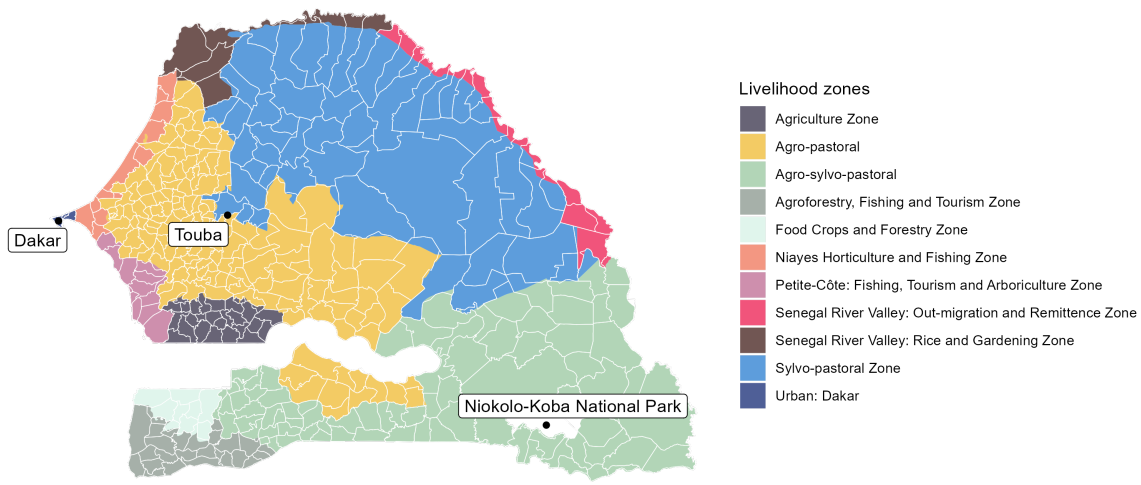
A Additional figures

A.1 Livelihood zones by main source of income in 2012

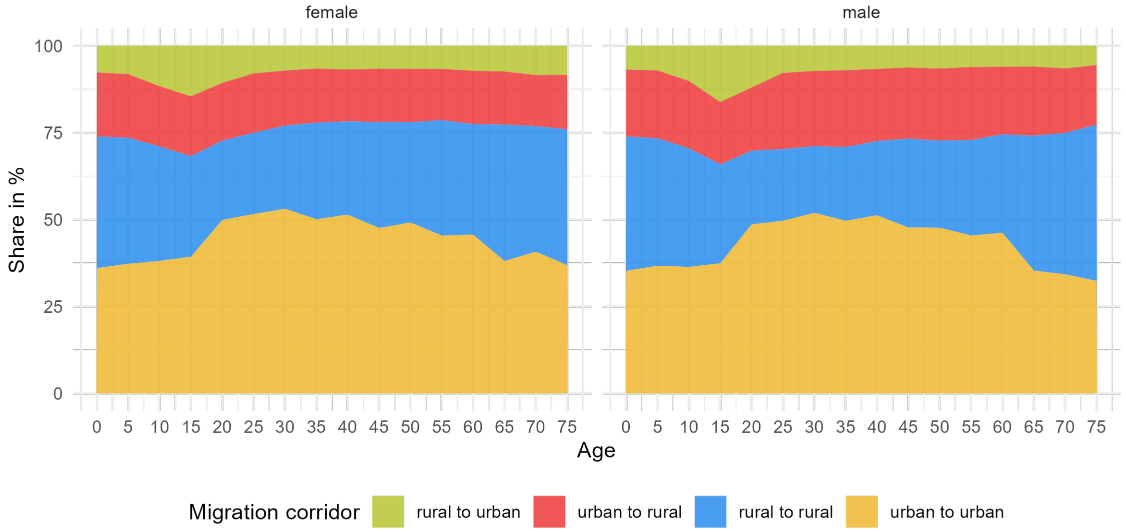
Figure A1: Livelihood zones by main source of income in 2012



Note. Data stems from the country briefing for Senegal of the Famine Early Warning Systems Network (2012).

A.2 Major migration corridors by locality types

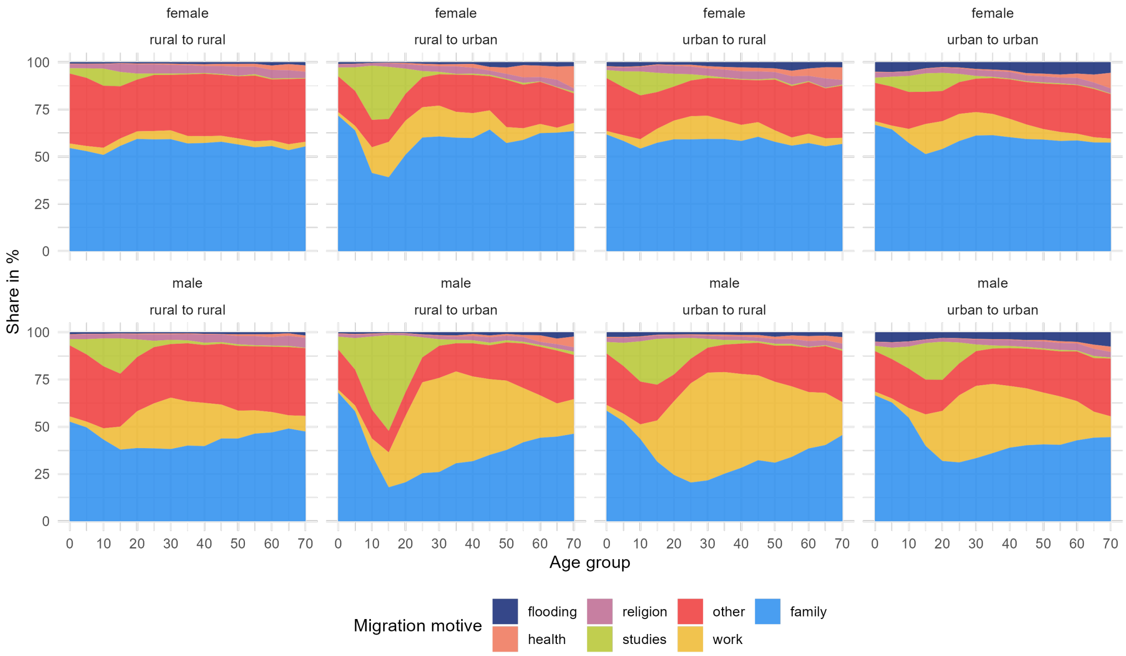
Figure A2: Major migration corridors by locality types



Note. Breakdown of migration corridors as share of total migratory moves between 2008 and 2013 by gender and 5 year age groups. Source: own calculations based on 2013 census.

A.3 Migration motives by migration corridor as shares

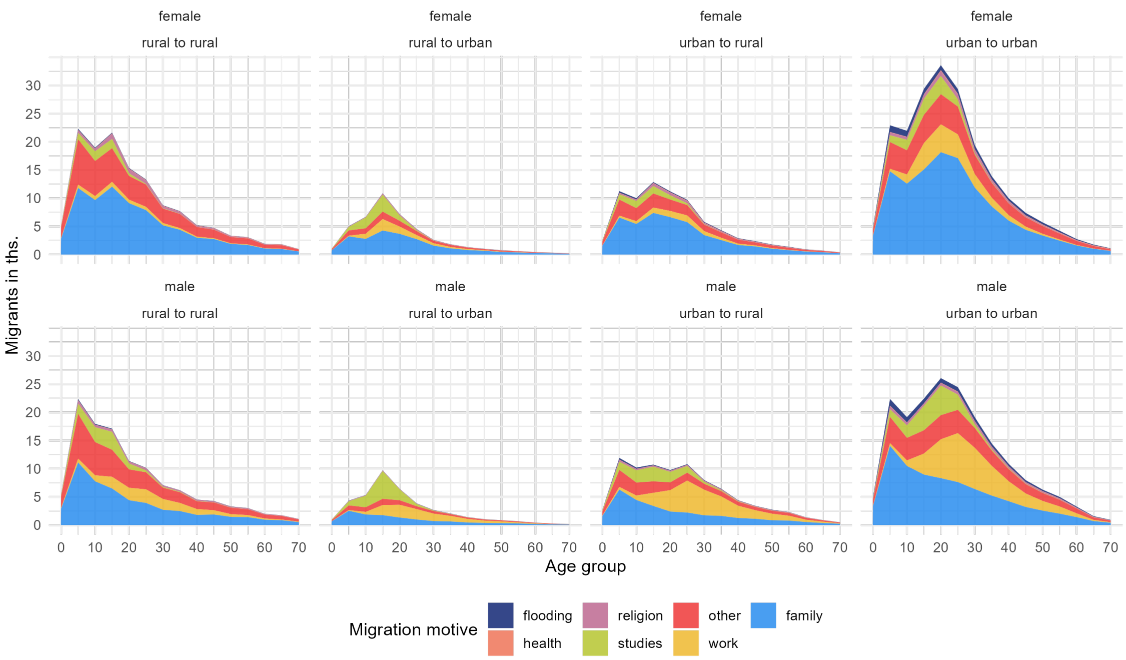
Figure A3: Migration motives by migration corridor as shares



Note. Breakdown of migration motives as share of total migratory moves between 2008 and 2013 by migration corridor, gender and 5 year age groups. Own calculations based on the Senegalese 2013 full count population census.

A.4 Migration motives by migration corridor in totals

Figure A4: Migration motives by migration corridor in totals



Note. Number of migratory moves by motive between 2008 and 2013 by migration corridor, gender and 5 year age groups. Own calculations based on the Senegalese 2013 full count population census.

B Additional tables

B.1 Descriptive statistics by migration episode

	2003-2008			2008-2013		
variable	*migrants*	*non-migrants*	*all*	*migrants*	*non-migrants*	*all*
age	27.07	28.10	28.04	28.24	28.48	28.45
sex ratio	0.94	0.91	0.91	0.90	0.93	0.93
literacy	0.57	0.41	0.43	0.55	0.43	0.46
married	0.59	0.58	0.58	0.49	0.47	0.48
education	12.44	11.35	11.58	11.63	10.40	10.75
Total	343.985	5.797.867	6.141.852	990.195	6.425.466	7.415.661

Note. The difference in sample size across both years is due to mortality. We focus on working age population between 20 and 60, limiting the attrition bias due to high mortality at higher ages. Additionally we exclude international migrants to ensure comparability across both waves and exclude confounding transit migration.

C Additional results

C.1 International migration

In this section we turn to international migration to broaden our analysis of the link between droughts and migratory decisions. The link between climate change and international migration has been a consistently "hot" topic in much of the developed world. Interventionist policies, reaching from intensified border controls and new visa regulations to financing of development project which are thought to enable developing countries to cope better with the consequences of climate change and therefore limit the inflow of people from the global south. In section 6.1 we found that droughts are related to a significant decrease in internal mobility, pointing to the existence of trapped populations. Only few papers attempted to estimate internal and international mobility responses in one coherent framework. Building on a similar modelling approach, we make full use of the census data to verify weather similar conclusions hold for international mobility.

International migration is registered in the census based on information stemming from in Senegal remaining households. In particular, we can track international migrants who left a specific household within the 5 years preceding the survey, including the precise year of departure and destination country. For each year from 2008-2013 derive the number of departures by destination country. In line with our model for internal migration, for each year t we compute the number of dry growing seasons between t and t-4 at the household location. We then proceed to estimate equation 2 for international migration.

Table C1 displays the results by groups of countries. We separately estimate the model for (i) bordering countries, (ii) non-bordering African countries, (iii) European countries and (iv) non-European OECD countries. Ex-ante we would have expected that the impact of droughts on short distance cross-border migration is similar to the findings relating to internal migration. We find no significant effect of droughts on emigration to other African countries, be it bordering or not. On the opposite, emigration rates to European destinations and other OECD destinations drops by 12.7% and 15.5%, respectively. This finding may again be rationalized with negative effects on household wealth, rendering the most costly type of emigration, emigration to EU and OECD destinations, less affordable and therefore less likely.

Table C1: Droughts and international migration

	All (1)	*Africa* (2)	*Bordering* (3)	*EU* (4)	*OECD* (5)
dry years (agri)	-0.0308	0.0467	-0.0462	-0.1268**	-0.1552***
	(0.0361)	(0.0504)	(0.0572)	(0.0573)	(0.0494)
R^2	0.46069	0.56219	0.62708	0.58528	0.81556
Pseudo R^2	0.71682	0.67856	0.65155	0.85149	0.78353
Observations	365,500	176,764	30,456	83,000	65,440
i fixed effects	✓	✓	✓	✓	✓
j-year fixed effects	✓	✓	✓	✓	✓

Note. Standard errors are clustered at the origin level. ***,**,* mean respectively that the coefficient is significantly different from 0 at the level of 1%, 5% and 10%.