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# Effects of changes in rainfall and temperature on age- and sex-specific patterns of rural-urban migration in sub-Saharan Africa

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## Abstract

We evaluate how changes in weather patterns affected rural-urban migration across 41 sub-Saharan African countries, by age and sex, over the 1980–2015 period. We combine recent age- and sex-specific estimates of net rural-urban migration with historical data on rainfall and temperature from the Climate Research Unit (CRU). We also compare standard unweighted estimates of rainfall and temperature to estimates weighted by the proportion of the country's total rural population in the CRU grid. Results show that rural out-migration of young adults is the most sensitive to shifts in weather patterns, with lower rainfall, lower variability in rainfall, and higher temperatures increasing subsequent rural out-migration—though the last of these is not observed in weighted models. The strength of these effects has grown stronger over time for 20–24 year olds, though weaker above age 30. In contrast, increasing temperature variability is associated with a higher rural in-migration of children (0–9) and older adults (55–64). Gender differences in these effects are minimal and concentrated in areas which experienced heavy reductions in rainfall.

**Keywords** Internal migration · Rural-urban migration · Climate variability · Age-specific migration · Africa

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# Introduction

Over the last two decades, heightened awareness of climate change alongside growth in migrant flows has drawn more scholarly attention to climate-induced migration, or more broadly, environmentally induced migration, especially in poor developing countries in the Global South (Hunter et al. 2015; Mcleman and Gemenne 2018). Heeding Bilsborrow's (1992) call, a growing share of this attention has been devoted to within-country studies, which merge household data with increasingly high-resolution data on rainfall, temperature, crop yields, vegetation indices, and related measures (Gray and Bilsborrow 2013; Arslan et al. 2015; Nawrotzki et al. 2015; Jessoe et al. 2018; Dallmann and Millock 2017; Nawrotzki et al. 2015; Sasson and Weinreb 2017). Yet even as this approach allows for more specific testing of hypothesized mechanisms linking environmental factors to households' livelihood adaptation strategies, especially at the micro and meso levels, an older approach, comprising aggregate, country-level analyses, remains popular, partly because it offers the advantage of breadth and generalizability (Black et al. 2011a; Beine and Parsons 2015; Cai et al. 2016; Cattaneo and Peri 2016).

Our central goal in this paper is to contribute to this older approach while also pointing to two ways in which aggregate estimates can be strengthened. In the context of an analysis in which we identify the effects of changes in rainfall and temperature on rural out-migration in sub-Saharan Africa (SSA), the first improvement entails differentiating rural out-migration by age and gender.[1] This comes as close as possible to exploring livelihood adaptation strategies at the household or extended family level with aggregate data. The second improvement is using the population distribution within a country to weight the contribution of each of the weather stations or remotely sensed grids toward an estimated national weather pattern. This helps counteract some of the imprecision that arises from normally undifferentiated smoothing of aggregate data at the national level since it more accurately reflects the rural population's experience of changes in rainfall and temperature. In addition, the difference between the weighted and unweighted estimates also tells us something about how much *unweighted* results—the standard in cross-national research—are driven by patterns in relatively underpopulated areas. We expand on this below.

We focus on SSA for a few reasons. First, there is broad consensus that high levels of population growth, poverty, and reliance on rain-fed agriculture, in addition to low levels of institutional adaptive capacity, make SSA the most vulnerable region to climate change (Hugo 2011; Rigaud et al. 2018). Second, there is also significant variability across countries in SSA in terms of population dispersion (Herbst 2000), which makes it a good candidate for our weighting procedure. Third, robust age- and gender-specific estimates of net rural out-migration in SSA, covering consecutive 5-year segments in the 1980–2015 period, have recently become available (Menashe-Oren and Stecklov 2017).

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[1] Male and female differences in migration throughout this paper are framed in relation to "gender," since mechanisms linking climate change to migration focus on how male/female differences are expressed in *social relations*. In discussing our data, however, or specific aspects of measurement, we refer to "sex." This difference in linguistic register reflects a basic limitation in our data and arguably in all extant demographic data.

Our findings point to key ways in which the effects of changes in rainfall and temperature on migration patterns vary by age, how age variation in turn changes over time, and, in contrast, how minimally the age-specific effects vary by gender. These findings are robust to models that account for unobserved time-invariant factors that are country-specific and to the use of population-weighted indicators of aggregated weather patterns. Overall, our theoretical framing and empirical findings both underscore the importance of incorporating age- and gender-specific models into research on climate variability and migration linkages. More generally, they support recent calls for focusing more attention on weather-related internal migration, a "trans-local" perspective that, as Borderon et al. (2019:530) argue, is "rather neglected."

## Climate variability and migration at the aggregate level

Given the complex array of factors associated with migration (Massey et al. 1993; Hugo 2011), it is not surprising that there is no consensus on the relationship between climate variability and migration—at least in cross-national studies at the aggregate level. This is true in terms of both the direction and magnitude of the relationship—contrast, for example, the key results reported by Cattaneo and Peri (2016) to those in Cai et al. (2016), or in the African context, those of Barrios et al. (2006) to Henderson et al. (2017). This lack of consensus is also true in terms of the underlying causal mechanisms—contrast the variable foci and approaches adopted by Black et al. (2011b); Piguet et al. (2011); and Hunter et al. (2015), among other comprehensive reviews of this literature that also point to empirical inconsistencies (Fussell et al. 2014; Cai et al. 2016; Henderson et al. 2017; Borderon et al. 2019).

These inconsistencies are driven by a number of factors, over and above the standard heterogeneity of underlying climate change and migration phenomena across settings and time: variation in definitions of migrants, measures of migration, study time frame, core explanatory variables, assumptions about the linearity of the relationship between those variables and migration—including feedback loops—and model specifications.

Here, we focus on an additional element that is absent from aggregate-level studies: the discrete differences in age- and gender-specific patterns of climate-induced migration. We argue that including these patterns allows for more insight into migration patterns—essential both for considering the implications of climate variability, as well as identifying potential policy interventions. It also comes closer to an aggregate test of some of the household-centered ideas about migration (e.g., Hunter et al. 2015).

### Age-specific patterns of climate-induced migration

Despite some notable exceptions (Beauchemin 2011), broadly consistent patterns in age profiles of migration have been found across a range of countries, contexts, and populations and in both international and internal migration (Castro and Rogers 1983; Stecklov et al. 2010; Garip 2012; Bernard et al. 2014; Juran and Broer 2017; and Menashe-Oren and Stecklov 2017). The evidence indicates that migration tends to rise sharply in adolescence and early adulthood, then falls gradually across the next few decades of the life course. In some contexts, a retirement migration bump is also observed (Raymer and Rogers 2007; Rogers and Jordan 2003).

In terms of rural-urban migration associated with shifts in weather patterns (intensified by climate change), our main concern here, we expect a number of factors to underlie these age-specific patterns. The first is the age-structured nature of individual incentives and constraints, as they relate to education and the labor market. Although educational opportunities are often an incentive for migration at younger ages, they need to be balanced against local family labor needs, especially in rural areas (Beegle et al. 2006). Empirical support for this relationship is, therefore, quite varied across SSA (Ginsburg et al. 2016). For older youths and young adults in rural areas, labor market opportunities that drive migration can also be highly constrained for various reasons, including limited credit markets and lack of access to land or other capital (Stark and Bloom 1985; Feder and Noronha 1987; Castles and Miller 2003; World Bank and IFAD 2017). On the other hand, young adults are also more likely to be childless, which opens the door to a wider array of opportunities and liberates them from certain obligations. Augmented by their generally higher levels of education, this raises their incentives to participate in the non-farm economy both in rural and urban centers. And even among migrants with children, grandparents or other non-migrant kin may offer culturally acceptable child-rearing solutions that facilitate movement from rural areas (Madhavan 2004).

A second factor underlying differential age-specific migration patterns arises from variation in how individuals, households, and extended families manage risk and uncertainty, especially in developing countries with weak formal safety nets. In rural areas of SSA, in particular—which remain home to the majority of Africa's population—an individual's adaptive capacity is shaped by the relative absence of public welfare schemes and formal credit and insurance markets. That leaves extended networks of kin—and occasionally close friends—as a critical source of social insurance, even where they live in separate households (Weinreb 2002; De Weerdt and Hirvonen 2016). These wider networks may be particularly critical in rural, agricultural settings (Rosenzweig and Stark 1989; Fafchamps 1992). Individuals reciprocally call on other members of the network for various purposes including to protect themselves from loss of income (Baez et al. 2017), insufficient food (Shipton 1990; Thornton et al. 2007), need to pay school fees (Baylies 2002), and to take care of orphaned family members (Weinreb et al. 2008).

Emphasizing the embeddedness of migration decisions in wider household or extended family contexts—often described in relation to the New Economics of Labor Migration (NELM) model of Stark and Bloom (1985) (for reviews, see Massey et al. 1993, and Hunter et al. 2015)—highlights how the same processes may generate different incentives for family members of different ages and genders. Thus, rural-urban migration among young males or the more educated has often been encouraged by local family members in the hope that the migrants will remit a portion of their anticipated earnings and improve income stability in the short-term as well as help preserve extended family farming enterprises in the long term (Becker 1990; Bollard et al. 2010). Yet increasing out-migration among younger males may conceivably *reduce* migration among older men or women, since grandparents often play a key role in caring for young children across much of rural SSA—both due to migration and orphanhood (Madhavan 2004; Schrijner and Smits 2018; Mathambo and Gibbs 2009). Subsequently, at a later stage in the life course, some of these migrants may return to their home areas. Depending on prior levels of fertility and the strength of "cumulative

causation" processes that can also drive migration, younger members of the household or extended family may migrate in return, maintaining the overall fiscal stability of the reciprocal system. This pattern may be particularly attractive in areas that maintain communal land tenure agreements (Gottlieb and Grobovšek 2019).

These are well-documented patterns in the migration literature. Our central point here is that if the migration effects of shifts in weather patterns work in the same way, we anticipate seeing both rural out-migration and in-migration throughout the life course as households and extended families reallocate available labor in what are considered to be age- and gender-appropriate ways. There have long been signs of these patterns in small-scale case studies in SSA (Findley 1994; Ezra and Kiros 2001; Henry et al. 2004; Afifi et al. 2016), though large-scale analyses over long time periods remain sparse.

Herein lies the challenge for most aggregate studies that ignore age. Strong patterns of rural out-migration among the young and rural *in*-migration among the middle-aged may counteract each other, generating a weak or even net zero effect in any aggregate analysis that, as is the case in most cross-national research, does not differentiate migration patterns by age. We address this challenge in our analysis.

## Gendered climate-induced migration

Familial deliberations about who should migrate, and when, are clearly gendered, reflecting both women's domestic and reproductive roles, and their generally inferior social position in traditional social hierarchies across SSA (Kandiyoti 1988; Caldwell et al. 1992). In terms of migration, the direct result of this has been that women in poor countries have historically been more constrained than men in their migration decisions (Donato et al. 2006; Curran and Rivero-Fuentes 2003; Massey et al. 2010) even though their more limited access to land or other natural capital (relative to male age-mates) may increase their incentives to migrate at the individual level (Carr 2005; Gray 2010).

Yet winds of change have blown here, too. There has been a notable feminization of international migration over the last few decades (Donato et al. 2006; Pessar and Mahler 2003; Curran and Rivero-Fuentes 2003), and it is increasingly clear that age patterns of within-country migration also vary by gender. Menashe-Oren and Stecklov (2017), for example, show that net rural-to-urban migration across SSA rises earlier and dips faster for women than for men, though the two age-specific curves have the same general shape. This is consistent with the *petites bonnes* phenomenon discussed by Hertrich and Lesclingand (2012), that is, the stream of adolescent rural women who move to urban areas to work as maids. It is also consistent with women's earlier age at marriage, which is also a major determinant of migration in certain areas of SSA (Ezra and Kiros 2001).

Just as the overall drivers of migration differ for men and women, those related to changing weather patterns intensified by climate change are also likely to do so. In their review of work on the effects of climate change on gendered migration patterns, including a special issue of *International Migration Review* in 2006, Hunter and David (2009) make a strong case that climate change may "differentially shape both migration's cause and consequence by gender." They do not explicitly address age, but it is implicit in the examples that they cite: the feminized nature of Asian migration streams, the results of which can be a reversal of roles within a household, with

younger wives emerging as migrant breadwinners, and their husbands as domestic providers (Piper 2008; Pinnawalla 2008); and push factors associated with environmental decline that directly affect women's work, like deforestation in Nepal (affecting time required by younger women, in particular, to collect firewood), or water availability in Mexico (affecting the fruit industry that once anchored wives as husbands journeyed north) (Bohra-Mishra and Massey 2011; Buechler 2009). Likewise, in later work, the idea is indexed by references to "household life cycle" and a set of examples that highlight the relationship between age, type and duration of migration, and type of agricultural investment (Hunter et al. 2015:7).

At the country level—the analytic level in our analyses—the principal way in which climate variability affects age-specific patterns of rural out-migration differentially by gender is through a combination of education and employment prospects, especially in rural areas that rely on rain-fed subsistence agriculture. As noted above, a standard assumption in the climate change-migration literature is that the effects of climate change on rural out-migration, especially the effects of shifts in weather patterns and increasing intensity and frequency of extreme weather events, are expected to be most pronounced in areas that rely on rain-fed subsistence agriculture (Porter et al. 2014; FAO 2019). These areas are the most vulnerable to changes in rainfall and temperature, particularly where those changes are unpredictable, leading households to engage in a range of risk management and coping strategies, including migration (Jaeger et al. 2010). These areas are also the most vulnerable to the depletion of other types of natural capital. Combined with the effects of climate change, this exacerbates the vulnerability of livelihoods (Thornton et al. 2007; Cooper et al. 2008; Kristjanson et al. 2012; Arslan et al. 2015, 2017).

The gendered effect of climate variability on migration, operating through women's education, comes into play here. Over the last few decades, significant increases in women's education across SSA have reduced the gender difference in education in almost all countries (World Economic Forum 2017). Despite this progress, the more pessimistic expectations about the effects of climate-related pressure on girls' schooling points to the likelihood of girls being pulled out of school early, that is, before enrolling in, or completing, secondary school. Under increasing financial pressure, parents may send some of these girls to the city, where domestic work is often available, even for uneducated women (Morokvasic 1984; Cattaneo and Robinson 2018). This has clear implications for migration patterns: areas with greater climate variability should see a somewhat younger age profile of rural out-migration for women compared with men.

A more positive outcome is also possible, however. By increasing women's opportunities in the labor market, women's rising educational levels have not only added to their own incentives to migrate to urban areas. They have also provided an extra incentive to key members of women's extended family to permit or sponsor women's migration, perhaps in anticipation of future remittances under a NELM framework, or as a way to enable them to have a better life. Either way, to the extent that climate variability is implicated in this process—by making agricultural income less reliable and increasing the need for income stability within the extended family—weather patterns associated with climate change may themselves place added upward pressure on women's education (and subsequent migration). Indeed, recent evidence indicates that girls are delaying their transitions out of school and into the labor market relative to boys (Doss et al. 2018), just as they are delaying marriage and childbirth. This has quite

different implications for women's age-specific migration patterns as it implies an older age profile among rural women out-migrants in areas with higher climate variability.

## Principal research questions

Based on this discussion of the effects of climate variability on age- and gender-specific migration patterns, we outline three sets of research questions.

The first question addresses life course issues. Are the effects of undesirable shifts in weather patterns on migration—for example, proportionately larger reductions in rainfall across time, or larger increases in temperature—greater among young adults? This would be expected if existing age- and gender-specific migration patterns reflect young adults' social positions within an extended family network, and young adults also have both the highest individual incentives to leave and the fewest responsibilities to anchor them. Or do climate pressures flatten migration effects across age?

Second, we have noted important points of comparison and contrast in the factors that drive age-specific migration patterns for men and women. Does this extend to the effects of climate variability on age-specific migration patterns? For example, if climate variability places increasing economic pressure on households and communities, does this weaken cultural resistance to younger women migrating to cities? If so, undesirable shifts in weather patterns might be associated with relatively larger increases in female than male migration, even if overall rates of male rural-urban migration remain higher than those of females.

The final set of questions is directed at understanding changes in these relationships across time. Over the 1980–2015 period, countries in SSA experienced a number of transitions that could have affected rural-urban migration. In addition to rapid increases in the level of women's education and some gains in gender equality, described above, these include the post-Cold War wave of democratization, trade liberalization, growth of both first- and second-tier cities, and continued high levels of population growth. Did these changes affect age- and gender-specific patterns of rural out-migration in different ways at different stages, perhaps intensifying its effects as population continued to grow, or slowing it as cities became less attractive (e.g., too large, dangerous, with little guarantee of employment)? Or, did these migration patterns take the path suggested by cumulative causation? Even if climate variability played a role in triggering migration at an early point in the 1980–2015 period, migration may have become a normal part of the life cycle toward the end of that period, suggesting that as climate variability intensified (relative to a fixed marker in the past), its effect on migration stabilized or even attenuated.

Changes in development policy across the same 35-year period also need to be considered. Standard policies in the late 1970s and early 1980s were disproportionately oriented to large projects, investments in urban areas, with development funds channeled through public institutions. Across the subsequent 35 years, the NGO sector grew dramatically, and more focused attention was paid to factors at the center of this paper: rural areas in general, and more particularly, targeting gender and youth issues and, most recently, climate change (Lim et al. 2004; Swidler and Watkins 2017). This, too, suggests that there could be an attenuation of the relationship between climate variability and migration, reflecting the growth in "climate-smart agriculture" policies,

micro-credit schemes, or other rural investments, all of which have the potential to improve the resilience of the rural sector (Negra et al. 2014; Vermeulen et al. 2016; Arslan et al. 2015; Arslan et al. 2017) and to help avoid some of the most pessimistic migration scenarios described by Rigaud et al. (2018).

Given our use of aggregate data, we cannot disentangle these potential mechanisms from each other—even if we had valid indicators of all of them, any model would, at this level of analysis, be overdetermined. But we can point to differences in *age-specific* effects across successive time periods within that 35-year window.

## Data

### Migration data

Our estimates of net rural-to-urban migration by age and gender are taken from Menashe-Oren and Stecklov (2017). Using a variant of the well-recognized census survival approach (Preston 1979), they use population counts by age and sex for the rural and urban sectors at two separate points in order to estimate time-specific net rural-to-urban migration profiles.[2] More details about this approach are provided in Appendix 1. Here, we simply note that the method yields a total of 9184 discrete 5-year estimates of net rural-to-urban migration rates for this analysis, covering 41 countries in SSA, 7 time intervals, 16 age groups, with separate estimates for men and women. (The countries excluded from our analysis due to data limitations are Cape Verde, Comoros, Democratic Republic of the Congo, Mauritius, São Tomé and Príncipe, Seychelles, South Sudan, and Tanzania.)

Average age-specific net rural out-migration migration profiles across our large sample of countries for the 1980–2015 period are shown in Fig. 1. These are broadly consistent with age patterns documented earlier (e.g., Castro and Rogers 1983), although they point to relatively early peaks: early teens for females (consistent with the *petites bonnes* phenomenon discussed above) and late teens for males. The combination of these high rates and young population age structure shows that a lion's share of rural-to-urban migration is occurring in the youth or young adult ages.

Female migration also falls at an earlier age, though we then observe an intriguing cross-over in the mid-40s. Whereas rates of male net rural out-migration become negative at 45—implying that more men move from urban to rural areas than the reverse—female net rural out-migration remains positive across all ages until 70. Given mean spousal age differences that range from 3.3 years in southern Africa to 6.6 years in western Africa (Barbieri et al. 2005), this positive female pattern may in part reflect a migration response to husbands' death (e.g., following young adult children to an urban

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[2] Our "rural" and "urban" categories are based on national administrative definitions. These are not always comparable or valid (Dorélien et al. 2013)—based on measures of population density, they are particularly prone to miscategorize semi-rural areas. However, they are the standard type of data used in country-level analyses and the standard type made available by research arms of multilateral organizations, from the UNFPA and FAO to the European Commission, which produces the Gridded Population data that we describe below. Our assumption here is that in a sample of countries and time periods as large as this one, these categories are sufficiently accurate to capture changes in patterns of movement, especially between unambiguously rural and urban sectors.
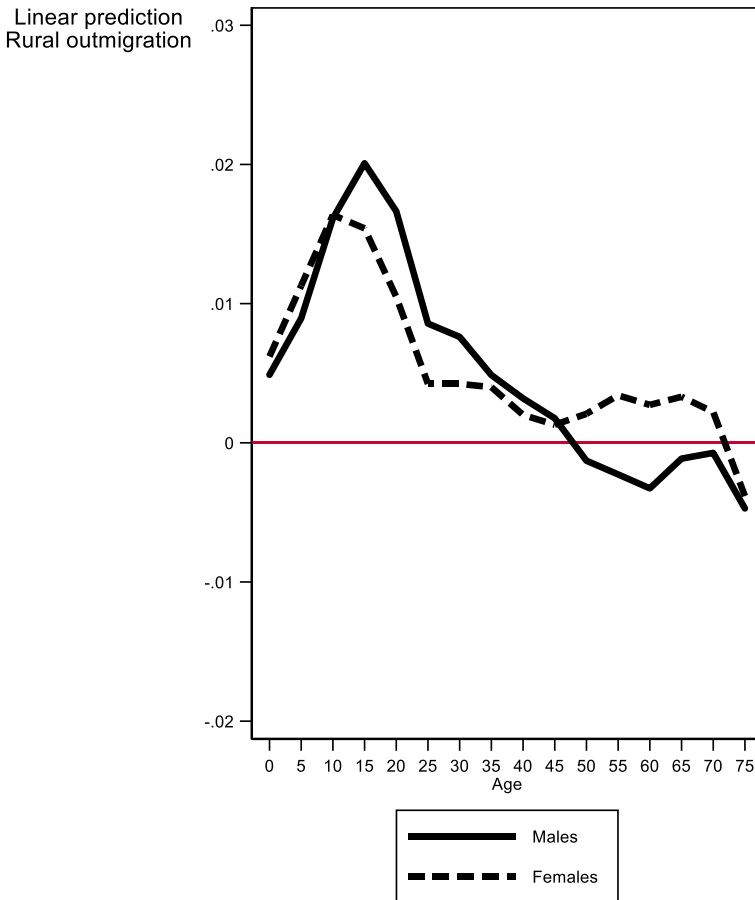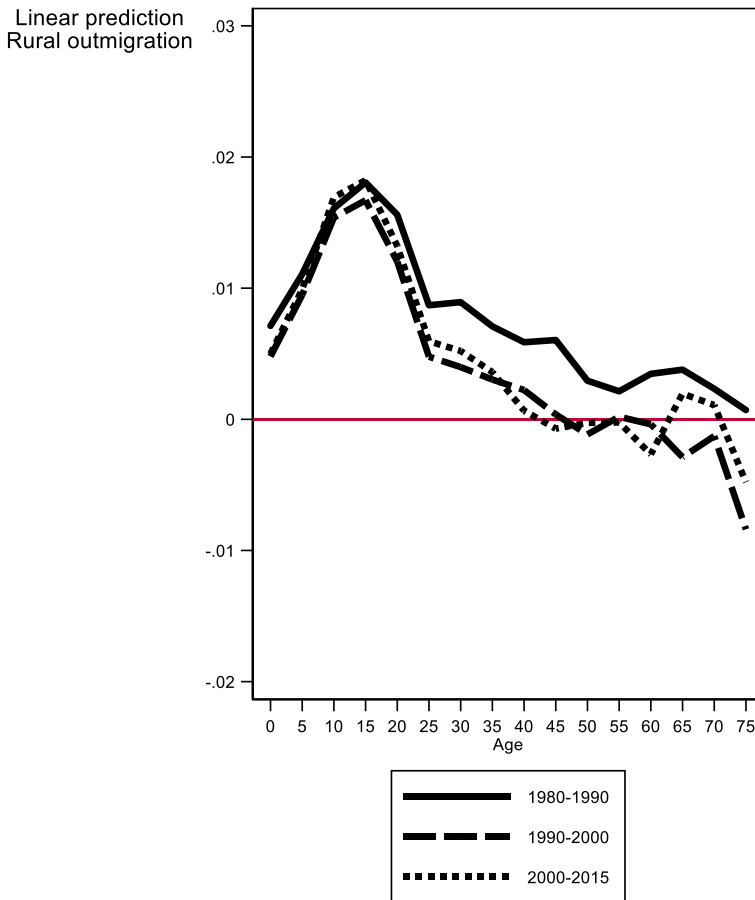
Fig. 1 Age-specific rate of rural out-migration in 41 countries in sub-Saharan Africa, 1980–2015, by sex

area). In contrast, the dip in the male age pattern may reflect the deterioration of urban living standards that drives some older economic migrants—disproportionately men based on these patterns—to return home (Potts 1995; Beauchemin and Bocquier 2004). It may also reflect the type of life course effect that we described above, in which older men return to rural areas, as their younger counterparts move in the opposite direction.

Figure 2 shows that rates of net rural out-migration have fallen across time, although this decline is also variable by age (supporting earlier findings on more limited numbers of countries by Beauchemin and Bocquier (2004)). A sharp contrast exists in how migration has shifted over time for different age categories with very little change at the central ages of migration—youth and young adults—but with rapid declines for those over 25 from the 1980–1989 period to 1990 and beyond. While net rural out-migration rates remained mostly positive, migration profiles indicate very little net migration to cities above age 55. In fact, at these ages, there is greater reverse migration from urban to rural areas (though care is needed in interpreting the rates at upper ages since

**Fig. 2** Age-specific rate of rural out-migration in 41 countries in sub-Saharan Africa, by period

assumptions underlying the cohort survival method can increase bias at higher ages—Menashe-Oren and Stecklov 2017).

## Climate variables

We combine the age- and sex-specific estimates of net rural-urban migration rates with historical data on rainfall and temperature from the Climate Research Unit (CRU) at the University of East Anglia. CRU time series data (1901–2015) include monthly values of total rainfall and average, minimum, and maximum temperature calculated at 0.5 degree resolution for the whole world. We prefer CRU data over newer data sources with higher resolution, like CHIRPS or ARC2, because their temporal coverage is too short. To measure change in weather patterns, we need a time series that extends to before 1980, which is the first year of our migration data. The lower resolution of CRU also does not pose a problem for identification given that our outcome variable, net rural-urban migration, is measured at the national level—meaning the advantages of finer spatial and temporal resolution in datasets like CHIRPS would be lost as we would need to aggregate the data to the national level.

Table 1 presents overall trends across the 1950–2015 period, aggregated over the 41 countries in our sample. Within the 35-year period covered by the rural-urban migration estimates, we see a 5.4% increase in rainfall overall—highest percentage increases across the Sahel and in Namibia and decreases in the southeastern countries (Madagascar, Mozambique, Malawi, Swaziland)—but also increasing variability: across the 35-year period, the within-year standard deviation in rainfall (averaged across a 5-year window) increased by 9.3% and the parallel coefficient of variation by 3.7%. However, relative to our "baseline years," overall rainfall has actually fallen relative to the 1950–1979 period and remained flat relative to the 1970–79 period, even as within-year variability has increased.

Trends in temperature are a little different. Across both the full 1950–2015 period and the 35-year period covered by the rural-urban migration estimates, we see a positive long-term trend in temperature: 0.9 degree across the period as a whole, and 0.6 degree across the final 35 years (respectively, 3.7 and 2.5% increases). In this case, however, the within-year standard deviation for the 1980–2015 period moves in the opposite direction, decreasing by 2.8%, which yields a larger (5.1%) reduction in the coefficient of variation. The equivalent reduction in the coefficient of variation for the 1970–2015 period is 1.4%.

We specify two main types of indicators using these data. Both are shaped by the constraint that migration is measured in 5-year intervals. This means that our empirical attention is more on the effects of longer-term indicators of climate variability and change rather than short run weather shocks—though they would pick up on particularly extreme single year events. The first set of measures are the mean rainfall and temperature in the 5-year period preceding our measurement of migration. The second

**Table 1** Mean, standard deviation (SD), and coefficient of variation (CV) for unweighted rainfall and temperature data, by period ($N = 41$)

| Period | Rainfall | | | Temperature | | |
|---|---|---|---|---|---|---|
|  | Mean | SD | CV | Mean | SD | CV |
| Baseline years |  |  |  |  |  |  |
| 1950–1979 | 1141.0 |  |  | 24.03 |  |  |
| 1970–1979 | 1097.8 | 78.5 | 0.072 | 24.03 | 2.12 | 0.088 |
| Period with migration data |  |  |  |  |  |  |
| 1980–1985 | 1044.4 | 75.7 | 0.072 | 24.31 | 2.23 | 0.092 |
| 1985–1990 | 1077.4 | 80.0 | 0.074 | 24.36 | 2.18 | 0.089 |
| 1990–1995 | 1030.0 | 75.8 | 0.074 | 24.39 | 2.19 | 0.090 |
| 1995–2000 | 1081.4 | 79.8 | 0.074 | 24.61 | 2.14 | 0.087 |
| 2000–2005 | 1080.8 | 78.4 | 0.073 | 24.77 | 2.16 | 0.087 |
| 2005–2010 | 1098.8 | 83.3 | 0.076 | 24.91 | 2.19 | 0.088 |
| 2010–2015 | 1101.1 | 82.7 | 0.075 | 24.92 | 2.17 | 0.087 |
| Change, 1950–2015 (%) | − 3.5 |  |  | 3.7 |  |  |
| Change, 1970–2015 (%) | 0.3 | 5.4 | 5.1 | 3.7 | 2.2 | − 1.4 |
| Change, 1980–2015 (%) | 5.4 | 9.3 | 3.7 | 2.5 | − 2.8 | − 5.1 |

set of measures are the within-year variability in rainfall and temperatures, averaged across the 5-year period preceding migration. These indicators are in line with the literature investigating the relationship between climate variability and migration in multiple countries over time (e.g., Barrios et al. 2006; Cai et al. 2016; Cattaneo and Peri 2016; among others).

## Other variables

As described below, our analyses are all in reduced form—we do not estimate the specific pathways through which changes in weather patterns affect age- and sex-specific migration (e.g., operating through production, infrastructure, and labor markets). Nonetheless, the models include a number of control variables to help identify the effects of climate variability on migration with more confidence. They include per capita GDP and TFR. GDP is measured at 5-year intervals and enables us to control for broad changes in income levels at the national level, and TFR is measured 15 years prior to the start of each migration period (World Development Indicators 2018) to allow us determine the extent to which migration effects are driven by population dynamics nearly a generation earlier. This type of cohort effect can be seen in reduced Mexican migration to the USA (Villarreal 2014). The inclusion of these measures has no qualitative impact on our main findings.

## Methodology

The central goal of our analysis is to estimate how age and gender-specific net rural-urban migration rates—only available in 5-year intervals—are affected by changes in weather patterns over the 1980–2015 period. To do this, we look at the lagged effect of a *change* in weather in a 5-year period $t$-5 on rates of net rural out-migration during the subsequent 5-year period $t$.

An initial set of models look separately at the effects of changes in rainfall and temperature on age-specific patterns of rural out-migration in discrete models. A final set of models, used to generate marginal effects graphed in Figs. 4, 5, and 6, simultaneously estimate interaction terms between age and each of the lagged measures of changes in weather.

A number of unmeasured factors could influence the relationship between climate variability and migration: topographical variations across countries, soil quality and tree coverage, traditional systems of agricultural land ownership, and variable standards for defining urban and rural boundaries. Some of these vary significantly over time, while others are fixed or at least relatively stable. It is not clear how one should interpret average national topography in relation to migration, or define and measure various forms of land ownership—(individual vs. collective, titled vs informal) at the national level (Deininger et al. 2017). Given these unmeasured factors and the challenge of accurately measuring some of them, we use within-country fixed effects (FE) estimators. These equally address the absence of many controls for country-level differences in fixed characteristics and also for variations across countries in how rural-urban boundaries are defined, since country practices tend to be relatively stable over time, as well as other factors associated with longer-term patterns of migration, like colonial

and post-colonial investments and land tenure policies (Piguet et al. 2011; Hunter et al. 2015). The FEs remove the time-invariant component of climate variability from the period 1950–1979; hence, the identification is based on the time-varying component. We examine the full range of climate variability in the descriptive material.

Each model has 15 age groups for each sex, meaning 30 observations per country per year, $t$. In all models, we use 0–4 as a reference age. We include dummy variables as controls for age, sex, and year and the country-level variables to control for the effects of TFR and per capita GDP, which are independently associated with migration, as described above.

The standard approach in cross-national analyses of this type uses unweighted national averages of weather variables. For rainfall and temperature, for example, all weather stations in a country from which CRU takes its data contribute equally to the country average, irrespective of the population distribution. The first set of models here uses that standard approach.

Our second and preferred approach is to weight each weather station's contribution to the national measure based on the spatial distribution of the country's rural population in associated CRU grids. This weighting improves the specificity of the link between the indicator of climate variability and rural out-migration, since it more accurately reflects the rural population's experience of changes in rainfall and temperature. In addition, the difference between analyses estimated with and without weighted rainfall and temperature variables is a reflection of the extent to which *unweighted* results are driven by patterns in relatively underpopulated areas. It would not be surprising if some of the most hard-hit areas have developed very fluid mobility regimes, but if the share of rural population living in these areas is small in size, they would be expected to play a more limited role (low-weight) in driving out-migration.

In the weighted measure the contribution of each CRU grid (0.5 degree resolution corresponds to a grid of 55 km × 55 km at the equator)—within which there is at least one weather station—was determined by the proportion of the country's total rural population in that grid. These data are from the Global Human Settlement Layer (GHSL) of the Joint Research Centre (JRC) of the European Commission, which is specifically designed to spatially differentiate rural-urban population distribution (based on administratively defined rural-urban boundaries). Since GHSL estimates are only available for 1975, 1990, 2000, and 2015, population distributions at 5-year intervals between these dates were estimated with a simple linear interpolation. Likewise, since the earliest weighted population estimate in GHSL is in 1975, this limits the comparison of change in weather to the post-1975 period and shortens our time series.

Figure 3 maps the ratio of weighted to unweighted rainfall data in these data. It confirms that rural populations are not equally distributed around countries' weather stations. Rather, in more arid regions—the Sahel, much of East Africa, and the western parts of southern Africa—rural residents disproportionately live in wetter areas, including both rural and urban populations. Rural residents in equatorial countries disproportionately live in dryer areas.

## Results

Our analysis begins by exploring how changes in rainfall patterns affect net rural out-migration in SSA. In Tables 2 and 3, we present four models based on interactions
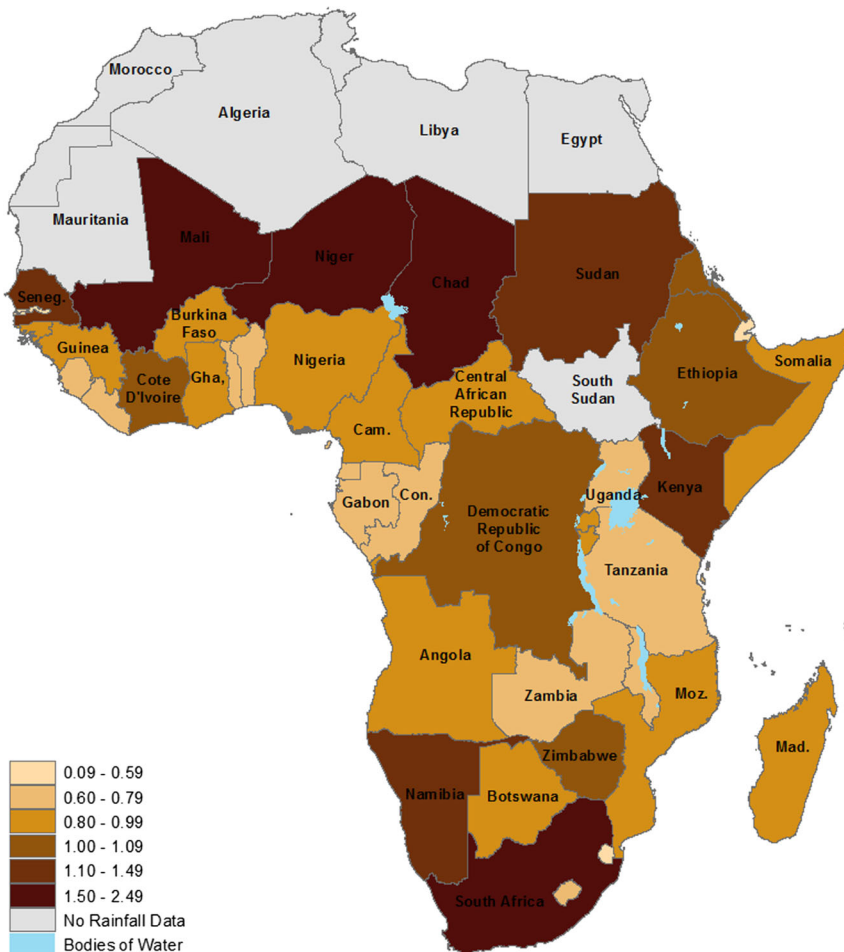
**Fig. 3** Relationship between ratio of weighted to unweighted rainfall data

between age and lagged measures of a single type of change in weather: changes in rainfall in Table 2 and in temperature in Table 3. A later set of models, noting the correlation between changes in mean rainfall and standard deviation of temperature, simultaneously estimates interaction terms between age and each of these measures of rainfall and temperature.

## Changes in rainfall

Model 1 in Table 2 looks at the effects of changes in mean rainfall during the 5 years preceding the migration interval and model 3 at the effects of changes in the within-year standard deviation of rainfall (averaged across the preceding 5 years)—both using unweighted measures of climate variability. Models 2 and 4 replicate these, respectively, using weighted measures of rainfall: this is our preferred approach. Parallel models also looked at logged versions of these dependent variables and at the effects of drought or excess rain and temperature (respectively, number of years at least one

**Table 2** Fixed effects models to estimate change in mean rainfall and variability in rainfall on age-specific rural out-migration in sub-Saharan Africa, 1980–2015. Partial estimates: other variables in Appendix Table 4

| | (1)<br>Unweighted mean | (2)<br>Weighted mean | (3)<br>Unweighted variability | (4)<br>Weighted variability |
|---|---|---|---|---|
| Age = 5 × rain | 0.00000396** | 0.00000540** | 0.0000602*** | 0.0000723** |
| | (3.26) | (3.24) | (3.45) | (3.04) |
| Age = 10 × rain | 0.00000252* | 0.00000426* | 0.0000430* | 0.0000534* |
| | (2.07) | (2.56) | (2.46) | (2.25) |
| Age = 15 × rain | − 0.00000473*** | − 0.00000502** | − 0.0000416* | − 0.0000534* |
| | (− 3.89) | (− 3.01) | (− 2.38) | (− 2.25) |
| Age = 20 × rain | − 0.0000105*** | − 0.0000116*** | − 0.000101*** | − 0.000107*** |
| | (− 8.65) | (− 6.96) | (− 5.80) | (− 4.51) |
| Age = 25 × rain | − 0.00000707*** | − 0.00000733*** | − 0.0000915*** | − 0.0000858*** |
| | (− 5.82) | (− 4.40) | (− 5.24) | (− 3.61) |
| Age = 30 × rain | − 0.000000283 | − 0.000000778 | − 0.0000166 | − 0.0000231 |
| | (− 0.23) | (− 0.47) | (− 0.95) | (− 0.97) |
| Age = 35 × rain | 0.00000125 | 0.000000549 | 0.00000149 | − 0.00000549 |
| | (1.03) | (0.33) | (0.09) | (− 0.23) |
| Age = 40 × rain | − 0.000000257 | − 0.000000864 | 0.000000131 | − 0.00000177 |
| | (− 0.21) | (− 0.52) | (0.01) | (− 0.07) |
| Age = 45 × rain | − 0.000000414 | − 0.00000112 | − 0.000000146 | − 0.0000121 |
| | (− 0.34) | (− 0.67) | (− 0.01) | (− 0.51) |
| Age = 50 × rain | − 0.000000493 | − 0.00000150 | 0.00000477 | − 0.0000160 |
| | (− 0.41) | (− 0.90) | (0.27) | (− 0.67) |
| Age = 55 × rain | 7.67e-08 | − 0.000000991 | 0.00000597 | − 0.0000150 |
| | (0.06) | (− 0.59) | (0.34) | (− 0.63) |
| Age = 60 × rain | − 0.000000482 | − 0.00000260 | 0.00000435 | − 0.0000342 |
| | (− 0.40) | (− 1.56) | (0.25) | (− 1.44) |
| Age = 65 × rain | − 0.000000139 | − 0.000000672 | 0.0000101 | − 0.00000275 |
| | (− 0.11) | (− 0.40) | (0.58) | (− 0.12) |
| Age = 70 × rain | − 0.00000152 | 0.000000110 | − 0.0000374* | − 0.00000953 |
| | (− 1.25) | (0.07) | (− 2.14) | (− 0.40) |
| Age = 75 × rain | − 0.00000336** | − 0.00000255 | − 0.0000524** | − 0.0000330 |
| | (− 2.75) | (− 1.51) | (− 2.98) | (− 1.37) |
| Constant | 0.000316 | 0.00168 | 0.000565 | 0.00146 |
| | (0.11) | (0.61) | (0.19) | (0.53) |
| Observations | 8919 | 8919 | 8919 | 8919 |
| Adjusted $R^2$ | 0.234 | 0.227 | 0.227 | 0.221 |

$t$ statistics in parentheses

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

standard deviation below or above the country mean within the 5-year window). Since results for all these models are substantively identical—in terms of age- and gender-

**Table 3** Fixed effects models to estimate change in mean temperature and variability in temperature on age-specific rural out-migration in sub-Saharan Africa, 1980–2015. Partial estimates: other variables in Appendix Table 4

|  | (1) Unweighted mean | (2) Weighted mean | (3) Unweighted variability | (4) Weighted variability |
|---|---|---|---|---|
| Age = 5 × Temp | 0.000798*** | 0.000160 | − 0.00153** | − 0.00225** |
|  | (3.74) | (1.12) | (− 2.66) | (− 3.13) |
| Age = 10 × temp | 0.000894*** | 0.000136 | − 0.00134* | − 0.00178* |
|  | (4.19) | (0.95) | (− 2.32) | (− 2.47) |
| Age = 15 × temp | − 0.000275 | − 0.000176 | 0.00172** | 0.00288*** |
|  | (− 1.29) | (− 1.23) | (2.99) | (4.01) |
| Age = 20 × temp | − 0.00144*** | − 0.000168 | 0.00482*** | 0.00773*** |
|  | (− 6.73) | (− 1.17) | (8.37) | (10.75) |
| Age = 25 × temp | − 0.00113*** | 0.0000587 | 0.00306*** | 0.00509*** |
|  | (− 5.30) | (0.41) | (5.30) | (7.07) |
| Age = 30 × temp | − 0.000190 | − 0.0000273 | 0.000280 | 0.000447 |
|  | (− 0.89) | (− 0.19) | (0.49) | (0.62) |
| Age = 35 × temp | − 0.0000114 | − 0.0000634 | − 0.000489 | − 0.000730 |
|  | (− 0.05) | (− 0.44) | (− 0.85) | (− 1.01) |
| Age = 40 × temp | 0.000197 | 0.0000133 | − 0.000289 | − 0.000630 |
|  | (0.92) | (0.09) | (− 0.50) | (− 0.88) |
| Age = 45 × temp | 0.000318 | − 0.0000676 | − 0.000392 | − 0.00116 |
|  | (1.49) | (− 0.47) | (− 0.68) | (− 1.61) |
| Age = 50 × temp | 0.000290 | − 0.000129 | − 0.000253 | − 0.00111 |
|  | (1.36) | (− 0.90) | (− 0.44) | (− 1.55) |
| Age = 55 × temp | 0.000313 | − 0.0000936 | − 0.000595 | − 0.00151* |
|  | (1.47) | (− 0.65) | (− 1.03) | (− 2.11) |
| Age = 60 × temp | 0.000258 | − 0.000249& | − 0.000606 | − 0.00182* |
|  | (1.21) | (− 1.73) | (− 1.05) | (− 2.53) |
| Age = 65 × temp | 0.000258 | − 0.0000591 | − 0.000720 | − 0.00135& |
|  | (1.21) | (− 0.41) | (− 1.25) | (− 1.87) |
| Age = 70 × temp | − 0.000489* | 0.000231 | 0.0000385 | 0.000561 |
|  | (− 2.29) | (1.61) | (0.07) | (0.78) |
| Age = 75 × temp | − 0.000709*** | 0.0000964 | 0.000263 | 0.000643 |
|  | (− 3.31) | (0.67) | (0.45) | (0.89) |
| Observations | 8919 | 8919 | 8919 | 8919 |
| Adjusted $R^2$ | 0.234 | 0.214 | 0.233 | 0.248 |

$t$ statistics in parentheses

& $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

specific effects of climate on migration—to models we present, we do not describe them.

Our main interest is in the interactions between rainfall and age, which show whether and how changes in rainfall patterns create distinctive age-specific patterns

of rural out-migration. We therefore only show these interaction terms in Table 2. All other parameter values can be seen in Appendix Table 4.[3] Note that these are all fixed effects models at the country level, so rainfall measures reflect changes relative to the country average.

The evidence across both sets of models in Table 2—mean rainfall and within-year variability in rainfall—indicates that the impact on migration varies sharply across the life course. In models 1 and 2, we see significant positive interactions for children between ages 5–14 and large negative interactions from ages 15–29—the young adult working ages. The negative coefficients imply that reductions in mean rainfall *raise* net rural out-migration in these age groups. In other words, a reduction in rainfall (relative to the within-country average) raises rural out-migration of young adults more than out-migration of older adults. The effects on older adults are in the same direction, though they are not statistically significant.

Models 3 and 4 show that increased variability in rainfall (relative to the country mean for the 1980–2015 period) increases net rural out-migration for children but *reduces* net rural out-migration at the same prime migration ages 15–29. In other words, increasing within-year instability (albeit averaged across a 5-year period) appears to keep more people in a rural area, perhaps to work the land when the rain comes. Here, too, the peak interaction effect occurs at ages 20–24. Model 3 also points to reduced rural out-migration among those aged at least 70, though this pattern is not significant with the weighted data (model 4).

## Changes in temperature

Table 3 looks at the effects of changes in temperature on net rural out-migration. As above, we focus here on the age-temperature interactions, presenting full results in Appendix Table 5. Model 1 in Table 3 looks at the effects of changes in mean temperature during the 5 years preceding the migration interval and model 3 the effects of changes in the within-year standard deviation of temperature. Models 2 and 4 replicate these, respectively, using weighted measures of temperature.

Regarding the effect of changes in mean temperature on subsequent rural out-migration, results from models 1 and 2 are inconclusive. Model 1 suggests that a rise in mean temperature is associated with higher out-migration during childhood years but lower out-migration throughout people's 20s (and again in people's 70s). None of these effects remain significant in model 2, which uses population-weighted data. Evidently, correcting the temperature data for the geographic dispersion of these populations helps to diminish spurious findings, driven in this case by strong effects in relatively underpopulated areas. This is an important result. It hints at distinct age effects in *less*

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[3] The temporal coefficients indicate variability in trends with an initial rise in migration in the late 1980s, followed by declines that lasted into the first decade of the twenty-first century, and ending with a slow rise back to the early 1980s level by 2015. There is clear evidence of the moderating effects of national wealth measured by GDP per capita, which tends to be higher in more urbanized countries in Africa (UN data; own calculations). Of particular interest is the significant positive coefficient of the TFR 15 years prior to migration estimate, which highlights the impact of past fertility levels on current pressures for rural-urban migration. Reductions in fertility reduce the number of adolescents entering the labor market 15–20 years later, pointing to parallels between rural-urban migration in SSA and undocumented migration from Mexico into the USA (Villareal 2014).

*populated* places that are facing rising temperatures—exactly the type of places that are least likely to have infrastructure to support affected people.

The effects of changes in standard deviation of temperature are more robust to weighting. Models 3 and 4 consistently suggest that increased variability in temperature reduces net rural out-migration for children, but *raises* net rural out-migration at peak migration ages 15–29. The effects are strongest in the model based on population-weighted values. The impact of temperature variability peaks at ages 20–24 and indicates that a doubling of the standard deviation of temperature raises the rate of net rural out-migration, which has a mean of 0.005, by 0.008 points. Interestingly, the mostly negative though insignificant effects for ages 30 and over are what we would expect given the decline for younger children, whose migration is partially determined by parent migration behavior.

Model 4 also provides some indication that rates of net rural out-migration are reduced at the higher adult ages (ages 55–64). This offers some support for the idea that migration-related reactions to climate variability may balance each other out across different ages. Whether these effects actually imply some substitution at the household level cannot be determined with these data, but as we argue below, an aggregated manifestation of age-substitution patterns is certainly consistent with that type of livelihoods adaptation strategy.

## Gender effects

Since there is a correlation between changes in rainfall and standard deviation of temperature, our final set of models simultaneously estimate interactions between each of these weighted measures and age, then look for gender-specific effects, and period effects within the context of this model.

In terms of gender-specific effects, the most important result to emerge from these analyses is that *none* of the age-gender-temperature interactions are statistically significant, which suggests similarity in the effects of change in temperature variability on both men's and women's migration. However, there are some statistically significant age-gender-rainfall interactions. This can be seen in Fig. 4, which graphs the total net effect of changes in rainfall on migration patterns, by age and gender, under two rainfall scenarios. The solid lines reflect the predicted age-specific rural net out-migration rates for men (thick line) and women (thin line) following 10th percentile changes in rainfall—a mild reduction relative to the historical norm. The dashed lines reflect the equivalent rural out-migration rates for men and women following 90th percentile changes—an increase in rainfall relative to the historical norm. For full model results, see Appendix Table 6.

Results confirm much higher net rural out-migration where mean rainfall has decreased, relative to where rainfall has increased, across all ages. Results also show similar age patterns for men and women within each climate-scenario up to about age 45: though the estimated male-female difference is larger where rainfall is lower than its historical norm, peaking in 20–24 age range. At older ages—above age 45 where rainfall has increased, and age 50 where it has decreased—we then see a reversal of the gender pattern, significant in the 55–64 age range. This is consistent with the idea that there may be a relationship between high net out-migration among prime-age individuals and simultaneous net rural in-migration among older counterparts, but not for women in areas where the relative amount of rainfall is lower.
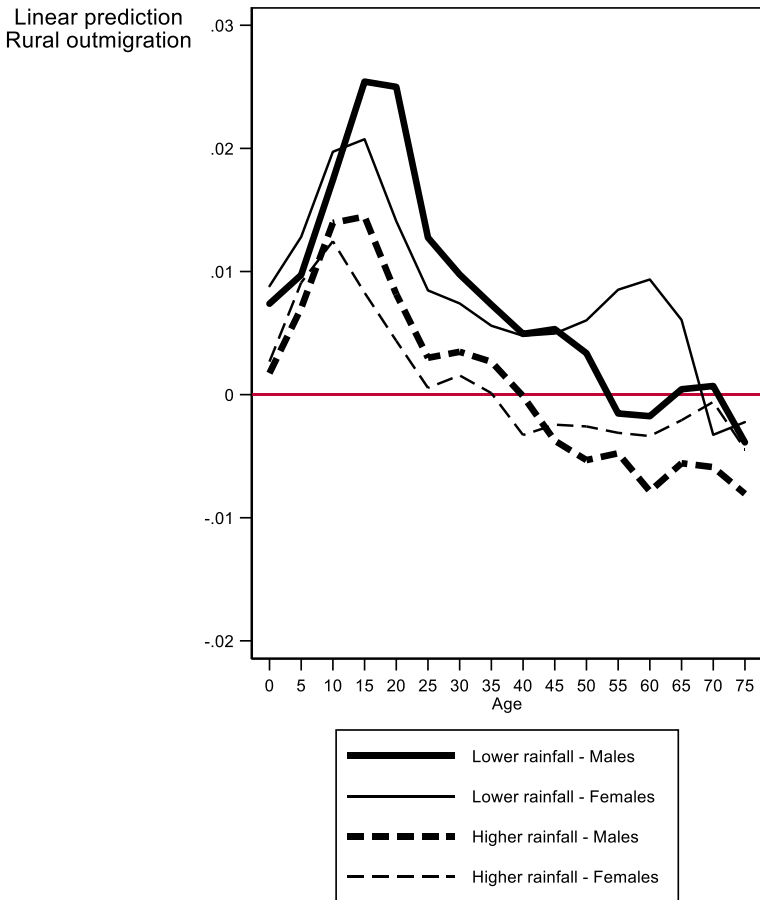
**Fig. 4** Adjusted probability of rural out-migration in 41 countries in sub-Saharan Africa, by gender and prior change in rainfall (based on model 3 in Appendix Table 6, with all other variables set to mean)

## Period effects

Our final set of models explore whether the impact of climate variability on migration varies between the early and late periods in our study. As above, we replicate estimated these in models that contain interaction terms between age and lagged, weighted rainfall (Table 2, model 3) as well as lagged weighted variability of temperature (Table 3, model 4), but now also adding discrete estimates for the early and late periods—1980–1999 and 2000–2014, respectively. The total effects of changes in mean rainfall on migration by period are graphed in Fig. 5 (changes in mean rainfall) and Fig. 6 (changes in variability in temperature). Full model results are shown in Appendix Table 7.

Figure 5 shows a consistent temporal difference in the effect of mean rainfall only among people aged at least 30 living in areas with a reduction in rainfall. In the 1980–1999 period (thick solid line), their rate of rural out-migration was much higher than that of people in countries where rainfall increased (thick dashed line). By the 2000–

2014 period, the differences between these two areas were significantly reduced (thin solid versus thin dashed line). At all other ages, and in countries that did not experience a reduction in rainfall, the rural out-migration rates are similar across the two periods.

Figure 6 replicates these tests using the results of the temperature variability models. Here, we see larger contrasts between the early and late periods, including a marginally significant gap at ages 20–24. Countries with a larger increase in temperature variability have higher subsequent rural out-migration at peak ages 20–24 in the 2000–2014 period than was the case in the 1980–1999 period (compare the thin and thick dashed lines), though that peak is later than in countries with smaller increases in temperature variability. We also see greater effects of temperature variability on rural out-migration above age 30 in the 2000–2014 period than in the 1980–1999 period. Countries with a larger increase in temperature variability have much lower subsequent rural out-migration above age 30 in the later than earlier period. In this case, therefore, climate variability affects migration of young adults in both periods.

Overall, these period-specific findings suggest that programs to combat the effects of climate change have done little to alter migration rates at young adult ages, at least



**Fig. 5** Adjusted probability of rural out-migration in 41 countries in sub-Saharan Africa, by period and prior change in rainfall (based on model 3 in Appendix Table 7, with all other variables set to mean)

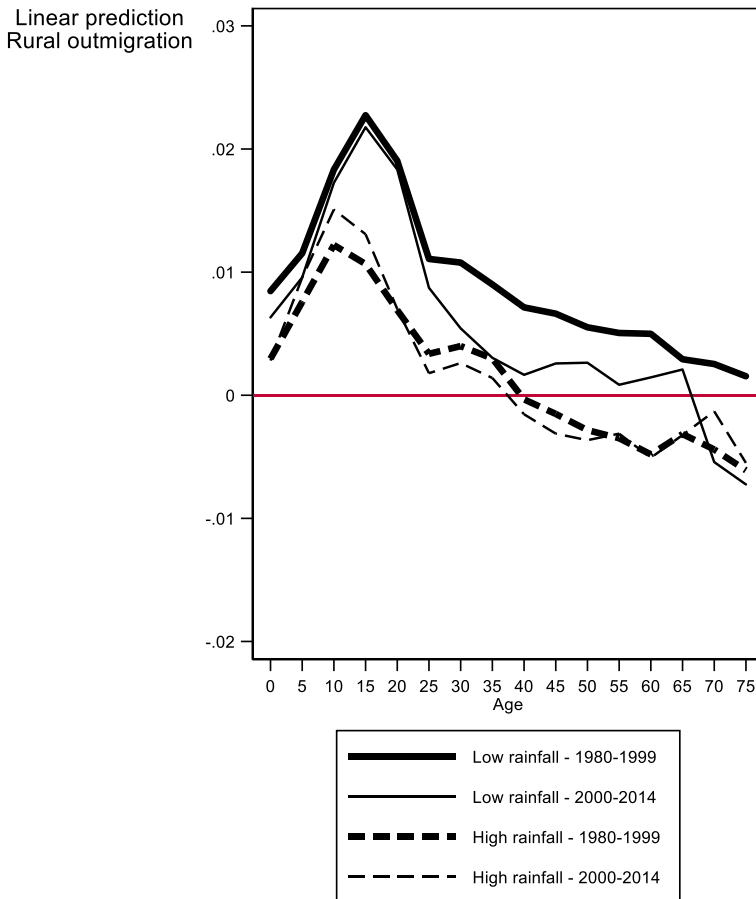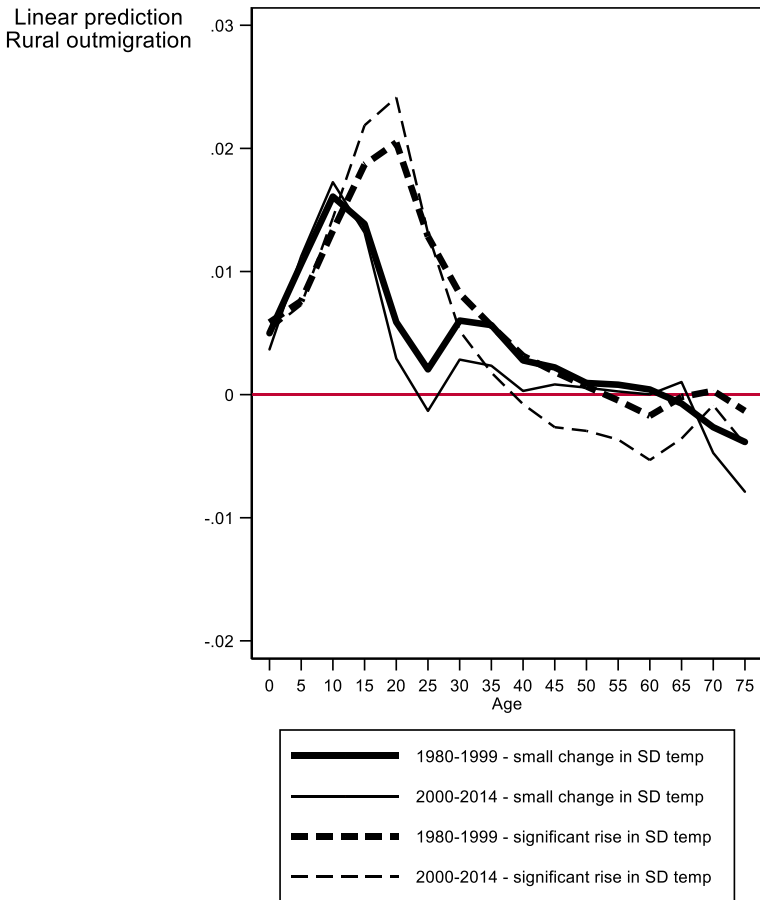**Fig. 6** Adjusted probability of rural out-migration in 41 countries in sub-Saharan Africa, by period and prior change in standard deviation in temperature (based on model 6 in Appendix Table 7, with all other variables set to mean)

migration in response to changes in weather patterns. But they may have altered net migration at marginally older ages, pulling more people back to rural areas. Again, this is consistent with a life course perspective on household adaptation: high net out-migration among prime-age individuals is associated with—and in some cases facilitated by—the simultaneous net rural in-migration among older counterparts.

## Conclusions

Our principal substantive goal in this paper has been to explore whether and how changes in rainfall and temperature patterns affect net rural-urban migration in SSA at different ages, by gender, and across time. Overall, we have shown that over the 1980–2015 period, migration induced by weather variability intensified by climate change did indeed vary in these ways. Our findings indicate that the effects were powerful enough to overcome imprecision in the data associated with both the country-level aggregation

(i.e., the fact that our measures of migration are estimated and calculated in 5-year intervals and hence cannot capture shorter-term circular migration patterns) as well as heterogeneity across regions in core measures of climate variability. In itself, the robustness of our results shows how important age variation is, even as it shifts somewhat differently for men and women and across time. In turn, this suggests that ignoring age variation may lead analysts to falsely conclude that climate variability does not affect migration.

More specific to the three research questions posed above, we have shown the following:

- Rural out-migration of young adults—both men and women—is the most sensitive to climate variability, with lower rainfall, lower variability in rainfall, and higher temperatures increasing subsequent rural out-migration. In addition, increasing temperature variability is associated with a higher rural *in*-migration for children (0–9) and older adults (55–64)—there is no equivalent effect of a change in rainfall.
- Gender differences in the effects of changes in weather on migration are concentrated in areas which experienced heavy reductions in rainfall and point to a more notable movement of older men than older women back to rural areas.
- Changes in temperature variability had a stronger effect on migration of 20–24 year olds in the later relative to the earlier period, but weaker effects on migration of those older than 30.

The robustness of these age-specific effects, alongside their variability by gender and time, has implications for further research. First, though it is clearly easier to identify the mechanisms linking age and gender to migration outcomes under various weather scenarios in micro-level studies—the level at which livelihood adaptation strategies are best measured—one of our central goals here has been to show that with more attention to age, gender, and population distribution, we can come closer to that finer resolution, even in aggregate studies. So we do not, for example, directly observe age-substitution—a basic type of livelihood adaptation strategy—at the household or community level with this type of study. But we can see aggregated manifestations of age-substitution, which is a substantive contribution that warrants an appeal for more investigation.

We can also see finer resolution by comparing results of parallel analyses estimated with and without weighting rainfall and temperature variables by population distribution. We argued above that the difference between these tells us the extent to which *unweighted* results are driven by patterns in relatively underpopulated areas. Only in models of changes in average temperature did we see a significant difference in models using weighted and unweighted data. But that itself is an important result since it points to distinct age effects only in hotter *less populated* places. In poor countries, these are precisely the type of places that are least likely to have infrastructure to support people affected by significant climate change. We also expect these weighted results to more closely approximate results from household surveys whose sample design is proportionate to the population. Our only reservations on this point are related to two potential weaknesses of the weighted measures. First, proportional weighting by population size may be too aggressive an approach if population size is non-linearly related to the vulnerability of an area to the migration effects of climate variability, especially where

that is intensified by climate change. Second, our weights ignore possible differences in age structure across the CRU grids.

These reservations aside, weighting climate or other environmental inputs can be used with other datasets, like those produced by the Global Precipitation Climatology Centre (GPCC) or Climate Hazards group Infrared Precipitation with Stations (CHIRPS). It also need not be limited to the national level. We can equally imagine applying population-weighted estimates at a more local level, for example, within a region or district. Using the same type of within-country FE modeling approach used here, this would have the added benefit of allowing researchers to look at time-varying factors within countries, that is, a within-country-year FE approach. Likewise, this approach can be extended to other important variables frequently used in the literature on environmental change and migration, especially in rural areas dependent on rain-fed agriculture—examples include soil quality and vegetation indices—or by incorporating aggregate measures of other types of migration not covered here: rural-to-rural, to semi-rural or peri-urban, international, as well as short-term patterns of circular migration. More generally, the robustness of these age-specific effects also has implications for policy interventions and program design. In showing that rates of net positive rural out-migration induced by weather variability intensified by climate change are concentrated in early adulthood—with suggestions of reverse effects at older ages—our findings highlight the importance of policy interventions that are sensitive to age structure by, for example, providing sustainable livelihood strategies to young adults in rural areas, perhaps even a pathway toward upward social mobility without requiring migration to urban areas. The young age structure of populations throughout SSA adds more weight to this consideration: given forecasts of reductions in rainfall, increases in temperature, and higher variability in both, the absolute number of migrants leaving rural areas in SSA will inevitably increase over the next couple of decades unless the *rates* of out-migration fall dramatically.

The processes of rural and structural transformation that increasingly link rural and urban areas by creating vibrant secondary cities, each anchoring their own network of towns, are expected to re-orient the discourse on rural out-migration more toward mobility, especially if policies are sufficiently inclusive of rural youth, providing them with opportunities for a decent livelihood without migration. Of course, this does not mean stopping rural-urban migration. Rather, it means recognizing that some people migrate who, absent significant long-term changes in weather patterns—including more frequent spikes and dips—would have stayed put, even in settings with significant cultures of migration. That is the implicit story underlying the different migrant trajectories that we have identified here, especially among young adults. Right now, especially in areas that rely on rain-fed subsistence agriculture, migration remains less a household choice than a core element of household adaptation and survival. Given the Intergovernmental Panel on Climate Change's forecasts for higher temperature increases in SSA than other regions, that is likely to remain the case in rural areas in Africa in general. As such, processes of rural structural transformation may improve individual welfare by allowing more people who want to stay put to do so without endangering household income. If sustainably is implemented, these transformation processes may also maintain and even improve agricultural production in spite of climate change *and* facilitate the flow of migrants toward secondary cities and towns easing the already stretched burden on the carrying capacity of main cities.

# Appendix

**Table 4** Fixed effects estimates of change in rainfall on age-specific rural out-migration in sub-Saharan Africa, 1980–2015: variables not presented in Table 2

|  | (1) Unweighted mean | (2) Weighted mean | (3) Unweighted variability | (4) Weighted variability |
|---|---|---|---|---|
| Age = 5 | 0.000557 | 0.0000820 | 0.0000875 | 0.000193 |
|  | (0.38) | (0.05) | (0.06) | (0.12) |
| Age = 10 | 0.00815*** | 0.00714*** | 0.00749*** | 0.00746*** |
|  | (5.58) | (4.47) | (4.93) | (4.52) |
| Age = 15 | 0.0166*** | 0.0160*** | 0.0149*** | 0.0150*** |
|  | (11.38) | (10.00) | (9.79) | (9.11) |
| Age = 20 | 0.0182*** | 0.0172*** | 0.0150*** | 0.0139*** |
|  | (12.47) | (10.74) | (9.87) | (8.45) |
| Age = 25 | 0.00820*** | 0.00709*** | 0.00783*** | 0.00617*** |
|  | (5.62) | (4.43) | (5.15) | (3.74) |
| Age = 30 | 0.000681 | 0.00105 | 0.00165 | 0.00182 |
|  | (0.47) | (0.66) | (1.09) | (1.10) |
| Age = 35 | − 0.00248 & | − 0.00164 | − 0.00129 | − 0.000836 |
|  | (− 1.70) | (− 1.03) | (− 0.85) | (− 0.51) |
| Age = 40 | − 0.00335* | − 0.00288 & | − 0.00363* | − 0.00351* |
|  | (− 2.30) | (− 1.81) | (− 2.39) | (− 2.13) |
| Age = 45 | − 0.00384** | − 0.00333* | − 0.00426** | − 0.00353* |
|  | (− 2.63) | (− 2.08) | (− 2.80) | (− 2.14) |
| Age = 50 | − 0.00444** | − 0.00367* | − 0.00532*** | − 0.00396* |
|  | (− 3.04) | (− 2.30) | (− 3.50) | (− 2.40) |
| Age = 55 | − 0.00555*** | − 0.00463** | − 0.00592*** | − 0.00454** |
|  | (− 3.80) | (− 2.89) | (− 3.90) | (− 2.75) |
| Age = 60 | − 0.00578*** | − 0.00407* | − 0.00661*** | − 0.00416* |
|  | (− 3.96) | (− 2.55) | (− 4.35) | (− 2.52) |
| Age = 65 | − 0.00537*** | − 0.00494** | − 0.00628*** | − 0.00534** |
|  | (− 3.68) | (− 3.09) | (− 4.13) | (− 3.24) |
| Age = 70 | − 0.00556*** | − 0.00724*** | − 0.00428** | − 0.00655*** |

**Table 4** (continued)

|  | (1) Unweighted mean | (2) Weighted mean | (3) Unweighted variability | (4) Weighted variability |
|---|---|---|---|---|
|  | (−3.80) | (−4.52) | (−2.81) | (−3.96) |
| Age = 75 | −0.00605*** | −0.00739*** | −0.00555*** | −0.00751*** |
|  | (−4.10) | (−4.56) | (−3.62) | (−4.50) |
| GDP per capita 5 years prior to start of 5-year migration estimate | −0.00000158*** | −0.00000158*** | −0.00000153*** | −0.00000153*** |
|  | (−8.42) | (−8.40) | (−7.89) | (−8.06) |
| TFR 15 years prior to migration estimate | 0.000784* | 0.000899** | 0.000840* | 0.00100** |
|  | (2.37) | (2.66) | (2.49) | (2.92) |
| Female | 0.000406 | 0.000406 | 0.000405 | 0.000406 |
|  | (1.57) | (1.56) | (1.56) | (1.56) |
| Year = 1990 | 0.00197*** | 0.00180*** | 0.00197*** | 0.00182*** |
|  | (3.73) | (3.45) | (3.71) | (3.47) |
| Year = 1995 | −0.00292*** | −0.00300*** | −0.00284*** | −0.00283*** |
|  | (−5.89) | (−6.05) | (−5.57) | (−5.58) |
| Year = 2000 | −0.00227*** | −0.00244*** | −0.00224*** | −0.00232*** |
|  | (−4.30) | (−4.69) | (−4.20) | (−4.41) |
| Year = 2005 | −0.00157** | −0.00154** | −0.00147** | −0.00131* |
|  | (−3.18) | (−3.11) | (−2.90) | (−2.56) |
| Year = 2010 | −0.000499 | −0.000459 | −0.000432 | −0.000266 |
|  | (−0.98) | (−0.89) | (−0.83) | (−0.51) |
| Year = 2015 | 0.000571 | 0.000690 | 0.000730 | 0.00107 & |
|  | (0.97) | (1.15) | (1.18) | (1.67) |
| Rain | 0.00000111 | −0.00000107 | −0.0000122 | −0.0000424 |
|  | (0.49) | (−0.43) | (−0.39) | (−1.14) |
| Mean rainfall 1–5 years before migration window |  |  | 0.00000132 |  |
|  |  |  | (0.48) |  |
| Mean weighted rainfall 1–5 years before migration window |  |  |  | 0.00000125 |
|  |  |  |  | (0.40) |
| Constant | 0.000316 | 0.00168 | 0.000565 | 0.00146 |
|  | (0.11) | (0.61) | (0.19) | (0.53) |
| Observations | 8919 | 8919 | 8919 | 8919 |
| Adjusted $R^2$ | 0.234 | 0.227 | 0.227 | 0.221 |

$t$ statistics in parentheses

& $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

**Table 5** Fixed effect estimates of change in temperature on age-specific rural out-migration in sub-Saharan Africa, 1980–2015: variables not presented in Table 3

|  | (1) Unweighted mean | (2) Weighted mean | (3) Unweighted variability | (4) Weighted variability |
|---|---|---|---|---|
| Age = 5 | −0.0148** | 0.00168 | 0.00810*** | 0.00822*** |
|  | (−2.81) | (0.60) | (5.47) | (6.12) |
| Age = 10 | −0.0111* | 0.00823** | 0.0138*** | 0.0136*** |
|  | (−2.10) | (2.96) | (9.29) | (10.10) |
| Age = 15 | 0.0184*** | 0.0150*** | 0.00785*** | 0.00717*** |
|  | (3.50) | (5.39) | (5.30) | (5.34) |
| Age = 20 | 0.0424*** | 0.0104*** | −0.00349* | −0.00488*** |
|  | (8.05) | (3.75) | (−2.36) | (−3.63) |
| Age = 25 | 0.0285*** | −0.000250 | −0.00598*** | −0.00716*** |
|  | (5.41) | (−0.09) | (−4.04) | (−5.33) |
| Age = 30 | 0.00502 | 0.000898 | −0.000239 | −0.000316 |
|  | (0.95) | (0.32) | (−0.16) | (−0.24) |
| Age = 35 | −0.000898 | 0.0000101 | −0.0000834 | −0.0000284 |
|  | (−0.17) | (0.00) | (−0.06) | (−0.02) |
| Age = 40 | −0.00842 | −0.00387 | −0.00297* | −0.00263& |
|  | (−1.60) | (−1.39) | (−2.01) | (−1.96) |
| Age = 45 | −0.0121* | −0.00301 | −0.00340* | −0.00245& |
|  | (−2.29) | (−1.08) | (−2.30) | (−1.83) |
| Age = 50 | −0.0120* | −0.00253 | −0.00439** | −0.00320* |
|  | (−2.29) | (−0.91) | (−2.96) | (−2.38) |
| Age = 55 | −0.0131* | −0.00372 | −0.00414** | −0.00309* |
|  | (−2.49) | (−1.34) | (−2.80) | (−2.30) |
| Age = 60 | −0.0126* | −0.00162 | −0.00492*** | −0.00341* |
|  | (−2.39) | (−0.58) | (−3.32) | (−2.54) |
| Age = 65 | −0.0118* | −0.00441 | −0.00390** | −0.00339* |
|  | (−2.24) | (−1.58) | (−2.64) | (−2.53) |
| Age = 70 | 0.00478 | −0.0115*** | −0.00723*** | −0.00803*** |
|  | (0.91) | (−4.12) | (−4.88) | (−5.97) |
| Age = 75 | 0.00772 | −0.0114*** | −0.0102*** | −0.0106*** |
|  | (1.46) | (−4.05) | (−6.86) | (−7.86) |
| GDP per capita 5 years prior to start of 5-year migration estimate | −0.0000016*** | −0.0000016*** | −0.0000016*** | −0.0000016*** |
|  | (−8.54) | (−8.33) | (−8.29) | (−8.44) |
| TFR 15 years prior to migration estimate | 0.000801* | 0.000793* | 0.000780* | 0.000773* |
|  | (2.51) | (2.43) | (2.43) | (2.45) |
| Female | 0.000406 | 0.000406 | 0.000406 | 0.000406 |
|  | (1.57) | (1.55) | (1.57) | (1.59) |
| Year = 1990 | 0.00245*** | 0.00202*** | 0.00199*** | 0.00199*** |
|  | (4.31) | (4.03) | (4.04) | (4.08) |
| Year = 1995 | −0.00238*** | −0.00287*** | −0.00290*** | −0.00291*** |

**Table 5** (continued)

|  | (1)<br>Unweighted mean | (2)<br>Weighted mean | (3)<br>Unweighted variability | (4)<br>Weighted variability |
|---|---|---|---|---|
|  | (− 4.02) | (− 5.74) | (− 5.86) | (− 5.98) |
| Year = 2000 | − 0.00167** | − 0.00220*** | − 0.00224*** | − 0.00225*** |
|  | (− 2.73) | (− 4.32) | (− 4.49) | (− 4.59) |
| Year = 2005 | − 0.000668 | − 0.00147** | − 0.00154** | − 0.00155** |
|  | (− 0.90) | (− 2.80) | (− 2.99) | (− 3.16) |
| Year = 2010 | 0.000639 | − 0.000383 | − 0.000475 | − 0.000493 |
|  | (0.73) | (− 0.68) | (− 0.91) | (− 0.97) |
| Year = 2015 | 0.00192& | 0.000695 | 0.000577 | 0.000566 |
|  | (1.87) | (1.07) | (0.98) | (0.97) |
| Temp | − 0.00130 | − 0.0000672 | − 0.00000110 | − 0.000181 |
|  | (− 1.51) | (− 0.32) | (− 0.00) | (− 0.13) |
| Constant | 0.0324 | 0.00260 | 0.00147 | 0.00181 |
|  | (1.57) | (0.62) | (0.33) | (0.58) |
| Observations | 8919 | 8919 | 8919 | 8919 |
| Adjusted $R^2$ | 0.234 | 0.214 | 0.233 | 0.248 |

$t$ statistics in parentheses

& $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

**Table 6** Fixed effects estimates of changes in population-weighted rainfall and SD temperature on rural out-migration (source of marginal effect graphed in Fig. 4)

| | Age | Age × female | Age × rain | Age × female × rain | Age × temp | Age × female × temp |
|---|---|---|---|---|---|---|
| **Age and interactions with age** | | | | | | |
| Age = 5 | − 0.00807 | 0.000685 | 0.00205 | 0.0000242 | − 0.000771 | 0.000233 |
| | (− 0.48) | (0.03) | (0.94) | (0.01) | (− 0.63) | (0.13) |
| Age = 10 | 0.0000975 | 0.0101 | 0.00202 | − 0.00179 | − 0.00108 | 0.000444 |
| | (0.01) | (0.42) | (0.93) | (− 0.58) | (− 0.88) | (0.26) |
| Age = 15 | 0.0144 | 0.00831 | − 0.000239 | − 0.00231 | 0.00101 | 0.000240 |
| | (0.85) | (0.35) | (− 0.11) | (− 0.75) | (0.83) | (0.14) |
| Age = 20 | 0.0242 | − 0.0136 | − 0.00328 | 0.00113 | 0.00413*** | − 0.000930 |
| | (1.43) | (− 0.57) | (− 1.51) | (0.37) | (3.37) | (− 0.54) |
| Age = 25 | 0.0231 | − 0.0144 | − 0.00361 & | 0.00154 | 0.00192 | − 0.000155 |
| | (1.37) | (− 0.60) | (− 1.66) | (0.50) | (1.57) | (− 0.09) |
| Age = 30 | 0.00554 | − 0.0116 | − 0.000569 | 0.00114 | 0.000139 | 0.000284 |
| | (0.33) | (− 0.49) | (− 0.26) | (0.37) | (0.11) | (0.16) |
| Age = 35 | 0.000657 | − 0.0000181 | 0.00646 | 0.0000950 | 0.000457 | − 0.000361 |
| | (0.04) | (− 0.27) | (0.04) | (0.15) | (− 0.29) | (0.01) |
| Age = 40 | 0.00768 | 0.00209 | − 0.00107 | − 0.000906 | − 0.00116 | 0.000455 |
| | (0.46) | (0.09) | (− 0.49) | (− 0.29) | (− 0.95) | (0.26) |
| Age = 45 | 0.0227 | − 0.0208 | − 0.00333 | 0.00259 | − 0.00188 | 0.00124 |
| | (1.34) | (− 0.87) | (− 1.53) | (0.84) | (− 1.53) | (0.71) |
| Age = 50 | 0.0123 | − 0.0102 | − 0.00225 | 0.00149 | − 0.00127 | 0.000749 |
| | (0.73) | (− 0.43) | (− 1.03) | (0.48) | (− 1.03) | (0.43) |
| AGE = 55 | − 0.00909 | 0.0232 | 0.000451 | − 0.00263 | − 0.000671 | − 0.000581 |
| | (− 0.54) | (0.97) | (0.21) | (− 0.85) | (− 0.55) | (− 0.33) |
| Age = 60 | − | | 0.000188 | 0.0121 | − 0.00108 | − 0.000638 |
| | − | | 0.000851 | − 0.000705 | | |
| | (− 0.01) | (0.51) | (− 0.50) | (− 0.21) | (− 0.69) | (− 0.41) |
| Age = 65 | 0.00118 | 0.00512 | − 0.000804 | − 0.000383 | − 0.00131 | 0.000330 |
| | (0.07) | (0.21) | (− 0.37) | (− 0.12) | (− 1.07) | (0.19) |
| Age= 70 | 0.00651 | − 0.0214 | − 0.00182 | 0.00286 | − 0.000648 | 0.00104 |
| | (0.38) | (− 0.89) | (− 0.83) | (0.92) | (− 0.53) | (0.60) |
| Age = 75 | 0.00491 | − 0.0151 | − 0.00210 | 0.00224 | − 0.000509 | 0.000716 |
| | (0.29) | (− 0.63) | (− 0.95) | (0.72) | (− 0.41) | (0.41) |
| **Other variables** | | | | | | |
| Female | | | 0.00100 | | | |
| | | | (0.06) | | | |
| Change in mean rainfall | | | − 0.00222 | | | |
| | | | (− 0.86) | | | |
| Change in SD of temperature | | | 0.000231 | | | |

**Table 6** (continued)

| | Age | Age × female | Age × rain | Age × female × rain | Age × temp | Age × female × temp |
|---|---|---|---|---|---|---|
| | | | (0.13) | | | |
| Female × change in mean rainfall | | − | | 0.00000248 | | |
| (− 0.00) | | | | | | |
| Female × change in SD of temperature | | | 0.0000750 | | | |
| | | | (0.06) | | | |
| Other variables | | | | | | |
| GDP per capita 5 years prior to start of 5-year migration estimate | | | − | 0.00159*** | | |
| (− 8.47) | | | | | | |
| TFR 15 years prior to migration estimate | | | 0.000863** | | | |
| | | | (2.67) | | | |
| Year = 1990 | | | 0.00163** | | | |
| | | | (2.97) | | | |
| Year = 1995 | | | − | 0.00307*** | | |
| (− 6.10) | | | | | | |
| Year = 2000 | | | − | 0.00256*** | | |
| (− 4.73) | | | | | | |
| Year = 2005 | | | − 0.00163** | | | |
| | | | (− 3.18) | | | |
| Year = 2010 | | | − 0.000564 | | | |
| | | | (− 1.08) | | | |
| Year = 2015 | | | 0.000596 | | | |
| | | | (1.02) | | | |
| Constant | | | 0.0152 | | | |
| | | | (0.81) | | | |
| Observations | | | 8919 | | | |
| Adjusted $R^2$ | | | 0.249 | | | |

All columns are estimated in the same model, but compressed for readability. $t$ statistics in parentheses

$^\&p < 0.10$, $^{**}p < 0.01$, $^{***}p < 0.001$

**Table 7** Fixed effects estimates of changes in population-weighted rainfall and SD temperature on rural out-migration (source of marginal effect graphed in Figs. 5 and 6)

| | Age | Age × later period | Age × rain | Age × later period × rain | Age × temp | Age × later period × temp |
|---|---|---|---|---|---|---|
| Age and interactions with age | | | | | | |
| | | Age = 5 | 0.000546 | − 0.00517 | 0.000912 | 0.00114 |
| | − 0.00163 | − 0.000682 | | | | |
| | (0.05) | (− 0.35) | (0.58) | (0.54) | (− 1.51) | (− 0.46) |
| | | Age = 10 | 0.0143 | − 0.00489 | − 0.000367 | 0.00115 |
| | − 0.00153 | − 0.000350 | | | | |
| | (1.32) | (− 0.34) | (− 0.23) | (0.55) | (− 1.41) | (− 0.24) |
| | | Age = 15 | 0.0334** | − 0.00550 | − 0.00387* | 0.000824 |
| | 0.00165 | 0.00134 | | | | |
| | (3.07) | (− 0.38) | (− 2.45) | (0.39) | (1.53) | (0.91) |
| | | Age = 20 | 0.0233* | 0.00167 | − 0.00390* | − 0.000707 |
| | | | | 0.00573*** | 0.00248 & | |
| | (2.14) | (0.11) | (− 2.46) | (− 0.34) | (5.31) | (1.68) |
| | | Age = 25 | 0.00329 | 0.00203 | − 0.00130 | − 0.000724 |
| | | | | 0.00415*** | 0.00123 | |
| | (0.30) | (0.14) | (− 0.82) | (− 0.34) | (3.84) | (0.83) |
| | | Age = 30 | 0.00567 | − 0.00930 | − 0.000755 | 0.00116 |
| | 0.000552 | − 0.000232 | | | | |
| | (0.52) | (− 0.64) | (− 0.48) | (0.55) | (0.51) | (− 0.16) |
| | | Age = 35 | 0.00284 | − 0.0108 | − 0.000300 | 0.00139 |
| | − 0.000391 | − 0.000500 | | | | |
| | (0.26) | (− 0.74) | (− 0.19) | (0.66) | (− 0.36) | (− 0.34) |
| | | Age = 40 | 0.00552 | − 0.00942 | − 0.00116 | 0.00134 |
| | − 0.000213 | − 0.000894 | | | | |
| | (0.51) | (− 0.65) | (− 0.73) | (0.63) | (− 0.20) | (− 0.61) |
| | | Age = 45 | 0.00770 | − 0.000887 | − 0.00156 | 0.000261 |
| | − 0.000519 | − 0.00159 | | | | |
| | (0.71) | (− 0.06) | (− 0.98) | (0.12) | (− 0.48) | (− 1.08) |
| | | Age = 50 | 0.00723 | 0.00162 | − 0.00168 | 0.0000377 |
| | − 0.000480 | − 0.00165 | | | | |
| | (0.66) | (0.11) | (− 1.06) | (0.02) | (− 0.44) | (− 1.12) |
| | | Age = 55 | 0.00806 | − 0.00841 | − 0.00179 | 0.00152 |
| | − 0.000898 | − 0.00139 | | | | |
| | (0.74) | (− 0.58) | (− 1.13) | (0.72) | (− 0.83) | (− 0.94) |
| | | Age = 60 | 0.0127 | − 0.00308 | − 0.00253 | 0.000749 |
| | − 0.00126 | − 0.00163 | | | | |
| | (1.17) | (− 0.21) | (− 1.60) | (0.36) | (− 1.17) | (− 1.11) |
| | | Age = 65 | − 0.00340 | 0.00922 | − 0.000340 | − 0.000734 |
| | − 0.000146 | − 0.00244 & | | | | |

**Table 7** (continued)

| | Age | Age × later period | Age × rain | Age × later period × rain | Age × temp | Age × later period × temp |
|---|---|---|---|---|---|---|
| (−0.31) | (0.63) | (−0.22) | (−0.35) | (−0.13) | (−1.65) | |
| | | Age = 70 | −0.00266 | −0.0357* | −0.000834 | 0.00532* |
| | 0.000874 | 0.0000875 | | | | |
| (−0.24) | (−2.42) | (−0.52) | (2.49) | (0.81) | (0.06) | |
| | | Age = 75 | −0.000826 | −0.0314* | −0.00128 | 0.00436* |
| | 0.000686 | 0.000265 | | | | |
| (−0.07) | (−2.05) | (−0.75) | (1.97) | (0.63) | (0.18) | |

Other variables

| | |
|---|---|
| Later period | −0.0107 |
| | (−1.04) |
| Change in mean rainfall | −0.00254 |
| | (−1.42) |
| Change in SD of temperature | 0.00267& |
| | (1.77) |
| Later period × change in mean rainfall | 0.00150 |
| | (1.00) |
| Later period × change in SD of temperature | 0.000216 |
| | (0.21) |

Other variables

| | |
|---|---|
| GDP per capita 5 years prior to start of 5-year migration estimate | −0.00133*** |
| | (−7.42) |
| TFR 15 years prior to migration estimate | −0.000163 |
| | (−0.57) |
| Constant | 0.0152 |
| | (0.81) |
| Observations | 8919 |
| Adjusted $R^2$ | 0.250 |

All columns are estimated in the same model, but compressed for readability. $t$ statistics in parentheses

& $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

### Appendix 1. The CSRM approach to estimating age- and sex-specific rural-to-urban migration rates

Our estimates of net rural-to-urban migration by age and sex are published in full in Menashe-Oren and Stecklov (2017). Here we summarize the method.

An early version of the census survival ratio method (CSRM) was developed by Hamilton and Henderson (1944) and then extended by Preston (1979). It has been repeatedly applied in United Nations Population Division (UN 1980; UN 2001) analyses, including in their estimates of the share of urban growth that is driven by net rural to urban migration.

The key feature underlying the CSRM is that age- and sex-specific net migration rates can be estimated in contexts with relatively little or no migration data using a minimum of two points in time as long as the rural and urban sector populations are separately measured. Given these minimum data requirements, Preston (1979) showed how net rural to urban migration rates could be calculated for each age group and by sex. In addition, he carefully described the assumptions that make this approach possible.

Underlying the CSRM is the notion that a broad measure of survival for the population can be estimated across time using data from national level cohort survival calculations. These survivorship estimates are then adjusted based on assumptions about rural and urban mortality level differentials. Given the estimated survivorship predictions, differences between the predicted cohort size in each sector and the actual measured size can be calculated. This difference is the net rural to urban flow.

CSRM has two key limitations, widely acknowledged by those who use it. The main one is that the net migration estimates also include reclassification as areas are rezoned over time (Preston 1979; Moultrie et al. 2013). Estimates of reclassification have indicated that it may have accounted for as much as 25% of urban growth in parts of sub-Saharan Africa in the 1980s, though it is unclear whether this figure will have changed in the period we examine here (Beauchemin and Bocquier 2004; Chen et al. 1998).

The second limitation of the CSRM is that it typically ignores international migration, since there is little if any data available for the types of societies where CSRM is most useful. In contexts with high levels of net international migration and strong differentials by age, the estimated survivorship measures that underlie the CSRM therefore yields some bias in the net rural to urban migration estimates.

Here, following Menashe-Oren and Stecklov (2017), we use country-level assessments of urban and rural populations by age and sex (URPAS) across seven 5-year intervals over the 1980–2015 period (United Nations 2014b) for 41 countries in SSA.

### Appendix 2

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