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Putting trapped populations into place: Climate change and inter-district migration flows in Zambia

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Abstract

Research shows that the association between adverse climate conditions and human migration is heterogeneous. One reason for this heterogeneity is the differential vulnerability of *populations* to climate change. This includes highly vulnerable, “trapped” populations that are too poor to migrate given deep and persistent poverty, the financial costs of migrating, and the erosion of already fragile economic livelihoods under climate change. Another reason for this heterogeneity is the differential vulnerability of *places*. However, despite the growing list of studies showing that the climate-migration relationship clearly varies across places, there is surprisingly little research on the characteristics of places themselves that trap, or immobilize, populations. Accordingly, we provide the first account of the “holding power” of places in the association between adverse climate conditions and migration flows among 55 districts in Zambia in 2000 and 2010. Methodologically, we combine high resolution climate information with aggregated census micro data to estimate gravity models of inter-district migration flows. Results reveal that the association between adverse climate conditions and migration is positive only for wealthy migrant-sending districts. In contrast, poor districts are characterized by climate-related immobility. Yet, our findings show that access to migrant networks enables climate related mobility in the poorest districts, suggesting a viable pathway to overcome mobility constraints. Planners and policy makers need to recognize the holding power of places that can trap populations and develop programs to support *in situ* adaptation and to facilitate migration to avoid humanitarian emergencies.

Keywords

Climate change; migration; Zambia; trapped populations; holding power; migrant networks

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Compliance with Ethical Standards

The analyses described in this paper were performed using secondary data obtained from various publically available sources as outlined in the Data and Methods section.

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Introduction

In studies of the association between adverse climate conditions and human migration, questions are routinely raised about the presence of heterogeneous populations characterized by differential vulnerability to climate change (Gray and Bilsborrow 2013; Gray and Mueller 2012a; Henry et al. 2004; Mastrorillo et al. 2016; Thiede et al. 2016). One type of population that has received considerable attention in prior work consists of those most vulnerable to climate change who are “trapped” in place by factors that include poverty, the financial costs of migrating, and the threat that climate change will further undermine already fragile economic livelihoods (Black et al. 2011b; Foresight 2011; Gray and Mueller 2012b). From a policy perspective, determining the existence and characteristics of trapped populations is critical for targeted monitoring designed to anticipate and prevent large-scale humanitarian emergencies under climate change (Martin et al. 2014; Zickgraf et al. 2016).

In addition to variation across populations, another source of heterogeneity in the climate-migration relationship is the differential vulnerability of places to climate change (Cutter et al. 2008; Cutter et al. 2003). However, unlike trapped populations, there is surprisingly little research on the characteristics of places that trap, or immobilize, populations. Accordingly, in this paper, borrowing insights from migration research on the “holding power” of places (defined below) (Herting et al. 1997, p. 270), we examine the association between adverse climate conditions and inter-district migration flows in Zambia in 2000 and 2010. Using climate and census micro data aggregated to the district level (MPC 2015), and gravity models of migration flows (Mastrorillo et al. 2016), we show that the climate-migration relationship is positive only for economically advantaged (hereafter, wealthy) districts. In contrast, economically disadvantaged (hereafter, poor) districts are characterized by climate-related immobility. Yet, the negative association between adverse climate conditions and migration in the poorest districts is attenuated by access to migrant networks, suggesting a possible pathway to overcome mobility constraints. As our work highlights the various characteristics of places that both promote and offset climate-related immobility, policies and programs should be developed and implemented with these intersections in mind.

Background

While the impacts of climate change are increasingly being felt around the globe (IPCC 2014b), they are not experienced evenly due to the differential vulnerability of populations and places (Adger 2006; Cutter et al. 2003). With respect to the focus of this paper, this insight applies to the association between adverse climate conditions and human migration (Hunter et al. 2015; McLeman 2014), which is demonstrably *not* “monolithic and unidirectional” (Gray and Wise 2016, p. 556).

Differential vulnerability of populations: Trapped populations

Among those most vulnerable to climate change are populations that are actually or potentially “trapped” in place by deep and persistent poverty, the financial (to say nothing of the psychic) costs of migration, and the fact that climate change will further undermine already fragile economic livelihoods (Black et al. 2011b; Foresight 2011; Gray and Mueller 2012b). Trapped populations are therefore unable to pursue migration as a climate adaptation strategy. As a result, they are likely to be at the epicenter of humanitarian emergencies (e.g., famine and starvation) that could be avoided by migrating.

Given the policy importance of detecting trapped populations, it makes sense that studies of the climate-migration relationship routinely consider and test for the presence of heterogeneous populations, each characterized by differential risks to climate change, to identify specific groups, e.g., women or children, most susceptible to being trapped in place (Gray and Bilsborrow 2013; Gray and Mueller 2012a; Henry et al. 2004; Mastrorillo et al. 2016; Thiede et al. 2016). Information on the existence and characteristics of trapped populations can be used to inform targeted monitoring and policy interventions of two varieties (Martin et al. 2014; Zickgraf et al. 2016). First, recognizing that most people do not and prefer not to migrate (Findlay 2011), policy efforts might assist trapped populations in adapting to climate change *in situ* (i.e., in place) by, for example, providing resources to ease livelihood constraints (Scoones 1999). Alternatively, guided by the idea that migrant remittances help to ease livelihood constraints (Stark and Bloom 1985; Stark and Levhari 1982), policy efforts might be designed to reduce barriers to migration.

Differential vulnerability of places: The “holding power” of places

Just as populations are differentially vulnerable to climate change, so, too, are places (Cutter et al. 2008; Cutter et al. 2003). Places differ in their vulnerability to climate change based on their physical and human geography, with place vulnerability defined as “the intersection and interaction of both the social vulnerability and biophysical/technological vulnerability” (Cutter 1996:537). Given that migration is an inherently a spatial phenomenon (Roseman 1971), it is therefore not surprising that the climate-migration relationship is influenced by place-level and other “macro” factors (Black et al. 2011a; Hunter et al. 2015).

However, what *is* surprising is that research on the differential vulnerability of places in the climate-migration relationship has yet to develop an analogue (conceptual or empirical) to that of trapped populations. In other words, there is little research on the characteristics of places that trap, or immobilize, populations. From a theoretical perspective, this is a curious omission given that the “holding power” of places (Herting et al. 1997, pp. 270-272) is a well-established concept in migration research that is used to refer to the absence of migration, or population immobility (see also, DeWaard 2013). The holding power of places is theorized to be greatest (i.e., immobility is most pronounced) when places are externally distinct from one another *and* internally homogenous, two features that reflect a synthesis of ideas from neoclassical economic models of migration (e.g., wage gaps) and the new economics of migration (e.g., relative deprivation), respectively (Bodvarsson and Van den Berg 2013). With respect to the focus of this paper, one implication is that places characterized by concentrated poverty run the greatest risk of being immobility hotspots.

From a policy perspective, failing to consider the holding power of places is problematic for at least two reasons: First, most policies and intervention programs are implemented at the regional (versus population) level. Failure to identify regional characteristics that lead to immobility may prevents the detection and monitoring of climate vulnerability hotspots (Laczko and Aghazarm 2009; Preston et al. 2011). Second, ignorance regarding place-based differences impedes the identification of characteristics that might help overcome mobility constraints. Policies would benefit from a detailed knowledge regarding factors that facilitate mobility among the poorest sectors of society as an important climate change adaptation strategy (Black et al. 2011b).

In this paper, we provide the first account of the holding power of places in the association between adverse climate conditions and migration flows among 55 districts in Zambia in 2000 and 2010. We take Zambia as our case because it is among the poorest nations of the world (UNDP 2014). Climate change has started to undermine the livelihoods of subsistence farmers highly dependent on rain fed agriculture (Kanyanga et al. 2013). For the coming decades climate models predict an increasingly variable hotter and dryer climate (Niang et al. 2014), while at the same time the population is expected to double in size (Kanyanga et al. 2013). The joint impact of climate change and population pressure will likely lead to the rapid depletion of finite natural resources, leading to migration as a means to access new farm land and resources in frontier regions in the absence of *in-situ* adaptation options (see Online Resource S1 Study region). While anecdotal (qualitative) evidence for climate-related mobility in Zambia has recently emerged (Simatele and Simatele 2015), quantitative research has yet to investigate the climate-migration link. Accordingly, we combine high resolution climate information for a 50-year period (1961-2010) with nationally representative data on inter-district migration to investigate climate-related mobility in Zambia using gravity models. Our quantitative analysis is guided by two research questions:

First, motivated by the idea that trapped populations are unable to migrate due primarily to economic circumstances (Black et al. 2011b; Foresight 2011; Gray and Mueller 2012b), we ask the corresponding place-based question: *Does the climate-migration relationship in Zambia depend on the economic characteristics of migrant-sending districts?* Provided that poor districts are characterized by pronounced holding power, and thus immobility, we then consider the well-established idea that migrant networks can facilitate migration in the presence of economic constraints (Massey 1990; Massey and Garcia Espana 1987). Migrant networks help to reduce the costs and uncertainties associated with a move by providing information (e.g., about labor market conditions in destination areas) and resources (e.g., financial assistance) to assist with relocation and settlement process (Villarreal and Hamilton 2012). It is often assumed that migrant networks can operate as “migration corridors” strongly facilitating climate-related migration (Bardsley and Hugo 2010, p. 249; Hunter et al. 2013). Indeed, prior research in Zambia suggests that social networks in the destination are crucial for enabling a move (Simatele and Simatele 2015). We therefore ask: *Do migrant networks attenuate climate-related immobility in poor districts?*

Data and methods

Data

To investigate the influence of adverse climate conditions on inter-district migration flows in Zambia, we make use of harmonized census data, originating from IPUMS-International (MPC 2015) and available through the Terra Populus (TerraPop) data extract system (Kugler et al. 2015; MPC 2013; Nawrotzki et al. 2016b). We obtained flat-weighted (unweighted) 10% extracts from 2000 and 2010 Zambian censuses. As a crucial component for this study, TerraPop allows attaching high resolution climate data. Climate information is available as monthly temperature and precipitation grids (0.5 × 0.5 degrees spatial resolution), sourced from the University of East Anglia's Climate Research Unit (CRU) (Harris et al. 2014) and merged with the census microdata via location-based integration (Nawrotzki et al. 2016b).

For this study, we employ gravity models of migration flows (see details below), which require constructing a file in which each row represents a unique migration flow between a given district of residence one year prior to the census (hereafter, *origin* district) and a given district of residence during the census year (hereafter, *destination* district). Each of n_o=55 origin districts is connected to each of n_d=54 destination districts by migration (for $o \neq d$), resulting in n_{od}=2,970 inter-district migration flows each year (n_{odt}=5,940 inter-district migration flows over the two census years t) (for geographical information see Online Resource S1 Study region).

Migration measure

Our dependent variable is a count of the number of persons that migrated from origin district o to destination district d during the year leading up to the census. An average of 85 persons (range 0 to 9,450) migrated between districts, with a larger number of moves recorded in 2000 (sample mean [μ] = 103) compared to 2010 (μ = 68). In our sample, a total of 305,020 (3.19 %) and 201,010 (1.67 %) persons migrated between districts in 2000 and 2010, respectively (see Online Resource Fig. S2 for maps of out, in, and net migration). Following prior research (Mastrorillo et al. 2016), we restricted our migration measure to working age (15-64 years) adults as the most mobile population in our sample. For a visual representation of our migration data, we aggregated (summed) inter-district migration flows in the 2010 census to the province level, and constructed a circular plot of inter- and intra-province migration flows (see Online Resource Fig. S3). The circular plot of bilateral flows reveals largest outmigration from the Lusaka and Copperbelt provinces but only little migration from Luapula, Western, and North Western provinces.

Primary predictors

Climate variables—We measure three dimensions of adverse climate conditions: cumulative exposure, spell length, and shock magnitude. The Intergovernmental Panel on Climate Change (IPCC) defines *climate change* as a change in the state of the climate that can be identified by "changes in the mean and/or the variability" for an extended period of time (IPCC 2014a. 120). In line with this definition, our climate variables measure changes in temperature and precipitation relative to a 30-year climate normal period (1961-1990) that has been recommended by the World Meteorological Organization (WMO) as the reference period to detect climate change and variability (Arguez and Vose 2011).

Following prior research (IPCC 2012; Nawrotzki and Bakhtsiyarava 2016; Nawrotzki et al. 2016b), we measure the cumulative exposure to climate shocks in each district as the number of months during the observation period in which the maximum monthly temperature was more than one standard deviation (SD) above (heat months), and precipitation was more than one SD below (drought months), the long-term (1961-1990) mean. The observation period was defined as the year prior to the census, plus one additional year to account for delayed migration responses (Nawrotzki and DeWaard 2016). All of

Zambia experiences a unimodal rainfall pattern, with a single rainy season (equal to the growing season) extending from October to April (Mulenga et al. 2016). We therefore restricted our climate variables to the growing season months, resulting in a total of 14 observation months (7 months in each census year).

The concentration of adverse climatic conditions in a short time period (e.g., heat spell or heat wave) may be more detrimental for agricultural production than the absolute occurrence of evenly-spread climate extremes (cf., Schlenker and Roberts 2006). Following this logic, we constructed a measure of the duration of adverse heat and drought events, or spells, by computing the maximum number of consecutive heat or drought months using a threshold of 1 SD, as outlined above (Nawrotzki et al. 2016a, supplements S6). Spells were permitted to span the growing season months between the two consecutive observation years.

Finally, to capture the magnitude of the average climate shock, we followed prior work (Dillon et al. 2011; Mastrorillo et al. 2016) and computed the average strength of monthly deviations from the long-term (1961-1990) mean. These measures were computed as the monthly temperature or precipitation in each district, minus the long-term monthly district mean, divided by the long-term district standard deviation. Before computing the 2-year average, we replaced negative z-scores with zeros to capture unidirectional climate effects (see Mastrorillo et al. 2016).

The different climate variables show largely similar patterns (Fig. 1). Heat and drought anomalies are strongest in the Northeastern and Southern parts of the country. Districts that experienced the strongest climate anomalies are those with historically temperate conditions of low temperatures and moderate rainfall (see Online Resource Fig. S4).

Wealth—To answer our first research question, we constructed a wealth index for each district based on the possession of various assets. Such indices are useful proxies of wealth in developing countries where monetary income is difficult to measure because many individuals are self-employed or work in informal settings (e.g., home production), are involved in seasonal and temporary labor arrangements, or obtain payment in non-monetary form (Montgomery et al. 2000; Nawrotzki et al. 2012). Following prior work (Hunter et al. 2014; Mberu 2006; Nawrotzki et al. 2013), we constructed a wealth index (Cronbach’s alpha = 0.904) based on 7 variables measuring housing quality (floor type), asset possession (ownership of refrigerator, TV set), and service and infrastructure access (access to electricity, access to piped water, type of cooking fuel, type of sewage system). The wealth index was computed at the household level using census data and subsequently aggregated (mean) to the district level. While most of Zambia is poor, wealth is concentrated in a few central districts in the Copperbelt province (Fig. 2a).

Migrant networks—To approximate access to migrant networks at the district level, prior research frequently uses the percentage of adults in the community with migration experience, known as the migration-prevalence ratio (Fussell and Massey 2004). In line with prior work (Villarreal and Hamilton 2012), we computed the proportion of adults (age≥15 years) with inter-district migration experience for each district during the prior census round. We use this measure as a place-level indicator of access to migrant networks. Access to migrant networks is spatially concentrated in the center of Zambia, and is strongest in Lusaka, Central, and Copperbelt provinces (Fig. 2b).

Control variables

To account for various sociodemographic factors known to influence migration patterns (White and Lindstrom 2006), our models control for the percentage of males, mean age, the percentage of the adult population married, and population size in both origin and destination districts. An important feature of gravity models, we also control for spatial relationships using a measure of the Euclidean distance between origin and destination districts, as well as an indicator of district contiguity. Details regarding the construction of and summary statistics for the control variables can be found in the Online Resource (see S2 Control variable construction and Table S2).

Models

We model inter-district migration flows between each pair of origin and destination districts using gravity models (Cohen et al. 2008; Greenwood 1997; Karemera et al. 2000; Lewer and Van den Berg 2008; Zipf 1946). These models have recently emerged as useful tools for studying climate-migration dynamics at the aggregate level (Abel and Muttarak 2016; Beine and Parsons 2015; Garcia et al. 2015; Mastrorillo et al. 2016). Because our dependent variable is a count of migrants that is characterized by many null, several low, and few high values, a Poisson distribution is commonly used for these types of models (Henry et al. 2003; Mastrorillo et al. 2016). However, preliminary tests (Harrison 2014) revealed substantial overdispersion in our outcome variable (variance > mean), which can bias standard errors and risk Type I errors (Zuur et al. 2009). As such, we employ negative binomial models, which are a generalization of the conventional Poisson model that explicitly account for overdispersion by including a dispersion parameter *theta* (Allison 2009; Cameron and Trivedi 2013). Our negative binomial gravity (NBG) model can be formally written as follows (Eq. 1):

$$\ln\left(mig_{odt}\right)=\beta_0+\beta_1\left(heat_{ot}\right)+\beta_2\left(drought_{ot}\right)+\beta_3\left(wealth_{ot}\right)+\beta_4\left(wealth_{dt}\right) \quad (1)$$

$$+\beta_5\left(mignet_{ot}\right)+\beta_6\left(mignet_{dt}\right)+\sum_{i}^{n}\beta_i\left(x_y\right)+u_o+v_d+\tau_t+\theta_{odt}$$

$$o=1,\ldots,n_o;\, d=1,\ldots,n_d$$

Our NBG model predicts the log count of migrants (*mig*) between each pair of origin (*o*) and destination (*d*) districts in a given census year (*t*). The parameter β_0 represents the conventional intercept, while the coefficients β_1 and β_2 show the effects of heat and drought on the number of inter-district moves, respectively. In this study, we focus on adverse climate conditions as "push" factors for migration from origin districts, and therefore include heat and drought measures only at the origin (for an investigation of climate as destination pull factor see Online Resource S4 Sensitivity analysis). We also estimate the effects ($\beta_{3\text{-}6}$) of wealth and migrant networks as origin push (ot) and destination pull (dt) factors. In addition, our NBG model controls for the effects (β_i) of several time-varying socioeconomic and geographic district characteristics (x_y). The parameters u_o and v_d represent origin and destination fixed effects, respectively, which account for the nested data structure and unobserved spatial heterogeneity across districts due to structural differences across origins and destinations (e.g., baseline climate, agricultural dependence, infrastructure, etc.). An indicator variable of the census year (τ_t) is included as a time fixed effect, and errors were clustered at the dyadic level (od) following Mastrorillo et al. (2016). Finally, the dispersion parameter *theta* (θ_{odt}) accounts for the overdispersion of the outcome variable. Information on the software used to construct the variables, estimate the models, and graph the results is provided in the Online Resource (S3 Software).

Results and Discussion

Socioeconomic determinants of migration

As a unique feature of our NBG model, we estimate the influence of origin push and destination pull factors on inter-district migration in Zambia (Table 1). All models account for shared origin-destination factors, including Euclidian distance, contiguity, and year fixed effects. Model 1 includes only origin push covariates. Model 2 includes only destination pull covariates. Model 3 is the fully adjusted baseline model that simultaneously accounts for origin push and destination pull factors. Low values on the Akaike Information Criterion (AIC) (Akaike 1974; Burnham and Anderson 2002, 2004) suggest superior model fit of the fully adjusted Model 3 relative to Models 1 and 2.

In line with prior research (Garcia et al. 2015; Henry et al. 2003), we find positive effects for origin and destination population size on migration. While more populated origin districts contain a larger pool of potential migrants, people tend to migrate to more populated areas (Cohen et al. 2008). Also consistent with previous research, the distance between origin and destination districts is negatively associated with migration, which is consistent with the idea that migrants typically prefer to move short distances given the costs of relocation (Findlay 2011). Relatedly, we observe larger migration flows between contiguous districts (Henry et al. 2003). Prior research shows that these core variables capture the majority of variation in internal migration flows in Africa (Garcia et al. 2015).

In addition to these core variables, our models control for the gender, age, and marital compositions of origin and destination districts. In African countries males are usually more mobile than females (Bakewell 2009; Tienda and Booth 1991). Accordingly, we find a positive association between the percentage of males in the origin district and inter-district migration. While an increase in the average age in the origin district reduces inter-district migration, it serves as a pull factor in destination districts. This observation is in line with a general demographic pattern of increased mobility among younger ages (Rogers and Castro 1981). Consistent with prior research (Abu et al. 2014; Riosmena 2009), we find no difference in migration by the marital composition of origin or destination districts. Inter-district migration flows tend to be larger to wealthier destination districts, in line with neoclassical economic theories of migration (Massey et al. 1993; Todaro 1969). Finally, access to migrant networks in origin districts is associated with larger inter-district migration flows. Networks help to offset the costs and uncertainties associated with a move through the provision of information regarding the relocation process as well as information on the housing and job market in the destination (Simatele and Simatele 2015; Villarreal and Hamilton 2012). The directions of these effects are in line with prior work and theoretical assumptions, thereby lending credibility to the baseline model.

The “holding power” of places

Toward answering our first research question (*Does the climate-migration relationship in Zambia depend on the economic characteristics of migrant-sending districts*), we added climate variables to the fully adjusted NBG model, and subsequently examined the interaction between each climate measure and wealth in origin districts (Table 2, Panel A).

In a country like Zambia where the majority of people live below the poverty line (Chapoto and Zulu-Mbata 2016; Kanyanga et al. 2013), most people reside at the very edge of subsistence. Economic livelihoods are heavily reliant on maize production, a highly climate sensitive livelihood activity (Lobell and Field 2007; Lobell et al. 2014). Under such conditions, even relatively small climate shocks may undermine peoples’ livelihoods and reduce the monetary base necessary to finance migration as a climate adaptation strategy (Foresight 2011). Given the confluence of high dependence on climate-sensitive production and high poverty rates throughout the country, it is not unlikely that large segments of society reside in a chronic state of immobility.

Consistent with this idea, we find no significant climate effects on inter-district migration flows (Table 2, Panel A, Additive climate effects). Only heat spell length reached marginal significance ($p<0.1$), and the direction of the coefficient is negative ($\beta = -0.06$), providing suggestive evidence that inter-district migration flows are smaller under increasing exposure to temperature shocks. Sensitivity analyses (see Online Resource S4) provide additional evidence that the lack of a significant relationship emerges (with few exceptions) regardless of migrant characteristics (e.g., gender, age, education, ethnicity), the type of model used (e.g., fixed vs. random effects), and cannot be attributed to influential cases or the time period used to construct the climate variables.

While nonsignificant climate effects provide an initial clue about the holding power of places, a closer look at the actual characteristics of places that trap, or immobilize, populations is necessary. Just as trapped populations are unable to migrate due primarily to economic circumstances, we examine the role of wealth in origin districts in moderating the climate-migration relationship (Table 2, Panel A, Interactive climate effects). We find significant positive interactions for wealth in origin districts and cumulative exposure to drought ($\beta = 0.02$, $p<0.05$), as well as drought magnitude ($\beta = 0.15$, $p<0.05$). A one unit increase in wealth increases drought-related migration by 2% ((exp(0.02)-1)*100). While an increase in cumulative drought exposure is associated with reductions in inter-district migration flows from very poor (10 & 30%ile) and moderately poor (50 & 70%ile) districts, it is associated with an increase in migration flows from the wealthiest districts (85 & 95%ile) (Fig. 3, Panel A (b)). This positive relationship between a decline in precipitation and internal migration has been observed for several other African countries including Burkina Faso (Henry et al. 2004), Mali (Findley 1994), and South Africa (Mastrorillo et al. 2016). Thus, consistent with prior research, showing that economically marginalized *populations* in Africa are less likely to migrate (Hunter et al. 2014), our results demonstrate that the climate-migration relationship in Zambia also depends on the economic characteristics of *places* in the form of origin districts.

The attenuating power of migrant networks

Given that the poorest districts are characterized by climate-related immobility, and thus holding power, we turn to answer our second research question (*Do migrant networks attenuate climate-related immobility in poor districts?*). To answer this question, we tested for the presence of three-way interactions between climate factors, wealth, and migration networks (Table 2, Panel B). Given that migration flows follow well-defined channels, or “migration corridors” (Adamo and de Sherbinin 2011; Bardsley and Hugo 2010), we consider the role of migrant networks in both origin and destination districts.

The results reveal significant three-way interactions for migrant networks in destination districts (Table 2, Panel B), highlighting the importance of social ties to the receiving region (Simatele and Simatele 2015). While we observe only one significant three-way interaction for heat (spell length), all three-way interactions for drought (shock exposure, spell length, shock magnitude) are significant. The negative sign of the coefficients indicates that the positive effect of migrant networks in destination districts (see Online Resource Table S9) is particularly important for economically disadvantaged districts. People residing in the poorest districts with little to moderate access to migrant networks in destination districts (10-50 %ile) are largely immobile in the presence of drought and heat exposure (Fig. 3, Panel B). In contrast, migration flows increase with access to dense migrant networks in destination districts (Fig. 3, Panel B (c) & (d)). In sum, the results from the three-way interactions show that access to dense migrant networks in destination districts can help alleviate immobility constraints experienced in the poorest districts in Zambia.

Summary and conclusions

The association between adverse climate conditions and human migration depends on the differential vulnerability of populations *and* places (Adger 2006; Cutter et al. 2003; Hunter et al. 2015; McLeman 2014). In this study, we went beyond the important and increasingly well-documented phenomenon of “trapped populations”, comprised of those most vulnerable to climate change (Black et al. 2011b; Foresight 2011; Gray and Mueller 2012b), to consider the characteristics of places that trap, or immobilize, populations in the presence of adverse climate conditions. To do so, we began by suggesting that the concept of the “holding power” of places (Herting et al. 1997) provides a useful location-based analogue to that of trapped populations. Using climate and census micro data aggregated to the level of Zambian districts in 2000 and 2010, and gravity models of migration flows, we showed that economically disadvantaged districts are characterized by climate-related immobility, which, importantly, is offset by dense migrant networks in destination districts. Our work thus simultaneously highlights the need for planners and policy makers to consider the characteristics of places that trap or immobilize populations and those that offset the holding power of places, thereby rendering migration a viable climate adaptation strategy.

Keeping a few limitations in mind (see S6 Limitations), this study has important policy implications. Global climate models suggest that during the 21st century the countries of Southern Africa will experience an increase in temperature above the global mean as well as a general drying of the region (James and Washington 2013; Niang et al. 2014). These trends will be accompanied by an increase in climate extremes, such as heat waves and droughts (Orlowsky and Seneviratne 2012; Sillmann and Roeckner 2008). At the same time population projections anticipate dramatic increases in the Zambian population, with a doubling by 2050 (Kanyanga et al. 2013). The combined impact of population growth and adverse climate change and variability will put increasing pressure on limited natural resources, which could be alleviated through a higher volume of internal population distribution via migration to less populated, less climate affected areas. Migration is therefore one approach to enhance livelihoods and build climate change resilience (Foresight 2011).

Unfortunately, our results suggest that climate-related immobility is pronounced in the most economically disadvantaged places in Zambia. Policies and programs should therefore be designed to facilitate migration, assist with *in situ* adaptation, and reduce climate vulnerability.

First, in the face of insufficient *in situ* adaptation options, migration to “greener pastures” may constitute the best climate change adaptation option available. As such, government agencies and humanitarian NGOs should encourage, assist, and manage climate-related relocation. Specifically, migration should be encouraged away from climate impacted regions such as Southern province (Simatele and Simatele 2015) to regions that have experienced relatively little climate change in the central region of Zambia (see Fig. 1), for which crop models predict only a small decline and in some instances even an increase in maize yield (Kanyanga et al. 2013).

Second, given the extent of marginalization and poverty in Zambia, policies and programs should be designed to provide *in situ* livelihood assistance, especially in the poorest districts. Assistance may take the form of disseminating information on various adaptation options and the provision of credit that would allow smallholder farmers to finance the implementation of adaptation strategies (Kanyanga et al. 2013). For example, the Zambian government might remove subsidies on crops such as maize that do not perform well under climate change and promote the planting of sorghum and millet as more drought and heat tolerant crops (Jain 2007; Thurlow et al. 2012).

Finally, the dissemination of climate forecast information may reduce climate vulnerability and help prevent adverse livelihood impacts on specific populations and in specific places in the first place (Simatele and Simatele 2015). This could involve expanding and strengthening Zambia’s radio-Internet system (RANET), which enables community radio stations to access satellite-based climate information and broadcast it in local languages (Kanyanga et al. 2013).

In conclusion, our study highlights an important point: Adverse climate conditions on the African continent may not spawn migration. Immobility, however, is problematic and may lead to ever-deeper cycles of poverty, vulnerability, and exposure to adverse climate impacts, putting trapped populations at risk of humanitarian emergencies (e.g., famines, starvation). Policies and programs that explicitly consider the holding power of places are needed to anticipate and prevent large-scale humanitarian emergencies under climate change, both now and in the future.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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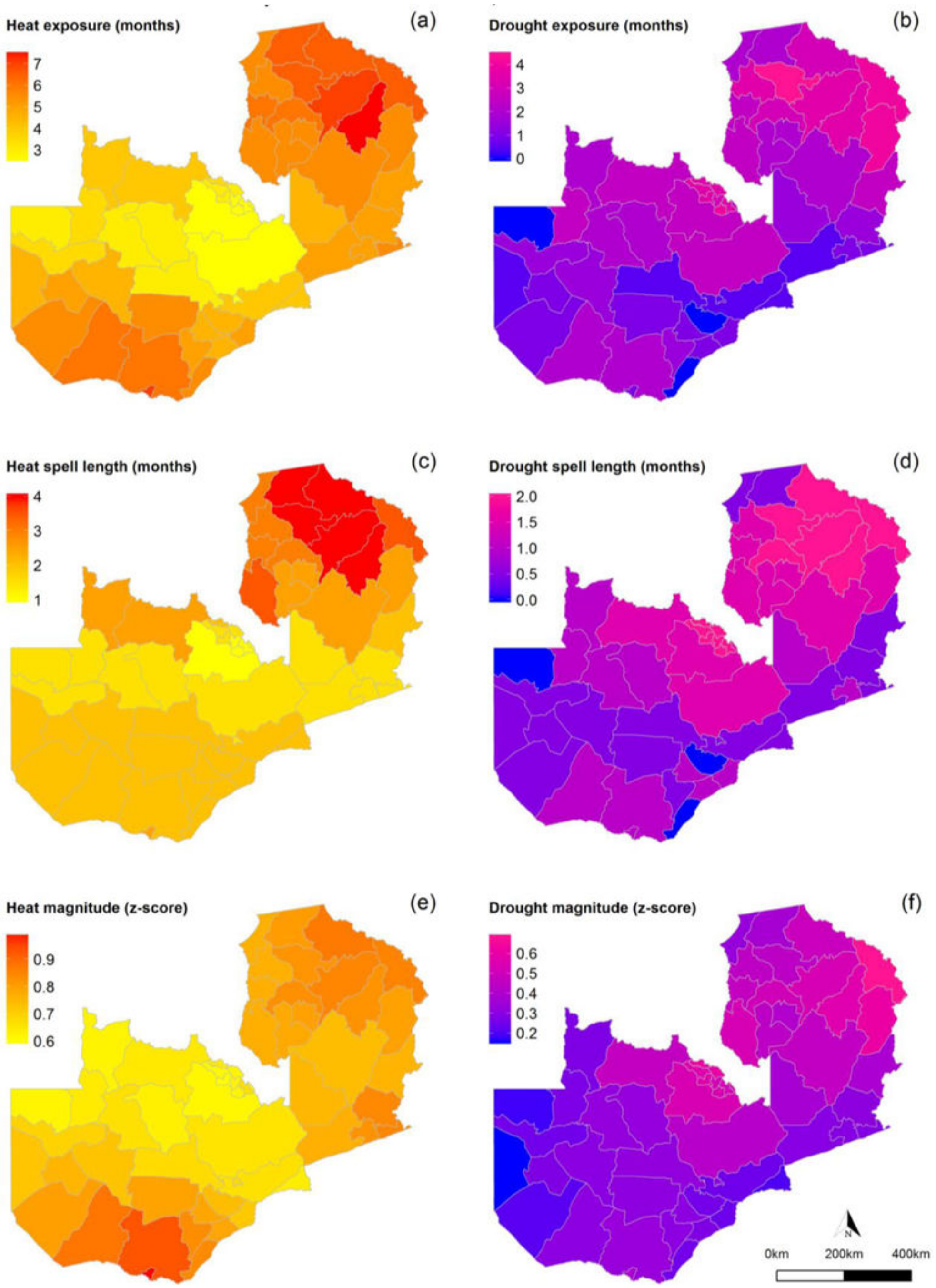


Fig. 1. Patterns of climate variability across districts in Zambia, 2000 and 2010

Notes: Values reflect average climate variability during growing season months observed for two years leading up to the 2000 and 2010 censuses.

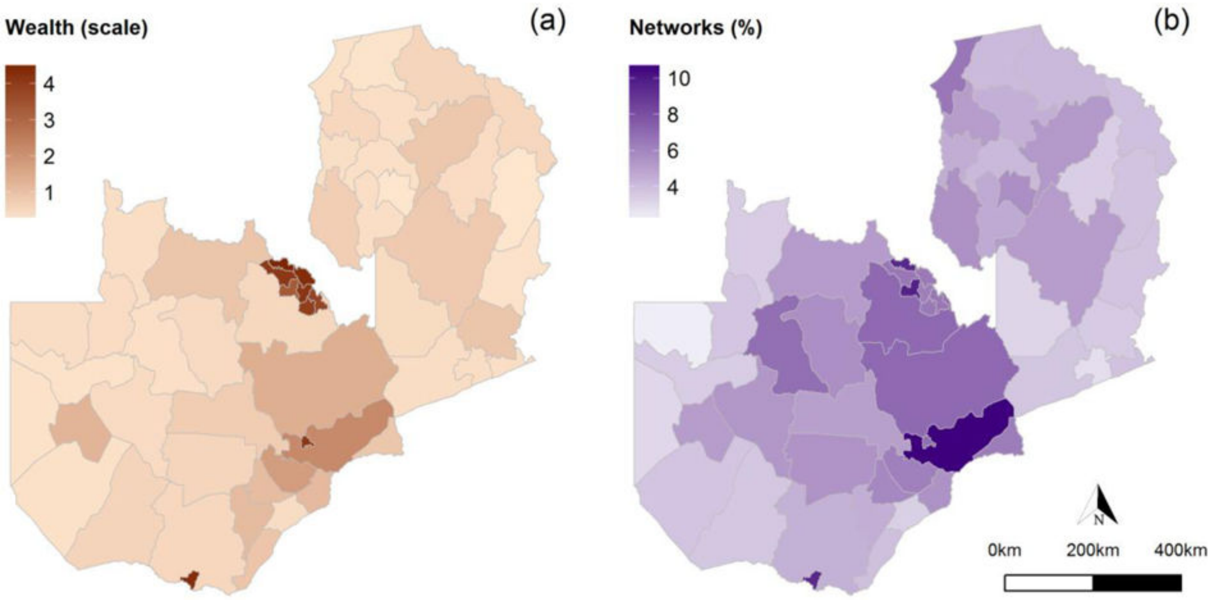
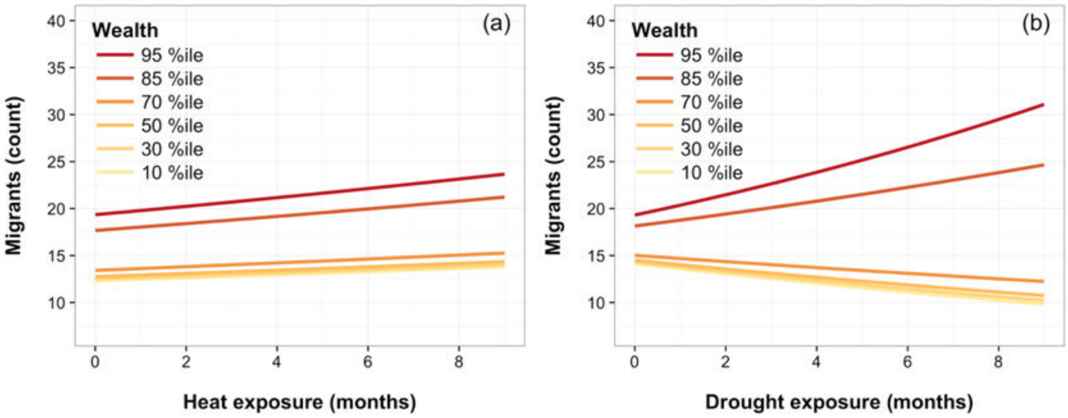


Fig. 2. Spatial distribution of wealth and migrant networks across districts in Zambia, 2000 and 2010

Notes: Wealth reflects average conditions across 2000 and 2010 censuses; Migrant networks, measured as % of adults with inter-district migration experience during the prior census year.

Panel A: 2-way interactions of climate x wealth



Panel B: 3-way interactions of climate x networks for the *poorest* districts (10 %ile)

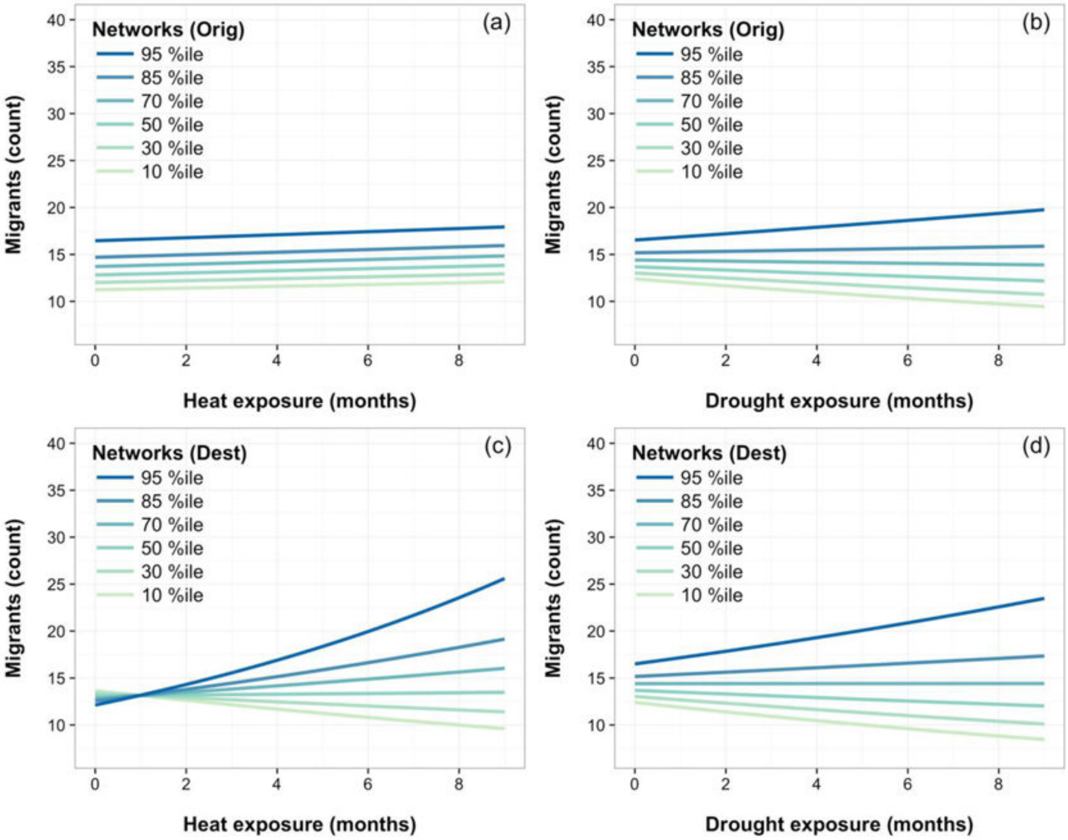


Fig. 3. Interactions between climate, wealth, and migrant networks predicting inter-district migration in Zambia, 2000 and 2010

Notes: Predictions generated using mean values for all variables but those in the interactions.

Table 1

Origin push and destination pull effects on inter-district migration flows in Zambia, 2000 and 2010

	Model 1		Model 2		Model 3	
	Push covariates only		Pull covariates only		Push and Pull covariates	
	b	**sig.**	**b**	**sig.**	**b**	**sig.**
Intercept	−5.13		−10.09	*	−21.85	***
Year 2010	−0.65	***	−0.73	***	−0.92	***
Distance	−1.80	***	−1.80	***	−1.80	***
Contiguity	0.60	***	0.61	***	0.61	***
Population (Orig)	0.66	*			0.66	*
Male (Orig) [a]	1.27	*			1.13	*
Age (Orig) [a]	−2.09	***			−1.92	***
Married (Orig) [a]	0.09				0.10	
Wealth (Orig)	0.14				0.21	
Networks (Orig) [a]	0.59	*			0.61	*
Population (Dest)			0.90	**	0.94	***
Male (Dest) [a]			−0.05		−0.07	
Age (Dest) [a]			1.49	***	1.26	**
Married (Dest) [a]			0.16		0.20	
Wealth (Dest)			0.65	*	0.62	*
Networks (Dest) [a]			0.11		0.12	
Model statistics						
Theta	1.11		1.11		1.12	
Pseudo R^2	0.75		0.75		0.76	
AIC	22,703		22,717		22,692	
N	5,940		5,940		5,940	

Notes: Orig = origin push factors; Dest = destination pull factors; The intercept, time dummy, and distance and contiguity measures constitute dyadic (Orig-Dest) variables; Population and distance variables were log transformed in line with prior research (Cohen et al. 2008);

[a] Coefficients reflect an incremental change of 10 units;

[+] p<0.1;

* $p<0.05$;

** $p<0.01$;

*** $p<0.001$

Table 2

Effects of adverse climate conditions on inter-district migration flows in Zambia, 2000 and 2010

Panel A: Additive effects and two-way interactions between climate and wealth

	Model set 1		Model set 2		Model set 3	
	Shock exposure		Spell length		Shock magnitude	
	b	sig.	b	sig.	b	sig.
Additive climate effects						
Heat	0.01		−0.06	+	0.07	
Drought	−0.02		−0.03		−0.18	
AIC	22,693		22,692		22,694	
Interactive climate effects						
Heat	0.01		−0.04		0.09	
x Wealth	0.00		0.04		0.03	
Drought	−0.02		−0.01		−0.18	
x Wealth	0.02	*	0.02		0.15	*
AIC	22,692		22,693		22,694	

Panel B: Three-way interactions between climate, wealth, and migrant networks

	Model set 1		Model set 2		Model set 3	
	Shock exposure		Spell length		Shock magnitude	
	b	sig.	b	sig.	b	sig.
Heat	0.00		−0.05		0.02	
x Wealth	−0.01		0.02		−0.10	
x Networks (Orig)	0.08		0.03		2.01	
x Networks (Dest)	−0.04		−0.17	*	0.34	
Drought	−0.01		0.01		−0.38	+
x Wealth	0.00		−0.02		−0.05	
x Networks (Orig)	−0.02		−0.01		0.12	
x Networks (Dest)	−0.07	**	−0.12	**	−0.56	***
AIC	22,628		22,620		22,636	

Notes: Models control for all origin push and destination pull covariates; Climate measures and wealth included at origin; Migrant networks coefficients reflect incremental change of 10 units; variables used in the interactions were grand mean centered; Orig = origin push factors; Dest = destination pull factors; only interaction components relevant to our research questions are shown (see S9 for a table containing the full set of interaction components);

[+] p<0.1;

[*] p<0.05;

[**] p<0.01;

[***] p<0.001