Environmental Migration as an Adaptation Strategy in sub-Saharan Africa[1]

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Abstract

We investigate the role of environmental migration as a possible adaptation to local environmental changes in sub-Saharan African countries. We proxy changes to the local environment by weather anomalies. Our findings, based on cross-country panel data for sub-Saharan Africa, indicate that weather anomalies increased internal and international migration. We also find that the environmental-induced increase in urbanization constitutes an attraction force for international migration, which softens the impact of weather anomalies on international migration. We estimate that temperature and rainfall anomalies caused a yearly displacement of 128'000 people in net terms during the period 1960-2000. Future weather changes could, on average, lead to an additional annual displacement of 11.8 million people by the end of the 21st century. Given its relatively low share in world emissions, mitigation actions are not a useful policy tool for sub-Saharan Africa. Rather, adaptation strategies should be promoted, like spatial mobility from rural to urban centers or sectoral mobility from agricultural to manufacturing activities. Such strategies should be designed in a way as to prevent negative consequences of mass migration following further environmental changes, like the spread of diseases or conflicts following movements to areas with already high population densities.

1 Introduction

The amount of people forced to leave their homes due to changes in local weather conditions[2] is believed to be everything else but negligible. Estimates range from an annual displacement of 15 million environmental refugees[3] during the 70s (El-Hinnawi, 1985) to 25 million for the sole year of 1995, of which 18 million originate from Africa (Myers, 1996). Increasing risks are predicted for the future, with a sea level rise of one meter potentially producing between 50 million (Jacobson, 1988) to 200 million environmental migrants (Myers, 1996). As reviewed by Piguet et al. (2011), these authors were seeking to raise awareness surrounding the potential impact of climate change on international migration. However, these estimates lack a robust empirical framework and are mostly extrapolations based on the amount of people living in affected, or potentially affected, regions. In its 2010 World Development Report on *Development and Climate Change*, the World Bank (2010, pp.108-109) notes that these “estimates are based on broad assessments of people exposed to increasing risks rather than analyzes of whether exposure will lead them to migrate.” Thus, despite the comprehensive overview of the Intergovernmental Panel on Climate Change (IPCC) fourth report, the lack of robust evidence regarding the relationship between migration and weather anomalies is unfortunate and summarized in Boko et al. (2007, p.450):

> ``Negative impacts of climate change could create a new set of refugees, who may migrate into new settlements, seek new livelihoods and place additional demands on infrastructure (Myers, 2002; McLeman and Smit, 2004). A variety of migration patterns could thus emerge, e.g., repetitive migrants (as part of ongoing adaptation to climate change) and short-term shock migrants (responding to a particular climate event). However, few detailed assessments of such impacts using climate as a driving factor have been undertaken for Africa."

The article, thus, has three broad aims. One, we show that there exists a small but increasing literature that tries to empirically estimate whether environmental reasons drive migration. This literature we

[2] We try to avoid the commonly used term `climate change' when discussing changes in local weather conditions. We do not have enough historical observations to conclude that weather anomalies, annual changes in weather from the long-term mean adjusted for local conditions, represents actual climate change or is simply a short-term phenomenon.

[3] The term ‘environmental refugee’ is itself under discussion. The distinction between refugee and migrant is an important policy debate, notably in terms of assistance and protection, see Black (2001), McGregor (1993), Kibreab (1997) or Suhrke (1994). In the rest of the paper, the term ‘environmental migrant’ will be used. In the data, the people crossing a border as a result of environmental damage would not be considered as refugees given the mandate to the UNHCR by the 51 Convention of Geneva, but they would be counted as migrants in national statistics.

review in Section 2. The broad consensus is that, especially for sub-Saharan Africa, environmental reasons have driven human migration in several cases. The main environmental push factors seem to be weather anomalies. These weather anomalies come in various forms, and cover anything from heat waves to flood. These articles then study either rural-urban or international migration, but never both in a unified framework.

Two, we shall argue that rural-urban and national-international migration are both intimately linked and ought to be analyzed simultaneously. We, therefore, developed a theoretical model that allows us to study the relationship between environmental push factors, rural-urban and international migration. The model shows the importance of the endogeneities in wages and urbanization. We present the outline of this theoretical model in Section 3.

Three, in Section 4 we collected a new cross-country panel dataset in order to study whether the theoretical results hold in practice. Our focus here is on Africa for several reasons. Inhabitants of most sub-Saharan countries already live on the brink of starvation; with often more than 60 percent of people living below the poverty line (see UN Human Development Report 2007/2008). For example, in 2004 around 800 million people were at risk of hunger (FAO 2004) leading to around four million deaths annually, around half of those in sub-Saharan Africa. Since many African countries rely heavily on agricultural production (in several countries up to 90% of the population work in the agricultural sector, see FAO 2004), even small changes in the weather conditions can have significant impacts on peoples' chances of survival. Given several scenarios provided by the IPCC (2007) that predict increases in temperature and declines in rainfall for most of sub-Saharan Africa, the number of deaths could easily double in the near future (Warren et al., 2006). Thus, from a policy perspective, sub-Saharan Africa is an extremely important and vulnerable region. Studying where these vulnerabilities come from, pin-pointing estimates of the number of environmental migrants and suggesting those countries where one would expect to see extensive environmental migration in the future is a prerequisite for successful preventive policy action.

Our results are as follows. Guided by the theoretical model, we study the economic geography channel of weather anomalies on wages and urbanization, both of which the theoretical model predicts to be the main variables that drive international migration decisions. We find that weather anomalies are, especially for agriculturally-dominated countries, an important determinant for international migration over the period 1960-2000. Our interpretation of the empirical results in the light of the theoretical model is as follows. We find that larger weather anomalies lead to lower rural wages. This induces migration into the cities since cities are generally not directly (or as severely as rural areas) affected by weather anomalies. Population increases in urban centers lead to positive agglomeration externalities and (indirectly) to lower urban wages. We find that, overall, the reduction in the wages outweighs the benefits of urban concentrations (or agglomeration forces) and, therefore, weather anomalies induce out-migration. Based on the empirical results we then estimate that a minimum of around 5 million people have migrated internationally between 1960 and 2000 due to variations in local weather in sub-Saharan Africa. This represents 0.3% of the population or 128'000 people every year. We then project the impact of weather anomalies on the future rates of migration in sub-Saharan Africa based on the moderate IPCC climate scenario A1B (see Section 4 for details). These estimates suggest that, in sub-Saharan Africa towards the end of the 21st century, every year an additional 0.12%, 0.34% and 0.53% of the sub-Saharan African population will move in best, median and worst weather forecasts of IPCC scenario A1B. Multiplied by the medium-fertility UN population projection for the end of the century, this would amount, every year, to an additional displacement of 4, 11 and 25 million inhabitants in the best, median and worst weather forecast of the IPCC climate scenario.

As a consequence, in this article we present evidence that migration has functioned, and is likely to become increasingly important, as an adaptation strategy for weather anomalies. From a humanitarian point of view, environmental migration is known to levy substantial strains on families, villages, but also those places that are targeted by mass migration. From a policy point of view, environmental migration may be of particular importance given the wide-ranging consequences attached, which range from conflict enhancement over brain drain to potentially instable rates of urbanization. In Section 5 we present several further issues and policy suggestions to address the difficult issue of environmental migration.

2 Empirical overview

There has been some controversy on whether migration strongly figures as a means of adaptation to environmental factors or not. For example, tentative projections by Myers (1996) suggest that we might see around 200 million environmental refugees if the average sea level rises by one meter. In contrast to this claim, Black's (2001) reading of the literature strongly suggests that much of the literature on environmental refugees until 2001 does not give rise to the conclusion that environmental, climate or weather conditions are a significant contributor towards migration. During the past ten years there have been substantial further contributions on this topic, belonging to either of the two points of view. Thus, in this overview we constrain ourselves to hard evidence on environmental factors inducing migration based on either case studies or econometric analysis.[4] Furthermore, we limit ourselves to evidence based on the last 60 years.

Most of the recent evidence supports the view that environmental factors have contributed to migration, both rural-urban and international migration. While most of the environmentally-induced migration in Africa has been linked to droughts, most migration in the US has arisen as a consequence of hurricanes and for quality of life reasons (also for Europe). Thus, the evidence points to two channels - one we dub the `amenity channel', which one may link to the amenity value attached to the environment (quality of life); and we call the other the `economic geography channel', which can be related to economic geography effects (income and urbanization). Most of the studies do not clearly separate the two channels, which makes it difficult to attribute empirical results to either one. Furthermore, most studies do not control for endogeneities affecting income or employment opportunities which subsequently affect incentives to migrate (exceptions being Munshi, 2003; Feng et al., 2010; or Naude, 2008). Not controlling for these endogeneities may lead to biased results.

There are four articles that point towards evidence suggesting that environmental factors do not induce migratory movements (Findley, 1994; Paul, 2005; Halliday, 2006; and Mortreux and Barnett, 2009). Findley (1994) studied droughts in Mali and concluded that droughts did not increase overall migration, but reduced long-term migration and increased short-term migration. This change in migration pattern should be attributed to the fact that long-term migration is associated with significant uncertainty of whether it is possible to find work quickly enough in order to support the family at home. Clearly, during a drought immediate finance is necessary, which is more easily obtained through short-distance migration. Supporting this income channel effect is the observation that "[d]uring the drought, 63 percent of the families said that they depended on remittances from family members who had already migrated." (Findley, 1994, p. 544). Halliday (2006) also pointed to liquidity constraints to explain how earthquakes in El Salvador tended to decrease the incentives to migrate to the United States. Thus, this supports our view that neglecting the effect of environmental factors on income may bias empirical results.

Paul (2005) finds that the 2004 flooding in Bangladesh did not lead to migration due to disaster aid. The obvious question is whether we would have observed migration without this disaster aid or not. A useful conclusion that one can draw from his works is, however, that though environmental factors might provide reasons for migration, good governance can work against this.

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[4] An overview is provided in the supplementary material of Marchiori, Maystadt and Schumacher (2012).

Finally, Mortreux and Barnett (2009) studied migration incentives in an island of Tuvalu and concludes that climate change does not figure as an important driver of migration decisions. Religious beliefs as well as no immediate threat of sea level rise seem to be the main reasons behind this point of view. This result stands in contrast to the more immediate threat of sea level rise faced by the Carteret Islands (Papua New Guinea islands). Here, evacuation started in 2009 and will continue throughout the next years as a response to the sea level rise which is likely to submerge the Carteret Islands.

In summary, the evidence tends to favor the result that the environment has an impact on rural-urban as well as on international migration. However, the literature review emphasizes also that it is important to distinguish between the amenity channel and the economic geography channel, as well as between internal and international migration. This task should, ideally, be undertaken in a unified framework.

3 A Theoretical Framework

Theoretically, we know very little about how climate change will impact migration.[5] Thus, what are the stylized facts that a study of rural-urban and urban-international migration should integrate?

It is well-known that weather anomalies bear the strongest direct impacts on agricultural activities, whereas the manufacturing sector is affected less (IPCC, 2007). Thus, countries with a large dependency on the agricultural sector are particularly vulnerable to weather anomalies (Deschenes and Greenstone, 2007; Fisher et al., 2011; World Bank, 2010). As the agricultural sector is predominantly rural, while the manufacturing sector is mostly urban, we should expect migration from the rural to the urban areas. Weather anomalies are, therefore, likely to foster urbanization (Barrios et al., 2006, Collier et al., 2008). Larger urbanization, in our framework, has two effects. One is that more workers in the city induce lower average wages due to decreasing returns to scale, while the second effect is a Marshallian externality on productivity that arises from labor sharing, input-output linkages or information. It represents agglomeration forces in the traditional sense of the New Economic Geography literature. In our framework, the decreasing returns to scale outweigh the agglomeration forces.

[5] Marchiori and Schumacher (2011) propose a dynamic North-South model of international migration from climate change. It is, however, unsuitable for our purpose, since it abstracts from the important agricultural sector in Africa. It is indeed well-known that gradual climate change bears the strongest impacts on low-skilled agricultural activities (IPCC, 2007), whereas high-skilled sectors like the manufacturing sector will be harmed less.

The internal migration implies that more workers are now available in the urban sector, this will exert a downward pressure on the urban wage at home, providing incentives for the urban workers to move across borders (Hatton and Williamson, 2003). Thus, international migration can be seen as a consequence of the increasing pressures in the urban areas following rural-urban migration. We dub the wage and urbanization effect the so-called ‘economic geographic channel’. In addition, one should be able to account for the fact that weather anomalies could potentially affect international migration, independently of the wage and urbanization channels. Such a direct impact is consistent with studies emphasizing how weather variability may affect amenities (Rappaport, 2007) or pure non-market costs such as the spread of diseases or a higher probability of death due to flooding or excessive heat waves (World Bank, 2010). Hence, we label this the ‘amenity channel’.[6]

The storyline that we suggest here is capturing what we believe to be the most reasonable underlying processes for weather-induced migration decisions (Figure 1 summarizes the mechanisms of the model). Assume we are in a situation where no worker wants to migrate. If the weather condition in one country worsens (e.g. a flood or a drought), then this has two effects. Firstly, the wage in the rural sector shrinks. This brings forth incentives for rural-urban migration. At the same time, there is a direct effect from the amenity value of the environment, like disease spread, which induces incentives for urban-international migration. Due to the inflow of agricultural workers into the urban sector, the wage in the urban sector decreases, which gives further incentives for urban-international migration. The inflow of environmental migrants reduces average wages in the foreign country, and our economy moves back into an equilibrium where we now see a larger urbanization in the country which has seen worsening weather conditions, a lower rural population, but also a lower total population due to the international migration.

To sum up, the model predicts that i) weather anomalies have a direct effect via amenities; ii) weather anomalies have indirect effects through changes in income and urbanization; iii) the environmental impact is stronger in economies that depend heavily on the agricultural sector; iv) the weather-induced change in income is endogenous to migration; v) the weather-induced change in urbanization is endogenous to migration.

[6] We present the theoretical framework in Marchiori et al. (2012). It is a continuous time, two-country model with a rural and urban sector, both pricing competitively. Weather anomalies affect the productivity in the rural sector. We allow for rural-urban and urban-international migration, where agents compare their wages in the different sectors and countries when deciding whether to migrate or not. This model predicts that larger weather anomalies induce international migration through rural-urban migration. Furthermore, the more depending a country is on the agricultural sector, the stronger the impact of weather anomalies on migration.

4 Empirical analysis

The empirical analysis is based on cross-country panel data. The dataset comprises 39 sub-Saharan African countries with yearly data from 1960-2000 (T=41).[7] This data consists of variables on migration, variables describing the climatic characteristics, the economic and demographic situations, as well as several country-specific variables. As the discussion of the theoretical model has shown that the empirical analysis may potentially be affected by endogeneity problems. In fact, the self-reinforcing and cumulative nature of migration makes economic wealth and the level of urbanization potentially endogenous variables. The following three-equation model is formulated to deal with direct and indirect effects of weather anomalies on migration:

$$MIGR_{r,t} = \beta_0 + \beta_1 WeatherA_{r,t} + \beta_2 (WeatherA_{r,t} \cdot AGRI_r) + \beta_3 \log\left(\frac{\hat{y}_{r,t}}{y_{-r,t}}\right) + \beta_4 \log\left(\hat{U}_{r,t}\right) + X_{r,t}\beta + \beta_{R,t} + \beta_r + \varepsilon_{r,t} \quad (1)$$

$$\log\left(\frac{y_{r,t}}{y_{-r,t}}\right) = \gamma_0 + \gamma_1 WeatherA_{r,t} + \gamma_2 (WeatherA_{r,t} \cdot AGRI_r) + X_{r,t}\gamma + Z_{r,t}\gamma + \gamma_{R,t} + \gamma_r + \nu_{r,t} \quad (2)$$

$$\log\left(U_{r,t}\right) = \theta_0 + \theta_1 WeatherA_{r,t} + \theta_2 (WeatherA_{r,t} \cdot AGRI_r) + X_{r,t}\theta + Z_{r,t}\theta + \theta_{R,t} + \theta_r + \mu_{r,t} \quad (3)$$

This baseline model suggests that $MIGR_{r,t}$, denoting average net migration rates, can be explained by a set of weather anomalies (defined below) $WeatherA_{r,t}$; by per capita GDP ($y_{r,t}$) as a proxy for domestic wage; by the foreign per capita GDP, i.e. average per capita GDP in the other SSA countries weighted by the distance to country r ($y_{-r,t}$); by the share of the urban population ($U_{r,t}$) as well as by a

[7] The dataset embraces countries from the four Sub-Saharan African regions. The *Central* region includes Burundi, Cameroon, Central African Republic, Chad, Congo Brazzaville, Congo Kinshasa, Gabon, Rwanda; the *East* comprises Djibouti, Ethiopia, Kenya, Mauritius, Sudan, Tanzania, Uganda; the *West* contains Benin, Burkina Faso, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo; the *South* incorporates Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Zambia, Zimbabwe.

vector of control variables ($X_{r,t}$), described below. As suggested by our theoretical model, we also allow weather anomalies to affect international migration through the economic geography channel, which works its way through per capita GDP and the level of urbanization. The theoretical model also invites us to assess the differentiated impact of weather variables in countries whose economies largely depend on the agricultural sector. We introduce, therefore, interaction terms $WeatherA_{r,t} \cdot AGRI_r$, where $AGRI_r$ is an "agricultural" dummy, which as in Dell et al. (2009) equals 1 for an above median agricultural GDP share in 1995.[8] Denoting $\alpha \in \{\beta, \gamma, \theta\}$, we also control for any time-constant source of country heterogeneity by the use of country fixed effects α_r and for phenomena common to all countries across time through the introduction of time dummies, α_t. We also follow Dell et al. (2009) in introducing a time-region fixed effect, $\alpha_{r,t}$, thus controlling for the importance of changes in the regional patterns of migration in sub-Saharan Africa (see Adebusoye, 2006).

4.1 Variables description

Data are collected from several sources to compute the variables introduced in the system of equations above.

$MIGR_{r,t}$: The *net migration rate* is defined as the difference between immigrants and emigrants per thousands of population, corrected by net refugee flows (see below). Bilateral data on migration flows or stocks is barely available for developing countries and particularly difficult to obtain for Africa (over a longer period). Thus, like Hatton and Williamson (2003), we rely on net migration flows as a proxy for cross-border migration. This data is available for the period 1960-2000 and provided by the US Census Bureau.

Moreover, as Hatton and Williamson (2003), we account for refugees who are driven by non-economic factors and included in the net migration estimates. Using the data from UNHCR (2009), we subtract the refugee movement from the net migration rate. In fact, the US Census includes net refugee movements in its net migration series by using UNHCR refugee data.[9]

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[8] We follow Dell et al. (2008) in using 1995 data for agricultural share because data coverage for earlier years is sparse.

[9] Nevertheless, our robustness analysis reveals that our main findings are not sensitive to this correction, see the 'Supplementary Material' in Marchiori et al. (2012).

$WeatherA_{r,t}$: *Weather variables* should capture the incentives for migration that come through weather anomalies. In line with the climatology literature (see e.g. Nicholson, 1986 and 1992; Munoz-Diaz and Rodrigo, 2004), we use anomalies in precipitations and in temperature. The anomalies are computed as the deviations from the country's long-term mean, divided by its long-run standard deviation (the long-run being the 1901-2000 period, see Barrios et al., 2010). The long-term mean gives an idea of the 'normal' weather conditions of a particular region. Anomalies thus describe in how far the weather conditions depart from this norm in a given year. Rainfall and temperature data originate from the IPCC (Mitchell et al., 2002).

$y_{r,t}$: *GDP per capita* is used as a proxy for the domestic wage. A comparison with the 'foreign' wage should reflect an individual's economic incentives to migrate. In Table 1 we use the notation y for this variable. The data originates from the Penn World Tables.

$y_{-r,t}$: *Foreign GDP per capita* proxies the 'foreign' wage, i.e. the wage outside the home country, and is measured as average GDP per capita in the other countries of the sample weighted by a distance function. In Table 2 we use the notation y^F for this variable.

$U_{r,t}$: *Urban population* is defined as the ratio of urban to total population in each country and originates from the United Nations (2009).

$X_{r,t}$: Our baseline regression includes a set of *control variables*. The occurrence of war seeks to capture the political motivations to migrate. We here use data on the number of internal armed conflicts (WAR) based on Bates et al. (2011). We also follow Hatton and Williamson (2003) in introducing four country-specific policy dummies. For example, they suggest controlling for the large expulsion of Ghanaian migrants by the Nigerian government in 1983 and 1985.

Time-regional dummies should capture the regional pattern of migration underlined by several authors (see footnote 7 for country-grouping by region). In fact, cross-border migration in sub-Saharan African is not distributed evenly across regions. In 2000, 42% of the international migrants in Africa lived in countries of Western Africa, 28% in Eastern Africa, 12% in Northern Africa, and 9% in Middle and Southern Africa (Zlotnik, 2003).

Our theoretical model suggests that rainfall and temperature anomalies affect the incentives to migrate through an amenity as well as an economic geography channel.

Given the results of our theoretical model as well as those in Barrios et al. (2006) we are well-aware that the size of the urban population is likely to be endogenous to wages, weather anomalies and several control variables. Hence, we resort to instrumental variables in order to deal with the endogeneities. We instrument GDP per capita with the absolute growth in the money supply. To deal with the potential endogeneity of urbanization, we also use a dummy indicating whether a country experienced the two first years of independence, as well as the interaction of this variable with a dummy that takes the value one if that country has been colonized by the UK. More detailed information on the validity of these instruments as well as robustness exercises are available in Marchiori et al. (2012).

4.2 Results

We present the main results of this article in Table 2. As predicted by the theoretical model we find robust and statistically significant evidence for both the amenity channel and the economic geography channel. With respect to the amenity channel, we find that weather anomalies in agriculturally-dominated countries induce out-migration. Thus, this supports the existence of environmental non-economic (non-market) pure externalities that exacerbate the incentives to move to another country. Similar evidence has been obtained by Rappaport and Sachs (2003) and Rappaport (2007) for the case of the US, and by Cheshire and Magrini (2000) for Europe. These articles suggest that weather-related migration, in richer regions like the US or Europe, may be due to a larger relative valuation of the environment from rising per capita income. For sub-Saharan Africa, it seems unlikely that the amenity channel is due to the fact that people simply want to live in places with nicer weather per se. Instead, we would more strongly emphasize the view that the amenity channel most likely captures health-related or risk-reducing migration. Health-related migration should be mainly due to weather anomalies spreading diseases like malaria, dengue or meningitis (World Bank, 2010). Indeed, sub-Saharan Africa is the region in the world with most deaths from malaria or similar diseases. Risk-reducing migration is likely due to the fact that a period of weather anomalies may be associated with higher future risks[10] and, consequently, migration might occur as a preventive step. Similar reasons have been advanced by Gutmann and Field (2010) who examine return rates of previous inhabitants in the aftermath of the hurricanes Katrina or Andrew.

With respect to the economic geography channel, we find the following. Firstly, weather anomalies clearly impact wages (proxied by relative GDP per capita). This result, thus, confirms and

[10] There is evidence that climatic variables help in explaining malaria transmission (Kiszewski et al., 2004).

complements previous works by Barrios et al. (2010). Furthermore, sub-Saharan African countries that have a large agricultural sector are particularly vulnerable. In regression (1), temperature anomalies have a negative impact on the GDP per capita ratio, in line with the findings in Dell et al. (2008).[11] The interaction term of rainfall anomalies and the dummy for above-median agricultural added value have the expected positive sign. Given the significant and positive coefficient of the GDP per capita ratio in the second stage of the estimation procedure (see column (3)), weather anomalies increase the incentives to migrate out of one's country of origin, particularly in countries that are highly dependent on the agricultural sector.

In line with Barrios et al. (2006), weather anomalies strengthen the urbanization process in agriculturally-dominated countries. Given the role of agglomeration economies, such an increase in urbanization constitutes an attraction force for international migrants. This is consistent with the mechanism described in our theoretical framework where decreased rural wages lead to a larger urban concentration, while in turn; stronger agglomeration forces provide incentives for in-migration. This result also finds support both with empirical New Economic Geography studies on the role of urbanization in attracting migrants (Head and Mayer, 2004) and more descriptive evidence on the importance of international migrants in African cities (Beauchemin and Bocquier, 2004). Given its positive and significant coefficient in the second-stage of the regressions, urbanization softens the impact of weather anomalies on international migration. As described in Marchiori et al. (2012), these results are robust to alternative specifications, the use of alternative dependent variables, alternative definition of the main variables of interest and the addition or omission of control variables.[12] The following Section discusses which channels dominate for international migration and provides estimates of the effect of weather anomalies on international migration.

[11] This result is useful in that it supports the assumption that temperature affects GDP which is the foundation for the whole integrated assessment literature, see e.g. Nordhaus (2008).

[12] The relevance of the instruments is confirmed in regressions (1) and (2) of Table 2. For instance, a decrease by a standard deviation in money growth should reduce relative GDP per capita by about 11%. Provided at least one instrument is valid, the Hansen overidentification test also fails to reject the null hypothesis of zero correlation between the instrumental variables and the error terms. F-tests on excluded instruments equal 30.84 in first-stage regression (1) and 12.99 in first- stage regression (2). As suggested by Angrist and Pischke (2009), we also test the robustness of the results under overidentifying restrictions to the Limited Information Maximum Likelihood (LIML) estimator. Our results are unaltered with the LIML estimator and we can reject the null hypothesis of weak instruments. We also follow Angrist and Pischke (2009) in checking the robustness of our results to a just-identified estimation. Just-identified 2SLS is indeed approximately unbiased while the LIML estimator is approximately median-unbiased for overidentified models. When just-identified estimation is implemented, results do not change whether the dummy for the first two years of independence is introduced as an exogenous explanatory variable or not. More detailed information can be found in Marchiori et al. (2012).

4.3 Projections

Overall, our results suggest that weather anomalies raise the incentives to migrate to another country. In this section we provide a tentative estimation of weather-induced migration flows in sub-Saharan Africa. We first estimate the historical migration flows induced by weather anomalies over the period 1960-2000. Subsequently, we provide an end of century projection for the change in migration flows based on IPCC forecasts for potential weather scenarios and based on population projections from the UN.[13]

4.4 Historical estimates

We compute the contribution of weather changes to past migration in sub-Saharan Africa over the period 1960-2000. Our calculations are based on the significant coefficients of our preferred regressions (i.e. columns (1) to (3) in Table 2) and on observed weather data in the 39 countries of our sample.

Our findings yield that 0.03% of the sub-Saharan African population living in the countries most exposed to weather anomalies (i.e. highly dependent upon the agricultural sector), was displaced on average each year due to changes in temperature and precipitations during the second half of the 20th century (see first column of Table 3). This estimate corresponds in *net* figures to 128'000 individuals having been displaced on average every year due to weather anomalies over the period 1960-2000, which represents in total, over the period 1960-2000, to 5 million people. Such a figure may seem rather low, but given the 'net' nature of our dependent variable, it represents a lower bound estimate.

4.5 End of century projections

To give a rough estimate of the possible consequences of further weather anomalies on migration flows in sub-Saharan Africa, we can make use of the climate projections described in the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC). The IPCC

[13] Computations are based on the significant coefficients of the weather variables as well as on the coefficients of the GDP per capita ratio and urbanization in regressions (3) to (5) of Table 2. More details can be found in the supplementary material of Marchiori et al. (2012).

projections are drawn from various climate models and scenarios and provide estimates on the future *change* in regional temperature and precipitation between the periods 1980-1999 and 2080-2099. Our migration projections are based on weather anomalies given by scenario A1B, which is described in detail in Chapter 11 of the IPCC report (Christensen et al., 2007, p.854). This scenario seems reasonable as it assumes greater economic integration in the future, which is in line with recent economic growth trends of emerging countries (China, India and even sub-Saharan Africa). Furthermore, assumptions on future green house gas emissions and world population increase are moderate.

According to our projections, an additional 0.121% to 0.532% of the sub-Saharan African population will be induced to migrate annually due to varying weather conditions towards the end of the 21st century (see columns 2 to 4 of Table 3). The UN Population Division provides projections of population changes over the 21st century according to low-, medium- and high-fertility scenarios (United Nations, 2009). Applying our projected net migration rates to these estimated population changes yields, in net terms, a figure of an additional 2.9 million environmental migrants every year for the period 2080-2099 compared to the period 1980-1999 in the low-fertility/best-weather-change scenario. The result is an additional 25 million migrants in the high-fertility/worse-weather-change scenario.

While there has been a long tradition of migration to the coastal agglomerations in Africa (Adebusoye, 2006), coastal areas could experience a significant proportion of their population fleeing toward African mainland due to weather changes by 2099. In fact, our individual country results (see Marchiori et al., 2012) indicate that West Africa, Benin, Ghana, Guinea, Guinea-Bissau, Nigeria and Sierra Leone may be among the most affected countries. In contrast, Eastern Africa, Kenya, Madagascar, Mozambique, Tanzania and Uganda may constitute a cluster of sending countries of environmental migrants. Southern Africa, Angola and Botswana could become important sources of environmental migrants while Congo and Gabon could also be pointed out in Central Africa.

5 Policy-relevant conclusions

In this conclusion we now distinguish between theoretical insights, our empirical findings with their potential consequences, and the policy insights that we draw from our analysis.

Theoretical insights: The problems associated with weather anomalies certainly rank as one of the important issues of our times. However, little academic evidence has been provided regarding one of its most often discussed consequences, namely human migration. In this article we propose a theoretical framework featuring rural-urban-international migration as a consequence of weather anomalies. Our theoretical model predicts that weather anomalies should work that way into international migration through two channels. Firstly, the theoretical model predicts that weather anomalies will lead to lower wages, particularly if the effect of weather anomalies on agricultural production is sufficiently strong. This will then induce agricultural workers to move into the cities in order to find work. Weather anomalies are therefore a key determinant of urbanization. Such a rural-urban flow, by decreasing the urban wage, magnifies the incentives of the internationally mobile worker to move to another country. However, due to agglomeration economies, an increase in urbanization tends to mitigate the impact of weather anomalies on international migration.

Empirical findings: We then collect a new dataset for African countries and use the results of our theoretical work as guidance for an empirical analysis of the impact of weather anomalies on international migration. Weather anomalies have a significant and robust impact on average wages. This result, therefore, supports the works by Barrios et al. (2010) and Dell et al. (2009), which show that weather anomalies have an important impact on GDP per capita. We then find that wages are robust and significant determinants of international migration. We also show that weather anomalies directly affect international migration, reflecting possible pure externality effects of weather anomalies. We dub this the amenity channel. Second, we observe that weather anomalies increase incentives to move to the cities. Such a channel of transmission is consistent with the paper of Barrios et al. (2006) who show that weather anomalies in Africa displace people internally. We also find that urban centers represent an attraction force, thus urbanization softens the impact of weather anomalies on international migration. We label these effects, via wages and urbanization, the economic geography channel. Overall we conclude that a minimum of about 5 million people have migrated between 1960 and 2000 due to anomalies in local weather in sub-Saharan Africa. This represents 0.03% of the population or 128'000 people every year. We then project the impact of weather anomalies on the future rates of migration in sub-Saharan Africa. We then provide the end of century projections based on IPCC climate change predictions and UN population projections. Considering the medium-fertility population forecast of the United Nations, our main results are that in sub-Saharan Africa towards the end of the 21st century every year an additional 11.8 million inhabitants may move as a consequence of weather anomalies.

Potential consequences: There are at least two potential consequences arising from the movements of population generated by climate change. First, end-of-century projections indicate that the number of migrants induced by climate change may reach significant numbers. Considering the medium-fertility population forecast of the United Nations, our results are that, towards the end of the 21st century, every year an additional 5 to 24 million inhabitants of sub-Saharan Africa may move as a consequence of weather anomalies. Such massive population movements can have consequences in terms of health and security on their hosting nations. In fact, they may speed up the transmission of epidemic diseases, as e.g. malaria (Montalvo and Reynal-Querol, 2007), in areas where the population has not yet developed protective genetic modifications (Boko et al., 2007). Second, projected migration flows, generated by environmental motivations only, display a centripetal process from coastal areas to central sub-Saharan African countries. This projected move towards mainland Africa could become a major geopolitical concern since population density, ethnic differences and social disparities have been recognized as factors enhancing conflicts; these factors has been argued to be relevant for the conflicts in North-Kivu in Congo, Burundi (Bundervoet, 2009), Rwanda (Andre and Platteau, 1998) or also Darfur (Fadul, 2006).

Naturally, such consequences remain to be verified both theoretically and empirically in order to be more affirmative on the relationship between migration flows and conflict onset. In fact, given the non-negligible amounts of environmental migrants that we estimate, some of our assumptions concerning these end-of-the century projections may not continue to hold. In particular, there might be a strong divergence between the desire to migrate versus the capacity to do so. For example, if there are large and persistent migration flows from one country into another, then the potential receiving country could restrict migration, just like Europe did for migrants from Africa and the US for those from Mexico. Additionally, problems of infrastructure and property rights may evolve.

Policy implications: Finally, our findings may pose new challenges for policy makers. After all, African countries account for only approximately five percent of world emissions. If one believes that increasing weather anomalies may be human-induced, then these variations are nearly exclusively driven by the developed world. This externality thus imposed on the sub-Saharan countries requires international attention based on equity and fairness criteria. In this respect, the recent advances presented in the Cancun Agreement provide a good starting point. However, one of the important components of the Cancun Agreement, namely Nationally Appropriate Mitigation Actions, will not be a useful policy tool for Africa due to the relatively low total emissions. Future policies should therefore focus more closely on adaptation policies.

As argued by Collier et al. (2008), the most obvious policy recommendation is to promote policies aiming at making crops and livestock less sensitive to weather anomalies. This may call for practices that encourage crop and livestock diversification or drought-resistant crop varieties and livestock species (Deressa et al., 2010). Increasing the adaptation capacity of the farmers may also require protecting the assets, especially of the poor, to allow them to cope with more frequent weather shocks. Increasing agricultural productivity, including through larger investments in agricultural science and technology, could increase farmers' resilience to changes in weather and increased frequency of extreme weather events (Nelson et al., 2009). However, our study indicates that spatial and sectoral mobility is also an efficient, although challenging, adaptation strategy. Easing the market reallocation from agriculture to manufacturing sectors and emphasizing the absorption role of urban areas will reduce the social costs of weather anomalies. Provided one is concerned about the security and health consequences of environmental migration, strengthening the buffering role of urban centers may constitute an interesting policy option. In that respect, reducing congestion costs and improving urban infrastructure may enhance the absorption capacity of agglomeration centers. There is certainly scope for increased urbanization as Sub-Saharan Africa remains one of the least urbanized region of the world (about 40% of the population live in cities, see United Nations Human Settlements Program, 2011). However, this requires giving priority to infrastructure investments such as improving public transport facilities, sanitation and water management as well as power generation likely to support sustainable urban development. Specific policies easing spatial and sectoral mobility, the factor absorption capacity at national and local levels or compensation mechanisms at supra-national level should help countries in dealing with the human capital depletion that threatens some of the most affected countries. Such policies may also relate to anticipating weather-induced migration by improving information about possible places of destinations, providing financial compensations for the affected areas and fostering community-based integration of environmental migrants by enhancing joint participation into development projects in the areas of destination (see de Sherbinin et al., 2011).

Our estimates of the potential future flow of environmental refugees lead also to important issues of governance. Firstly, the legal status of environmental migrants must be clarified. For example, migration hot spots due to frequent natural disasters must be anticipated and developed in a such a way as to assure the human and legal rights of the migrants. This includes insuring basic needs as well as protection from conflicts and providing support for those migrants that consider returning home. Migration flows due to long-run changes in local environmental conditions must be channeled in such a way as to minimize the impact on receiving cities or nations. These challenges are clearly difficult due to the non-negligible level of governance problems in sub-Saharan countries (for example, sub-Saharan countries score very low on Transparency International's Global Corruption Index), and furthermore due to the financial constraints. While some governance problems are only solvable through long-term commitments, some issues could be tackled rather quickly and easily with international support. Firstly, the legal and human rights of environmental migrants can be firmly established through a legal basis. This would be the task of the UNHCR. Secondly, that these rights are actually put in place should be monitored by international institutions in conjunction with local governments. Thirdly, international financial and humanitarian support must be provided. However, the financial support should be linked to the development of local governances in the sending countries.

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Figures and Tables

Figure 1: Outline of theoretical model

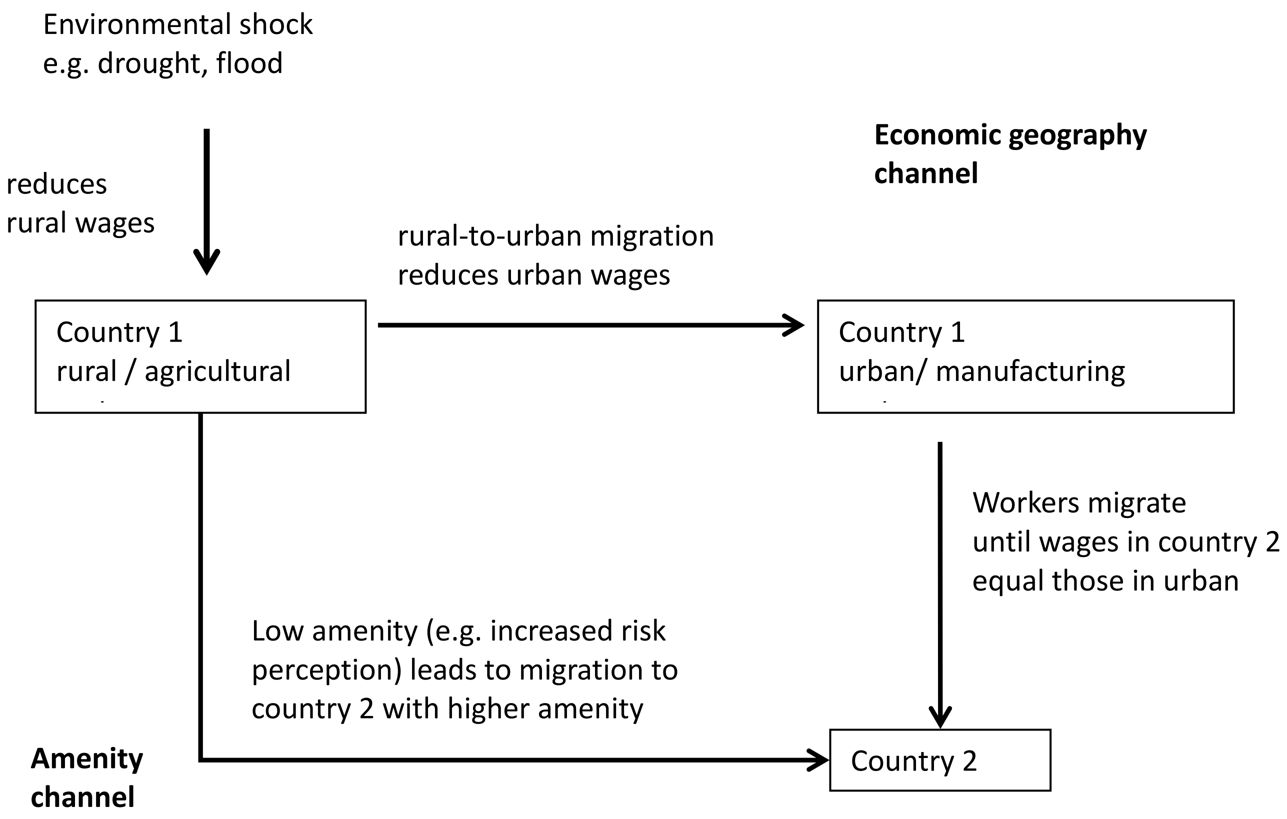
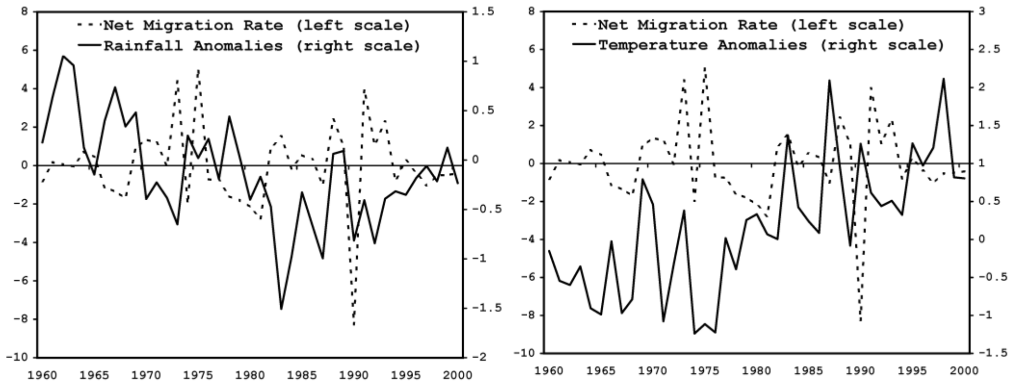


Figure 2: Weather anomalies and net migration rate in sub-Saharan Africa



Source: IPCC for rainfall and temperature data, US Census for net migration

Table 1: Short description of main variables

CODE	Definition/Description
MIGR	Net migration rate: Difference between numbers of immigrants and emigrants per thousands of population, corrected by the refugee movement
RAIN	Rain Anomalies, deviations from the country's long-term mean, divided by its long- run standard deviation
TEMP	Temperature Anomalies: deviations from the country's long-term mean, divided by its long-run standard deviation
y/y^F	GDP per capita over GDP per capita in other African countries weighted by distance.
WAR	War onset, value 1 for civil war onset
WAR^F	War onsets in other countries weighted by distance
URB	Share of urban population in total population
AGRI	Whether a country has an agricultural value added above the median in 1995 (similar to Dell, 2009)
Δ Money	Money plus Quasi-Money: Absolute growth in money supply
New State	Independence: value 1 if country is in the two first years of independence
$MIGR^a$	Original net migration rate, without refugee movement correction
NetREF	Net refugee movement per thousands of population

A more detailed variable description containing also the different sources for the data is provided in Marchiori et al. (2011).

Table 2: Two-stage regressions

Regression	(1)	(2)	(3)
Models	FE2SLS	FE2SLS	FE2SLS
SE	robust	robust	robust
Stage	1^{st}	1^{st}	2^{nd}
Dependent Variable	$\log(y/y^F)$	log(URB)	MIGR
RAIN TEMP	-0.023	-0.00332	0.843
	[0.0140]	[0.00832]	[0.832]
RAIN*AGRI	-0.0432***	-0.0204**	2.841**
	[0.0153]	[0.00876]	[1.239]
TEMP*AGRI	0.0494***	0.00162	-1.258
	[0.0187]	[0.00997]	[0.936]
WAR_{t-1}	0.00811	0.0455***	-4.253**
	[0.0218]	[0.00980]	[1.693]
WAR^F_{t-1}	-0.0738	0.0104	2.997
	[0.0877]	[0.0259]	[5.709]
$\log(y/y^F)$	-0.182	0.02	0.86
	[0.150]	[0.0850]	[7.194]
log(URB)			21.58***
			[7.216]
			67.51***
			[24.14]
Instruments			
ΔMoney	0.131**	0.0596	
	[0.0557]	[0.0350]	
New State UK	-0.641***	0.230***	
	[0.0892]	[0.0484]	
New State	-0.0297	-0.0362	
	[0.0504]	[0.0338]	
HW-Dum	Incl.	Incl.	Incl.
Region-Dum	Incl.	Incl.	Incl.
Time-Dum	Incl.	Incl.	Incl.
Region-Time	Incl.	Incl.	Incl.
Observations	750	750	750
Number of countries	39	39	39
F-test	88.87***	65.79***	22.17***
F-test on excl. IV	30.84***	12.99***	
Underid test			7.595***
P-value Hansen			0.871
Endo stat			14.53***
Root MSE	0.2283	0.09746	10.82

** significant at 5%; *** significant at 1% (significance at 10% not highlighted). Robust standard errors are in square brackets. y stands for domestic GDP per capita, y^F stands for foreign GDP per capita. “HW-Dum” stands for the 4 dummies of Hatton and Williamson (2003) for Ghana and Nigeria for the years 1983 and 1985, “Region-Dum” includes region dummies, “Time-Dum” time dummies and “Region-Time” time-region dummies. R-squared is not shown, because, in the case of 2SLS/IV, it is not an appropriate measure of the goodness of fit and has no statistical meaning (see www.stata.com).

Table 3: Weather-induced migration for the sub-Saharan Africa region

	1960-2000	Projections for the end of the 21st century best	median	worst
Annual net (international) migration rate[(a)]	**-0.30**	**-1.21**	**-3.40**	**-5.32**
Annual number of net migrants[(b)]	-128'414			
Total number of net migrants	-5'136'569			
Proj. ann. net migrants (low fertility)[(c)]		**-2'910'008**	-8'493'369	-13'332'808
Proj. ann. net migrants (medium fertility)[(c)]		-4'053'671	**-11'784'960**	-18'477'402
Proj. ann. net migrants (high fertility)[(c)]		-5'528'551	-16'014'948	**-25'080'975**

Table displays net (international) migration rate and the net number of (international) migrants displaced out of SSA countries due to weather changes over the period 1960-2000 and projections for the end of the 21st century. Negative numbers for net international migration mean that there were more emigrants than immigrants.

(a) Net migration rate is expressed in 1000 of population.

(b) Calculated using 1960-2000 population averages.

(c) *Proj. ann. net migrants* stands for projected annual number of net international migrants. The three cases (i) low fertility, (ii) medium fertility and (iii) high fertility refer to projected migrants obtained by multiplying the projected net migration rates of the first row with the (i) 2080-2099 averages UN low fertility population projections, (ii) medium fertility projections and (iii) high fertility projections.