"The Impact of Weather Anomalies on Migration in sub-Saharan Africa"

MARCHIORI, Luca ; MAYSTADT, Jean-François ; SCHUMACHER, Ingmar

Abstract

This paper analyzes the effects of weather anomalies on migration in sub-Saharan Africa. Theoretically, we show how weather anomalies induce rural-urban migration that subsequently triggers international migration. We distinguish two transmission channels, an amenity and an economic geography channel. Empirically, based on annual, cross-country panel data for sub-Saharan Africa, our results suggest that weather anomalies increased internal and international migration through both channels. We estimate that temperature and rainfall anomalies caused a total displacement of 5 million people in net terms during the period 1960-2000, i.e. a minimum of 130'000 people every year. Further weather anomalies, based on IPCC projections on climate change, could lead to an additional annual displacement of 11 million people by the end of the 21st century.

Document type : *Document de travail (Working Paper)*

Référence bibliographique

MARCHIORI, Luca ; MAYSTADT, Jean-François ; SCHUMACHER, Ingmar. *The Impact of Weather Anomalies on Migration in sub-Saharan Africa.* IRES Discussion papers ; 2011034 (2011) 80 pages

The Impact of Weather Anomalies on Migration in sub-Saharan Africa

L. Marchiori, J-F. Maystadt and I. Schumacher

Discussion Paper 2011-34

Institut de Recherches Économiques et Sociales
de l'Université catholique de Louvain

IRES

UCL

The Impact of Weather Anomalies on Migration in sub-Saharan Africa *

Luca Marchiori † Jean-François Maystadt ‡ Ingmar Schumacher §

October, 2011

Abstract

This paper analyzes the effects of weather anomalies on migration in sub-Saharan Africa. Theoretically, we show how weather anomalies induce rural-urban migration that subsequently triggers international migration. We distinguish two transmission channels, an amenity and an economic geography channel. Empirically, based on annual, cross-country panel data for sub-Saharan Africa, our results suggest that weather anomalies increased internal and international migration through both channels. We estimate that temperature and rainfall anomalies caused a total displacement of 5 million people in net terms during the period 1960-2000, i.e. a minimum of 130'000 people every year. Further weather anomalies, based on IPCC projections on climate change, could lead to an additional annual displacement of 11 million people by the end of the 21^{st} century.

Keywords: International migration, urbanization, rural-urban migration, weather anomalies, sub-Saharan Africa.
JEL Classification: F22, Q54, R13.

*For helpful suggestions we would kindly like to thank two anonymous referees, Luisito Bertinelli, Frédéric Docquier, Gilles Duranton, Timothy Hatton, Giordano Mion, Dominique Peeters, Eric Strobl, Jacques Thisse. We benefited from comments by the participants at the Annual Conference of the European Society for Population Economics (June 2010), of the Third Conference of Transnationality of Migrants - TOM, Marie Curie Research Training Network Conference (October 9-10, 2010), the CSAE Conference on Economic Development in Africa (March 20-22, 2011), the Norface Conference "Migration: Economic Change, Social Challenge" (April 6-9, 2011) and the Conference on Adaptation to Climate Change in Low-Income Countries (May 18-19, 2011). We are also grateful to Francesco Ortega and Giovanni Peri for accepting to share their data on bilateral migration flows. Finally, the paper benefited from financial support from the Belgian French-speaking Community (convention ARC 09/14-019 on "Geographical Mobility of Workers and Firms").

†Central Bank of Luxembourg, 2 Boulevard Royal, L-2983 Luxembourg, and IRES, Université catholique de Louvain. *E-mail:* luca.marchiori@bcl.lu.

‡International Food Policy Research Institute (IFPRI), Washington DC. *E-mail:* J.F.Maystadt@cgiar.org. This author acknowledges financial support from the Fonds de la Recherche Scientifique (FNRS) and from the Belgian French-Speaking Community (convention ARC 09/14-019 on "Geographical Mobility of Factors").

§Central Bank of Luxembourg, 2 Boulevard Royal, L-2983 Luxembourg, and Department of Economics, École Polytechnique Paris. *E-mail:* ingmar.schumacher@polytechnique.edu. The research presented here does not necessarily reflect the views and opinions of the Banque centrale du Luxembourg.

1 Introduction

It is now well-known that local weather anomalies are able to impose significant strains on economies (World Bank, 2010). A topic that has received much media coverage but less academic research is how exactly these weather anomalies influence the incentives to migrate to places that are perceived to be less affected by weather anomalies. The amount of people that had to leave their homes due to changes in local weather conditions is believed to be everything else but negligible. Estimates range from an annual displacement of 15 million environmental refugees[1] 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[2] lack a robust empirical framework and are mostly extrapolations based on the amount of people living in affected regions. 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 (Boko et al., 2007).

The general knowledge of the effect of weather anomalies on migration is still somewhat limited, especially for a topic which is so very much at the heart of the modern, international debate. Studies that investigate the environmental motives for rural-urban migration are, for example, Findley (1994),

[1] 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.

[2] In its 2010 World Development Report on *Development and Climate Change*, the World Bank (2010, pp.108-109) underlines 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."

Barrios et al. (2006), Henry et al. (2003), Mueller and Osgood (2009) or Saldaña-Zorrilla and Sandberg (2009). Articles that look at international environmental migration are Munshi (2003) and Feng et al. (2010), focusing on Mexican-US migration, as well as Naude (2008), who studies whether natural disasters induces conflicts which lead to out-migration (for a theoretical work, see Marchiori and Schumacher, 2011). While each of the articles provides an important contribution to our understanding of how weather anomalies may drive migration, neither of the articles studies migration in within the more holistic perspective that we try to advocate here.

As we shall argue, rural-urban and national-international migration are both intimately linked and ought to be analyzed within a unified framework. It is, therefore, the objective of this article to provide a theoretical and empirical analysis of the impact of weather anomalies on rural-urban-international migration. Based upon the empirical analysis we also forward a tentative estimate of the number of environmental migrants in Africa between 1960 and 2000, as well as projections of future environmental-driven migration based on UN population forecasts and IPCC future climate scenarios for the end of the 21^{st} century.

What are the stylized facts that a study of rural-urban and urban-international migration should integrate? Firstly, it is well-known that weather anomalies bear the strongest direct impacts on agricultural activities, whereas the manufacturing sector is hurt 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). As this 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 effects 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'. In line with these stylized facts, our framework encompasses the above channels. The theoretical model 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.

We then 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 particular reasons. Inhabitants of most sub-Saharan countries already live on the brink of starvation, with often more than 60% 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. Since many African countries are heavily relying 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. Around half of those

deaths are believed to have arisen in sub-Saharan Africa. Given several very likely scenarios of 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). In the light of the recent events and IPCC projections one wonders which are the most important driving forces behind the migration decisions in the sub-Saharan region. To our knowledge, Hatton and Williamson (2003) are among the first to have conducted an empirical analysis on the determinants of migration in Africa. Their study underlines the importance of the wage gaps between sending and receiving regions as well as demographic booms in the low-wage sending regions for explaining net migration within sub-Saharan Africa. While taking into account economic and political determinants of migration, they do not account for a potential environmental push factor that may be important in determining African migration. The articles that look into part of this question are Barrios et al. (2006, 2010). In their 2006 article, the authors find that weather conditions in sub-Saharan Africa lead to a displacement of people internally. However, our theoretical model hints at further effects from weather anomalies, namely that changes in urban centres and relative wages provide motivation for international migration, too. For example, increased urbanization is likely to mitigate the impact of weather on international migration due to agglomeration forces. One of our motivations, therefore, is to understand the importance of these economic geography effects for migration in sub-Saharan Africa.

Though most previous studies proxy weather anomalies by rainfall (Barrios et al., 2006, 2010), it is also well-known that a significant part of weather anomalies in sub-Saharan Africa is related to increases in temperature. Even small changes in temperature can very often be decisive for whether a region is semi-arid like Italy or arid like Namibia. Dell et al. (2009) show that the detrimental impact of weather anomalies on economic performances is mainly driven by annual variations in temperature. Therefore, our aim here is to look specifically at both temperature and rainfall anomalies which provide

a fairly complete picture of the true extent of weather anomalies (IPCC 2007).

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 leads to a lower wage. This induces migration into the cities since cities are generally not directly (or as severely as rural areas) affected by weather anomalies. Increases in urban centers lead to agglomeration externalities. However, increased weather anomalies also (indirectly) induce 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 3.5 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.

This paper is organized as follows. Section 2 introduces the theoretical framework. Section 3

presents the data, methodology and the empirical results of our study. Section 4 concludes.

2 A Theoretical Framework

In this section, we introduce a simple theoretical model that helps in motivating the modeling choices in the subsequent empirical analysis. The model is used as a roadmap to understand the impact of weather anomalies on migration flows. For this aim we built a simplified model that is able to describe the mechanisms underlying the link from weather anomalies to rural-urban and urban-international migration, allowing for the amenity as well as the economic geography channel.

In the following framework, a change in any variable x_t over time is denoted by $\dot{x}_t$, the derivative by a subscript. We assume that there exists a mass 1 agricultural workers that may work in the rural sector or in the urban sector. These workers are thus mobile across sectors. A share $L_t \in [0, 1]$ constitutes agricultural workers who work in the urban sector, while $1 - L_t$ work in the rural sector. There are $N_t \in [0, 1]$ urban workers that only work in the urban sector but are mobile across countries. There are two sectors, the rural sector with production technology $Y^a(c, 1 - L_t)$, where c denotes weather, and the urban sector with $Y^u(N_t + L_t, N_t)$. Both productions exploit decreasing returns to scale in labor.[3]

Weather is assumed to affect total productivity in the rural sector. One would ideally want to measure weather through a random variable, say z, with support $z \in [0, \infty]$. Zero would then represent the best outcome, while infinity would designate the worst. On average we would expect the outcome $E(z) = \int_0^\infty zf(z)dz$, with $f(z)$ denoting the probability function. In order to allow for a concise

[3]Our assumption on decreasing returns to scale in agricultural production could be questioned on the grounds of the replication argument. An obvious remedy in this case is to assume the existence of another factor of production, like land X, that is constant, non-tradable and unpriced, such that $Y^a = Y^a(c, 1 - L_t, X)$, with Y^a now being homogeneous of degree 1 in land and labor. This would preserve the results presented above. One could even go one step further and assume that the new factor of production earns a return itself, but that this return is the residual profit from production. In any case, the decreasing returns to scale in labor are a crucial assumption that cannot be dispensed of if one wants the model to have an interior solution.

and precise theoretical analysis, and without an important loss of generality, we shall avoid modeling weather as a stochastic process here. Hence, we simply denote a random draw from the distribution $f(z)$ as $c > 0$. On average, we would thus expect that $c = E(z)$, while a year with a worse outcome would imply $c > E(z)$.[4]

We take capital and knowledge as given and being encompassed in the total factor productivities. Both sectors price competitively and prices in each sector are given. The rural sector produces according to $w^a(1 - L_t, c) = p^a Y^a_{1-L}$, with $w^a_{1-L} < 0$, $w^a_c < 0$ and $\lim_{L \to 1} w^a = \infty$. The optimal wage in the urban sector is given by $w^u(L_t + N_t, N_t) = p^u Y^u_L$, with $w^u_L < 0$,$w^u_N < 0$. While the first part of w^u reflects the total amount of workers active in the urban sector, the second part stands for a Marshallian externality on productivity that arises from labor sharing, input-output linkages or information (Duranton and Puga, 2004). It represents agglomeration effects.[5] Workers compare their wages across sectors and countries and migrate in case they obtain higher wages elsewhere. Within this framework, agricultural workers then decide to move from the rural to the urban region according to

$$\dot{L}_t = w^u(L_t + N_t, N_t) - w^a(1 - L_t, c). \tag{1}$$

Thus, the amount of agricultural workers that work in the urban sector increases if the wage in the urban sector is higher than in the rural one.

As for international migration, we assume that urban workers compare their wage at home with the wage of the country they intend to migrate to, denoted by $w^*(1 - N_t)$; and a direct weather effect,

[4]In this way we also avoid the analytics associated with a system of stochastic differential equations and a stochastic steady state. Though mathematically feasible, we would not learn more about migration dynamics.

[5]Functional forms consistent with these assumptions are, e.g., $Y^a = A(c)(1 - L_t)^\alpha$, $\alpha \in (0, 1)$, $A(c) > 0$ with $A'(c) < 0$, where A denotes total factor productivity in the rural sector that is negatively affected by weather anomalies, represented by $c > 0$. Also, $Y^u = B(N_t)(L_t + N_t)^\beta$, where $B_N > 0$ is the marginal effect of N on the Marshallian externality, $\beta \in (0, 1)$ is the elasticity of labor.

given by $g(c)$, with $g_c > 0$.

We assume that workers that migrate have a negative impact on the other country's wage, such that $w^*_{1-N} < 0$. The term $g(c)$ assumes that weather anomalies also have a direct impact on urban workers through a change in the amenity value of the weather at home. It should capture what we dubbed the amenity channel. For sub-Saharan Africa, we expect such amenities to reflect non-market costs induced by weather anomalies such as poor environmental quality, possible spread of diseases like malaria, denge or meningitis and consequently increasing numbers of deaths (World Bank, 2010).

Thus, workers from the urban region migrate internationally according to

$$\dot{N}_t = w^u(L_t + N_t, N_t) - w^*(1 - N_t) - g(c). \tag{2}$$

As such, urban workers migrate if the net international wage exceeds the wage they would otherwise obtain in the urban sector at home or if the amenity channel is very strong. From now, the subscript t is dropped for presentation purpose.

Assumption 1. *We assume that* (1) $\lim_{L\to 0} w^a(1-L, c) < w^*(1-N) + g(c)$*;* (2) $w^u(L, 0) > w^*(1) + g(c)$*; and* (3) $w^u(L+1, 1) < w^*(0) + g(c)$.

The first part of this assumption basically means that, if all agricultural workers were to stay in the rural sector, then the international wage must be higher than the rural wage. If it were lower, then there would be no reason for moving into the urban sector and we would see a corner solution in L. The second and third parts of the assumption simply require the national wage to be sufficiently responsive to international migration. All three conditions are weak and straight-forward.

We are now ready to study this rather intuitive model of weather anomalies inducing rural-urban and urban-international migration.

Proposition 1. *At equilibrium, a larger weather anomaly induces international migration through rural-to-urban migration.*

Proof. We assume that $\dot{N} = \dot{L} = 0$. Combining then (1) with (2) gives the equilibrium condition $w^*(1-N) + g(c) = w^a(1-L, c)$. Since $w^*(1-N) + g(c) > 0$, by Assumption 1 and $\lim_{L \to 1} w^a = \infty$, then there exists an interior solution in L. Taking now the interior solution of L as given, then Assumption 1 also assures an interior solution in N. Deriving the weather anomalies' impact on the equilibrium locational decisions gives us

$$\frac{dL}{dc} = \frac{w_c^a(w_N^u + w_{1-N}^*) - g_c w_N^u}{w_N^u w_{1-L}^a + w_{1-N}^*(w_L^u + w_{1-L}^a)} > 0, \tag{3}$$

$$\frac{dN}{dc} = \frac{g_c}{w_N^u + w_{1-N}^*} - \frac{w_L^u}{w_N^u + w_{1-N}^*}\frac{dL}{dc} < 0. \tag{4}$$

Hence, the proposition follows. □

Thus, weather anomalies increase rural-to-urban migration as well as urban-to-international migration. Additionally, a stronger amenity effect induces a larger international migration directly, which increases the wage in the urban sector at home and therefore gives further incentives for rural-urban migration. The larger the effect of weather anomalies in the rural sector, the more pronounced will be the rural-urban migration, and the larger will be the international migration.

The next proposition derives the equilibrium dynamics of this model.

Proposition 2. *The system of equations* (1) *and* (2) *has an asymptotically stable equilibrium point* $\{\bar{L}, \bar{N}\}$.

Proof. By Proposition 1 we know that there exists an interior equilibrium solution in L and N that we denote as $\{\bar{L}, \bar{N}\}$, where $\{\bar{L}, \bar{N}\}$ solves $\dot{N} = 0$ and $\dot{L} = 0$. We derive the Jacobian around the steady

state $\{\bar{L}, \bar{N}\}$. This is given by

$$\mathcal{J}\Big|_{(\bar{L},\bar{N})} = \begin{bmatrix} w^u_L + w^a_{1-L} & w^u_N \\ w^u_L & w^u_N + w^*_{1-N} \end{bmatrix},$$

The trace is tr$\mathcal{J} = w^u_L + w^a_{1-L} + w^u_N + w^*_{1-N} < 0$ and the determinant is $\det \mathcal{J} = w^u_N w^*_{1-N} + w^a_{1-L}(w^u_N + w^*_{1-N}) > 0$. Since the eigenvalues are given by

$$\lambda_{1,2} = \frac{1}{2}\left(\text{tr}\mathcal{J} \pm \sqrt{(\text{tr}\mathcal{J})^2 - 4\det \mathcal{J}}\right),$$

we know that either both eigenvalues are negative or complex with negative real part. Thus, the equilibrium point $\{\bar{L}, \bar{N}\}$ is asymptotically stable. Disregarding complex dynamics for simplicity, this implies that $\lambda_1 < 0$ and $\lambda_2 < 0$. □

As a consequence, we know that, given a change in the weather conditions, both L and N will converge to a unique, interior steady state.

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 illustrates the migration mechanisms graphically. Assume we are at the equilibrium point $\{L, N\}$, and now the weather condition in the sending country worsens, such that $dc > 0$. This has two immediate effects. Firstly, the wage in the rural sector shrinks, thus shifting the w^a curve down. This brings forth incentives for rural-urban migration. At the same time, there is a direct effect from the amenity value of the environment which induces incentives for urban-international migration. However, due to the inflow of agricultural workers into the urban sector, the wage in the urban sector decreases (per unit of N), and therefore the curve w^u shifts down. This gives further incentives for urban-international migration. Due to the Marshallian externality, this effect is not as pronounced as it otherwise would be. International factor price

equalization is then achieved via two channels. International migration has a positive effect on international wage via agglomeration forces and a negative effect via decreasing returns to scale to labor. Conversely, the urban wage will increase, as shown by the shift of the w^u curve in the left panel. Given assumption 2, the later effect will dominate the former, leading to a decrease in the foreign country's wage. We thus arrive at a new equilibrium point that is given by $\{L', N'\}$.

Simple comparative statics furthermore suggest that a stronger agglomeration effect would flatten the curve w^u and thereby diminish the change in international wages. Without the direct effect of the amenity value of weather, the curve $w^*(1-N)+g(c)$ would not shift up and therefore international migration would be lower. Similarly, with little international migration, the curve w^u in the left part of Figure 1 would shift up by less, the effect being a lower amount of sectoral migration.[6]

To complete the analysis we now derive the effect of weather anomalies on several variables that give us crucial hints for the way we should set up the empirical analysis.

We, firstly, derive the effect of weather anomalies on urbanization. We here define urbanization as $\psi = (L+N)/(1+N)$.

Proposition 3. *Weather anomalies increase equilibrium urbanization if the amenity channel is weak enough and agglomeration forces are sufficiently small.*

Proof. Since urbanization is defined as $\psi = (L+N)/(1+N)$, then we can easily calculate

$$\frac{d\psi}{dc} = \frac{1+N}{(1+N)^2}\frac{dL}{dc} + \frac{1-L}{(1+N)^2}\frac{dN}{dc}.$$

[6]The direction of the changes presented here rests crucially on the assumption that $w_N^u < 0$. If agglomeration forces were stronger than the diminishing returns to labor in production, then it could be possible that some effects are reversed. However, it seems rather natural for us to assume that wages are more responsive to migration than to agglomeration effects. This is also what we confirm in the subsequent empirical analysis.

Substituting for $\frac{dN}{dc}$, assuming $g_c \to 0$, gives

$$\frac{d\psi}{dc} = \frac{1}{(1+N)^2} \frac{(1+N)(w_N^u + w_{1-N}^*) - (1-L)w_L^u}{w_N^u + w_{1-N}^*} \frac{dL}{dc}.$$

Then $(1+N)(w_N^u + w_{1-N}^*) - (1-L)w_L^u < 0$ implies $\frac{d\psi}{dc} > 0$. □

This result may be explained as follows. Since weather anomalies induce rural-urban migration, then the subsequent decrease in the urban wage will induce international migration. As a consequence, we see an increase in urbanization, since both the number of inhabitants decreases and the number of rural workers in the rural sector decreases. This holds unless the amenity effect of $g(c)$ is too strong or if the residual of $w_N^u - w_L^u$, representing the effect of N on the agglomeration externality, is too large.

The next proposition derives the amenity channel.

Proposition 4. *A stronger amenity channel leads to out-migration.*

Proof. The amenity effect is given by the effect of $g(c)$ on N only. By equation (4), this effect is negative. □

Therefore, the stronger the effect of weather anomalies on the amenity value at home, the more will urban workers be inclined to migrate abroad. We dub this the amenity channel since it explains how weather anomalies affect migration directly without going through other variables like urbanization or wages.

Our final proposition is related to a country's exposure to weather anomalies. We define a country that is depending on one sector as one where that sector produces a relatively larger share of GDP.

Proposition 5. *The more depending a country is on the rural sector, the stronger the impact of weather anomalies on migration.*

Proof. From the profit functions we know that a higher c implies a lower Y^a versus Y^u. Furthermore, from equation (3) we know that L at steady state is increasing in c. From equation (4), the proposition thus follows. □

This result seems rather intuitive. Take any country whose GDP is highly exposed to weather anomalies, then one will also see a larger impact of weather anomalies on the country that is more exposed. This exposure term might be very low for countries that are more urbanized and, thus, whose production is mostly independent of weather anomalies, like countries with a larger manufacturing sector. It could, however, be large for those countries that are very dependent on the agricultural sector and where even small changes in the weather conditions might lead to a significant exposure of a large share of GDP.

This framework leaves out several aspects. For example, it has been established that migrants move with their demands and can affect consumer prices (Saiz, 2007; Lach, 2007) as well as the profitability of locally provided goods and services. In addition, migrants can also constitute complementary factors in the production of the receiving countries and strengthen agglomeration economies (Ottaviano and Peri, 2011). We did not allow for changes in prices, (costly) trade in goods or firm re-allocations, and introduced agglomeration effects as well as consumer surplus considerations in a somewhat stylized way. Nevertheless, we believe that the model captures the crucial qualitative links of rural-urban and urban-international migration.

Another point could be that the sending country is a small economy. In this case one would expect that the receiving country's wage is not responsive to international migration, such that $w^* = \bar{w}^*$. Though this does not qualitatively change the results presented above, we are likely to see a larger rural-urban and a larger international migration from the small country. The reason is that, in this case,

international migration does not drive down the receiving country's wage and, as a consequence, more international migration is necessary to restore equilibrium.

3 Empirical analysis

Since Todaro (1980) and the review of Yap (1977), it has become standard in the literature to relate, in an aggregate migration form, the migration rate to changes in expected income and to changes in the degree of urbanisation (see also Taylor and Martin (2001)). We will not depart from this tradition. However, Propositions 1, 3 and 4 of our theoretical framework not only point to the importance of the amenity channel but also to the economic geography (via income and urbanization) channel through which weather anomalies could affect international migration. The theoretical model and its discussion also shed light on possible risks of endogeneity. As discussed above, the self-reinforcing and cumulative nature of migration makes economic wealth and the level of urbanisation potentially endogenous variables. Therefore, we develop a three-equation model, with one equation for the net migration rate, one for GDP per capita and one for the level of urbanisation. We collect a new dataset of 39 sub-Saharan African countries with yearly data from 1960-2000. This cross-country panel data consists of variables on migration, variables describing the weather characteristics, the economic and demographic situations, as well as several country-specific variables. The country list can be found in Table 1 in the Appendix. Our three-equation model is formulated as follows:

$$
\begin{aligned}
\text{MIGR}_{r,t} = {} & \beta_0 + \beta_1 \text{ WeatherA}_{r,t} + \beta_2 \ (\text{WeatherA}_{r,t} * \text{AGRI}_r) + \beta_3 \log\left(\frac{\widehat{\text{GDPpc}}_{r,t}}{\text{GDPpc}_{-r,t}}\right) \\
& + \beta_4 \log(\widehat{\text{URB}}_{r,t}) + \beta \ \text{X}_{r,t} + \beta_{R,t} + \beta_r + \epsilon_{r,t} \qquad (5)
\end{aligned}
$$

$$
\log\left(\frac{\text{GDPpc}_{r,t}}{\text{GDPpc}_{-r,t}}\right) = \gamma_0 + \gamma_1 \text{WeatherA}_{r,t} + \gamma_2 \left(\text{WeatherA}_{r,t} * \text{AGRI}_r\right) + \gamma \text{Z}_{r,t} + \gamma_{R,t} + \gamma_r + \epsilon_{r,t} \qquad (6)
$$

$$
\log(\text{URB}_{r,t}) = \theta_0 + \theta_1 \text{WeatherA}_{r,t} + \theta_2 \left(\text{WeatherA}_{r,t} * \text{AGRI}_r\right) + \theta \text{Z}_{r,t} + \theta_{R,t} + \theta_r + \epsilon_{r,t} \qquad (7)
$$

This baseline model suggests that $MIGR_{r,t}$, which represents average net migration rates, can be explained by a set of weather variables (weather anomalies, defined below) $WeatherA_{r,t}$; by per capita GDP ($GDPpc_{r,t}$) 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 ($GDPpc_{-r,t}$); by the share of the urban population ($URB_{r,t}$) as well as by a vector of control variables ($Z_{r,t}$), described below. As suggested by Propositions 1 and 3, 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 urbanisation. Proposition 5 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 $(WeatherA_{r,t} * AGRI_r)$, 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.[7] 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

[7] We follow Dell et al. (2009, footnote 10) in using 1995 data for agricultural share because data coverage for earlier years is sparse.

for the importance of changes in the regional patterns of migration in sub-Saharan Africa (Adebusoye, 2006).

3.1 Variables description

Data are collected from several sources to compute the variables introduced in the system of equations above. Descriptive statistics are provided in Tables 2 and 3 (Table 1 in the supplementary material offers a detailed description with data sources for the different variables).

- $MIGR_{r,t}$: The *net migration rate* is defined as the difference between immigrants and emigrants per thousands of population, corrected by net refugee flows (see below). Typically research on international migration uses bilateral data on migration flows or stocks to analyze migration into developed countries. However, such data is barely available for developing countries and particularly difficult to obtain for Africa (over a longer period). The reason is that cross-border migration in sub-Saharan Africa is poorly documented (Zlotnik, 1999).[8] Thus, we do not use directly observable data for international migration. 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. The data is constructed from a combination of directly observable international migration data based on official population registers and indirect observations, i.e. migration estimates using a variety of sources, including censuses, surveys, and administrative records.[9] Moreover, as Hatton and Williamson (2003), we account

[8]Directly observable cross-border migration data for Africa can be found in the United Nations Demographic Yearbooks and in the ILO's International Migration Database, but the number of entries is very scarce. In order to deal with the lack of bilateral migration data and to control for possible spatial dependency introduced by such data constraint, we exploit spatial weighting matrices in order to capture the influence of some variables in neighboring countries. In line with the seminal work of Ravenstein (1885) on the role of distance in migration flows, such a weighting also constitutes a way to take into account the costs of migration across borders, which should be positively correlated with distance (Clark, 1986).

[9]The US Census Bureau's strategy to construct its migration data series can be summarized as follows. First, the US

for refugees who are driven by non-economic factors and included in the net migration estimates. To do so, 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. Using the same source (UNHCR, 2009), we compute the *net* refugee movement (NetREF), which is expressed per thousand of the country's population, as the difference between the change in the stock of refugees living in a country (change in refugees residing in country r) and the change in the stock of refugees from that country living elsewhere (change in refugees originating from country r). Nevertheless, our robustness analysis reveals that proceeding or not to such a correction in the dependent variable leaves our main findings unchanged (see Section 3.4).

- $WeatherA_{r,t}$: *Weather variables* should capture the incentives for migration that come through weather anomalies. In line with the climatology literature (see for example, Nicholson, 1986, 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. Rainfall and temperature data originate from the IPCC (Mitchell et al., 2002). Like Barrios et al. (2010), we take the long-run to be the 1901-2000 period and denote the weather anomaly WeatherA, which represents either rainfall anomaly (RAIN) or tem-

Census Bureau uses direct net international migration observations from country censuses on foreign born population or data from general sources such as Eurostat, the International Labor Organization (ILO), International Organization for Migration (IOM), the Organization for Economic Cooperation and Development (OECD). Net migration can be estimated for the intercensal period from census data, especially when it contains information such as place of birth of the foreign-born population or date of arrival and departure. Second, when no or few direct migration observations are available, the US Census relies on indirect estimation techniques, which are applied through an iterative process to generate most accurate results (US Census, 2010, p.22-26). For instance, the census cohort analysis attributes irregularities in the comparison of population by year of birth across two or more censuses to net migration. The residual technique calculates net migration as differences between observed census population distribution and population distribution resulting from a population projection that accounts for natural increases but not migration (US Census, 2010, p.22-26). The residual technique is likely to include illegal and undocumented migrants compared to the more direct, observational approach.

perature anomaly (TEMP), as follows

$$\text{WeatherA}_{r,t} = \frac{\text{WeatherA}_{level,r,t} - \mu_r^{LR}(\text{WeatherA}_{level})}{\sigma_r^{LR}(\text{WeatherA}_{level})} \tag{8}$$

where $\text{WeatherA}_{level,r,t}$ stands for the level of either rainfall or temperature of country *r* in year *t*, and $\mu_r^{LR}(\text{WeatherA}_{level})$ and $\sigma_r^{LR}(\text{WeatherA}_{level})$ are country r's mean value and standard deviation, respectively, in rainfall or temperature over the long-run (LR) reference period. As pointed out by Barrios et al. (2010), anomalies allow one to eliminate possible scale effects and take account of the likelihood that for the more arid countries variability is large compared to the mean (Munoz-Diaz and Rodrigo, 2004). 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 normal in a given year.[10]

- $GDPpc_{r,t}$: *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 the tables we use the short hand notations y for this variable. One problem for directly translating the theoretical framework into an empirical one is that we do not have separate data on rural and urban wages. This is, however, of a lesser problem for the following reasons. Firstly, according to our theoretical framework, weather impacts the rural wage and using GDP per capita is a compromise that may, nevertheless, be a good proxy for the average wage. Secondly, our theoretical framework predicts that weather anomalies drive rural and urban wages in the same direction. Thus, whenever weather anomalies reduce rural wages then they also drive down urban wages. This implies that average wages, proxied by our GDP per capita, fall. Furthermore, the more easily

[10] Since the anomaly transformation provides a partial correction to year-to-year fluctuations, the reader should keep in mind that we are capturing deviations in the weather from the norm.

migrants can move between rural and urban areas the more quickly will the wage differential between both areas be minimized.

- $GDPpc_{-r,t}$: *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 $\sum_{s=1}^{N} f(d_{r,s}) wage_{s,t}$, where $f(d_{r,s}) = 1/(d_{r,s})^2$.[11] In the tables we use the short hand notations y^F for this variable.

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

- $Z_{r,t}$: Our baseline regression includes a set of *control variables*. The occurrence of war seeks to capture the political motivations to migrate. Data on the number of internal armed *conflicts* (*WAR*) are used. This is particularly relevant in the case of Africa where internal conflict have been by far the dominant form of conflict since the late 1950s (Gleditsch et al., 2002). We expect a negative sign, as war should lead to out-migration. Forced migration is undeniably an important feature of migration in Africa. Between the early 80's and the mid 90's, Africa hosted 30% to 45% of the world total refugee stock. The number of refugees in Africa has increased from 1960 to 1995, but due to resolution of conflicts, important repatriations were made possible since the 1990's. Nevertheless, refugees accounted for a large share of the total migrant *stock* in

[11] Although Head and Mayer (2004) warn against giving a structural estimation to this proxy, the 'foreign' wage could be interpreted as the Real Market Potential introduced by Harris (1954). It is unfortunately not possible to proceed to the Redding and Venables (2004) estimation of the real market potential on the investigated period, given the lack of bilateral trade data availability before 1993 (Bosker and Garretsen, 2008). We use distance data from the CEPII (Mayer and Zignago, 2006), and more specifically the simple distance calculated following the great circle formula, which uses latitudes and longitudes of the most important city (in terms of population). The Foreign GDP per capita is therefore constructed by making the less restrictive assumption regarding migration costs, i.e. increasing linearly with distance. As indicated in Section 3.4., our results are nonetheless robust to alternative proxies for migration barriers, including colonial link, contiguity, common colonial ruler and linguistic proximity.

Africa passing from 25% in 1980, to 33% in 1990 and to 22% in 2000 (Zlotnik, 2003).[12] We also follow Hatton and Williamson (2003) in introducing four country-specific policy dummies. For example, Hatton and Williamson (2003) suggest to control for the large expulsion of Ghanaian migrants by the Nigerian government in 1983 and 1985.

- *Time-regional dummies* are introduced using the grouping described in Table 1 of the Appendix. This should capture the regional pattern of migration underlined by several authors. In fact, across-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 each Middle and Southern Africa (Zlotnik, 2003:5). Moreover, trans-boundary migration occurs often among countries of the same region, as regions have their own attraction poles and economic grouping, e.g. the Economic Community of West Africa States, the Southern African Development Community and the Common Market of East and Southern Africa (Adebusoye, 2006). Surveys of the population aged 15 years and older carried out showed that, in 1993, 92% of all the foreigners in Ivory Coast, which is a main attraction pole for migrants in the region, originated from seven other countries in Western Africa (Zlotnik, 1999).

Figures 2.a and 2.b plot net migration rate against rainfall and temperature anomalies, respectively, for the 39 sub-Saharan African countries of the sample over the period 1960-2000. Temperature is on an increasing track whereas rainfall exhibits a decreasing pattern, indicating that sub-Saharan Africa

[12] Given the fact that migration data incorporate refugee figures, we do not follow Hatton and Williamson (2003) in introducing net numbers of refugee flows as an explanatory variable. It would generate an obvious endogeneity problem due to the simultaneity between this additional variable and the dependent variable. We prefer to substract the net refugee flows directly from our dependent variable. Still, we will show that results are not fundamentally changed when we follow Hatton and Williamson (2003)'s approach. Our estimation also differs from the one of Hatton and Williamson (2003) in the sense that we include a country fixed effect while their paper uses a Pooled Ordinary Least Squares (POLS) estimation. An F-test unambiguously confirms the presence of unobserved fixed effects and the Hausman test unambiguously supports the use of a fixed effect model over a random effect one.

is experiencing weather changes over the period of our investigation. Moreover, Barrios et al. (2006) stress that rainfall in sub-Saharan Africa remained constant during the first part of the 20^{th} century until the 1950s, peaking in the late 1950s and being on a clear downward trend since that peak. While weather variables indicate clear trends, average net migration does not. Thus, judging purely based on correlation, it is difficult to state whether net migration rate and rainfall/temperature anomalies move together. Furthermore, our identification strategy exploits year-to-year anomalies of temperature and rainfall anomalies *within* countries that cannot be observed in the averaged series of Figures 2.a and 2.b.

Given the relatively long time period used, the non-stationary nature of our variables may be a point of concern, leading to possible spurious relationships (Maddala and Wu, 1999). We perform the Fisher panel data unit root test on the dependent and the explanatory variables (see Table 2 in the supplementary material). The tests show that all series are stationary at any reasonable level of confidence.

3.2 Dealing with endogeneity

Despite the introduction of region-time dummies which are likely to capture some time-specific and time-region-specific events, we might be in trouble if an unobserved effect is both country-specific and time-variant. For example, the reputation of migrants or the presence of people with the same nationality could accumulate over time and be specific to some countries. There is some evidence for what is called the 'friends and relative' argument, i.e. the fact that migrants are attracted to locations to which they already have some relations (see Hatton and Williamson, 2003). Assume that the presence of migrants from the same nationality would affect GDP per capita negatively, it means that our estimates might be biased downward. Another source of time-varying unobserved effect could result from some

form of ‘selective’ migration policy introduced both in terms of skills and countries of origin by some OECD countries. Such factors could impact GDP per capita and potentially affect migration through another channel than these economic variables. Also, a causal interpretation could be problematic given the potential simultaneity problems that threaten the estimation of some variables. Although empirically the causality from migration to wages is at best weak, we cannot neglect this possibility.[13] Our theoretical framework clearly points to a potential simultaneity, since migrants move with their demand for goods and affect the production in the receiving countries, and thereby alter wages in both the country of origin and the destination country.

To be more precise, our theoretical model suggests that rainfall and temperature anomalies affect the incentives to migrate through an amenity as well as an economic geography channel. Though the amenity channel poses no challenge econometrically, the existence of the economic geography channel hints at possible endogeneities. The two main variables that comprise the economic geography channel are, according to our theoretical contribution, wages and urbanization. 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. An increase in urbanization should theoretically increase the incentives to further migrate as migrants move with their income and strengthen agglomeration forces. This is what is usually referred to as the home market effect (Krugman, 1991).

One approach to deal with this simultaneity issue is by resorting to instrumental variables in a fixed effect framework that copes with unobserved time-constant and time-region heterogeneity. One of the difficulties is to find a valid instrumental variable that will not affect the net migration rate through

[13]Among others, Card (1990), Friedberg and Hunt (1995), Hunt (1992) as well as Ottaviano and Peri (2011) cannot find empirical evidence supporting this causal link. With the exception of Maystadt and Verwimp (2009) who study the issue in the particular context of refugee hosting, no similar assessment has been undertaken in the African context.

another channel than the potentially endogenous variable. In regression (1), we instrument GDP per capita with the absolute growth in the money supply. The relevance of this candidate rests on the importance of monetary variables in determining GDP variation.

Indeed, one of the most familiar rules in monetary policy is the Taylor rule, which links monetary policy with inflation and the output gap. Under this rule, which is followed by e.g. the Fed in the US, deviations from the potential output should induce monetary policy actions, thus making money supply, at least for the US, endogenous to GDP. However, sub-Saharan African countries, just like the Euro area countries, do not follow the Taylor rule but focus only on fighting inflation. This is also confirmed in Kasekende and Brownbridge (2011),[14] who write that "[t]he implementation of monetary targeting frameworks in sub-Saharan Africa has, in practice, paid little attention to the stabilization of output." As a result, monetary policy in sub-Saharan Africa can be viewed as clearly monetarist in nature. Hence, by changing the money supply, policy makers are able to induce changes in interest rates which affect the incentives for investments, and thereby production and wages. Indeed, contractions in the money supply have been shown to be the source of such strong contractions in production as those during the Great Depression (Friedman and Schwartz, 1971), or as such large expansions as the Great Moderation (Brunnermeier (2008); Bean (2010); Cecchetti (2009)). The channels through which monetary policy may affect production are now well-studied, and include direct channels like the interest rate channel, or indirect ones, like the credit channels (see Cecchetti (1995); Gertler and Bernanke (1995); Mishkin (1996)). Hence, especially in countries with inflation targets like the sub-Saharan African countries, the causality clearly goes from monetary policy to GDP.

[14] The authors are Deputy Governor and Economic Advisor to the Governor at the central bank of Uganda.

3.3 Results

We present the main results of this article in Table 4. As predicted by the theoretical model we find both 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, denge 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[15] and, consequently, migration might occur as a preventive step. Similar reasons have been forwarded by Gutmann and Field (2010) who emphasize why not all previous inhabitants returned 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 complements previous works by Barrios et al. (2010). Furthermore, sub-Saharan African countries that have a large

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

agricultural sector are particularly vulnerable. In regressions (1), (3) and (7), temperature anomalies have a negative impact on the GDP per capita ratio, in line with the findings in Dell et al. (2009).[16] The interaction term of rainfall anomalies and the dummy for above-median agricultural added value ($AGRI$) 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 (2), (5), (6) and (9)), 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.[17] 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

[16]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).

[17]Further analyses (available from the authors) show that our results on rainfall differ from those in Barrios et al. (2006) because we have a different sample (migration data causes a reduction in the sample size). Although non-significant, our coefficients have a similar effect on urbanization, in terms of magnitude, as Barrios et al. (2006). They find that a one percent decrease in rainfall (i.e. -10 mm per year and per country) yields a 0.45 percent increase in urbanization. Our (non-significant) rainfall coefficients indicate that a one percent decrease in rainfall induces a 0.98 percent (unweighted country average) and a 0.81 percent (population-weighted average) increase in urbanization. We note that even though temperature anomalies dominate in our sample, results on other samples e.g. Henry et al. (2003), Barrios et al. (2006) or regions (Munshi, 2003, for Mexico) emphasize the role of rainfall, while yet others push the importance of temperature alone (Dillon et al., 2010; Burke et al., 2009). Thus, though different samples find robust results for an impact from weather anomalies, they differ in whether rainfall or temperature is the main driver. Since both drive evapotranspiration, the differences in results may arise through the possibility that for some countries, evapotranspiration is more strongly driven by temperature while in others rain might be more important simply due to differences in geographic conditions or the local flora and fauna.

on international migration. Section 3.5 discusses which channels outweigh for international migration and provides estimates of the effect of weather anomalies on international migration.[18]

These results hinge crucially on the use of our three regressions, instrumental variables framework. As we argued above, only a unified framework may be able to simultaneously account for the channels that we identified within our theoretical framework. Thus, for consistency we describe our use of the instruments in more detail now. Our first-stage regression confirms that a decline in the growth of money is statistically associated with a fall in GDP per capita. A decrease by a standard deviation in money growth should reduce relative GDP per capita by about 11%. In regressions (3) to (5), we show results under overidentifying restrictions by introducing two additional instruments. We 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 colonial power. According to Miller and Singh (1994)'s catch-up hypothesis and consistent with the results of Barrios et al. (2006), restrictions on internal movements during colonial times have been followed by a strong urbanization after independence.[19] This has been particularly the case in former British colonies whose administration favored the establishment of new colonial urban centers (Falola and Salm, 2004). Although Figure 2 does not seem to depict a different trajectory in net

[18]Our preferred specification (3)-(5) yields average partial effects (APE) of rainfall and temperature in agriculturally-dominated countries (Agri=1) and in countries with below median agricultural GDP share (Agri=0) taking on the following values: $APE_{RAIN,Agri=1}$=1.07, $APE_{RAIN,Agri=0}$=0, $APE_{TEMP,Agri=1}$=-0.65 and $APE_{TEMP,Agri=0}$=0.53. These values account for the amenity and economic geography channel of weather on migration.

[19]Hance (1970, p.223) documents that restrictions on movements to the cities under colonial regimes greatly explain the low urban levels of less than 10% in the three main Eastern African countries (Ethiopia, Somalia and Kenya). According to Njoh (2003), colonial authorities worked fervently to discourage Africans from living in urban areas. Governments in colonial Africa, and South Africa during the apartheid era, crafted legislation to prevent the rural-to-urban migration of native Africans. The covert goals of this policy were to preserve the 'white' character of the cities and keep the black population in the rural areas. As reported by Roberts (2003) "colonial relationships between core countries and their dependencies set the stage for differences in urbanization among less-developed countries. In the colonial situation, provincial cities often served mainly as administrative and control centers to ensure the channeling for export of minerals, precious metals or the products of plantations and large estates; but wealth and elites tended to concentrate in the major city. When countries became independent and began to industrialize, it was these major cities that attracted both population and investment. They represented the largest and most available markets for industrialists producing for the domestic market. They also were likely to have the best infrastructure to support both industry and commerce in terms of communications and utilities."

migration in the years where most African countries became independent, we cannot exclude a priori the possibility that state independence has affected cross-border migration by another channel than rural-urban migration. However, using three instruments with two endogenous variables allows us to test the exogenous nature of these instruments (overidentification test). Beyond the reasonable nature of the overidentifying restrictions, statistical tests support our confidence in the validity of these instrumental variables. Provided at least one instrument is valid, the Hansen overidentification test fails to reject the null hypothesis of zero correlation between these instrumental variables and the error terms. F-tests on excluded instruments equal 30.84 in first-stage regression (3) and 12.99 in first-stage regression (4). 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. Regression (6) indicates that our results are unaltered with the LIML estimator and that we can reject the null hypothesis of weak instruments. In regressions (7), (8) and (9), 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.

3.4 Robustness

Robustness checks are not shown in the paper (but presented in Section 4 of the supplementary material). These robustness checks relate to the use of alternative dependent variables, alternative definition of the main explanatory variables of interest and the addition or omission of control variables. Regarding the dependent variable, our results are robust to the definition used by Hatton and Williamson

(2003), i.e. without subtracting the net refugee flows from the migration rate but introducing them as an explanatory variable (see Table 5 in the supplementary material). Since now the dependent variable incorporates the movement of refugees, the net refugee flows (NetREF) exhibit a positive coefficient which is close to 1. Although it unduly increases the risk of endogeneity, our results are unaltered by this inclusion.[20] Furthermore, we test the robustness of our findings to an alternative definition of our variables of interest (see Table 6 in the supplementary material). Our results are unaltered when rainfall and temperature are expressed in levels (with or without logarithmic transformation) rather than in anomaly terms. Moreover, the inclusion of a foreign-defined version or of lagged values for weather variables, which do not feature significant explanatory power, does not change our main results. Using alternative definitions for GDP per capita does not change our findings. In fact, our main results are confirmed when replacing GDP per capita by the GDP per worker, using the Chain transformation instead of the Laspeyres index in the real terms transformation (see Table 7 in the supplementary material), or exploiting alternative weights in the spatial decay function to compute the foreign wage (see Table 8 in the supplementary material). These alternative weights include other proxies than the distance for migration costs, including colonial link, contiguity, a common colonial ruler and linguistic proximity. Moreover, we also test the robustness of our results to the omission of some control variables (see Table 9 in the supplementary material). Since the works by Miguel et al. (2004), Burke et al. (2009) and Hsiang et al. (2011), we cannot exclude that weather affects conflict and, hence, the inclusion of the conflict variable may wipe out some of the explanatory power of our weather variables.

[20] Moreover, Hatton and Williamson (2003) point out that demographic pressure is an important determinant of international migration. Our main results remain valid when introducing such a demographic variable in our specification with the lagged value of population density, which is significant and affects net migration negatively. However, potential endogeneity issues induced by the introduction of population density require to be cautious with this specification. Furthermore, the entry into the ACP agreements could also constitute another determinant of international migration. Completing the data by Head et al. (2010) on the entry into ACP with data for Botswana and Namibia, adding the entry into ACP as an additional control variable does not alter the main results and shows a non-significant coefficient. These results are shown in the supplementary material.

Therefore, the inclusion of the conflict-related variables may undermine our estimations of weather-induced migration. Although introducing a potential omitted variable bias, omitting the conflict-related variable does not alter the main results of this paper. Finally, we test the robustness of our results to an alternative dependent variable, based on bilateral migration flows between our 39 SSA countries and 14 OECD destination countries (see Table 10 in the supplementary material based on data from Ortega and Peri (2009, 2011)). Results obtained from two-stage estimations like in our baseline confirm our main findings of Table 4. Like in Mayda (2010), we find that a higher GDP per capita at origin or lower GDP per capita at destination reduces outmigration. Moreover, these robustness results indicate that decreased rainfall anomalies increase the economic incentives to migrate from countries highly dependent on the agricultural sector, while temperature anomalies in turn increase that economic incentives. Our main findings hold, therefore, also for migration outside Africa.

It is likely that our proxy for the domestic wage could be subject to measurement errors and thus potentially bias our results.[21] Nevertheless, we believe that this should not significantly influence our results for the following reasons. Firstly, these measurements errors are partly dealt with through the use of the instrumental variables. Secondly, by restricting the sample to sub-Saharan African countries, we are more likely to have relatively similar GDP and institutional structures, which is an important determinant of sound comparisons over time (Deaton and Heston, 2010). Thirdly, we test the robustness of our results to alternative GDP per capita measurements. Replacing GDP per capita by GDP per worker or using the Chain transformation instead of the Laspeyres index in the real terms

[21]One would expect these errors to be largely dependent on the institutional environment in the countries under concern. In this case, they would not cause any bias if they were constant over time or time-specific, as we use country- and time-specific fixed effects. Nevertheless, since some countries might have experienced institutional changes that induced a variability in the measurement error then this could potentially leave some room for biases. For example, poor countries may be more likely to have a less developed statistical capacity and migration data may be more likely to be based on the residual approach, or more inclusive of illegal and undocumented migrants. Consequently, a change in economic development and statistical capacity may be associated with a change in demographic accounting methodology, for example from a residual to an observational approach. In that case, the estimated coefficient of the GDP ratio is likely to feature a downward bias.

transformation does not change the main results (see supplementary material).

3.5 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. Our 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 4. More details can be found in the supplementary material.

3.5.1 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 (3) to (5) in Table 4 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 6). Table 6 also indicates the share of this weather-induced migration that is due to rainfall and temperature as well as the fraction that is due to the amenity effect of weather and to the economic geography effects (GDP per capita ratio and urbanization). Rainfall changes drove changes in net migration more strongly than temperature over the period 1960-2000, while weather anomalies affect

international migration mainly through the economic geography channel, thus economic incentives, to migrate. 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 only about 3% of the 4 million annual internal (rural-urban) migrants caused by weather anomalies. This means that we estimate that in total, over the period 1960-2000, 5 million people have been displaced due to weather anomalies. Such a figure may seem rather low, but given the 'net' nature of our dependent variable, it represents a lower bound estimate.[22]

3.5.2 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 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) and its forecasted weather changes are reproduced in Table 5. 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

[22] We find that, in net terms, 0.851 people out of 1000 individuals living in sub-Saharan Africa (SSA) left their country every year over the period 1960-2000. This value is obtained by computing the number of net migrants from countries with a *negative* average net migration rates over the period 1960-2000 divided by total SSA population. Similarly, by focusing on countries with positive average net migration rates, we find that 0.637/1000 migrated to another of the 39 SSA countries of our sample. The difference between these two values, indicates that 0.241/1000 established in another country of the world. Considering only the effect of weather changes, we find that 0.305/1000 left one of the 39 SSA countries, 0.159/1000 found home in another of these 39 countries and 0.146/1000 in another country of the world. This means also that 35.83% (305/851) of people leaving their country did so because of weather changes.

emission and world population increase are moderate (see further details in the supplementary material).

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 21^{st} century (see columns 2 to 4 of Table 6). The UN Population Division provides projections of population changes over the 21^{st} 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 results are an additional 25 million migrants in the high-fertility/worse-weather-change scenario.

In order to present country-specific results we constructed a map.[23] 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. 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.

Concerning the end of century projections we have to add that, given the non-negligible amounts of environmental migrants that we estimate, some of our assumptions may not continue to hold. In particular, there might be a strong divergence between the desire to migrate versus the capacity to do so.[24]

[23] For illustrative purposes, the map displays values for Cape Verde, Guinea-Bissau, Somalia and South Africa. These countries were dropped from our initial sample due to few observations on various variables. To include them in the map, we applied our coefficients to available data on migration, population and weather for these countries.

[24] We are grateful to one referee for suggesting this line of thought.

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. Then, massive population movements could speed up the transmission of epidemic diseases such 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). Finally, the expected 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 have 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.

4 Conclusion

The problems associated with weather anomalies certainly rank as one of the important issues of our times. However, few academic evidence has been provided regarding one of its most often heard 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 its 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.

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), who show that weather anomalies bear an important impact on GDP per capita. We then find that wages are robust and significant determinants of international migration. We also obtain 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 0.3% 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. 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 million inhabitants may move as a consequence of weather anomalies.

These results impose serious and challenging questions for policy makers. After all, African coun-

tries account for only approximately five percent of world emissions. If one believes the academic literature and the works of the IPCC in that 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), policies aiming at making crops less sensitive to weather anomalies is the most obvious policy recommendation. Easing the market reallocation from agriculture to manufacturing sectors and emphasizing the absorption role of urban areas will also reduce the social costs of weather anomalies. However, our paper also qualifies the market-oriented solution promoted by Collier et al. (2008). Specific policies easing the factor absorption capacity at national level 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.

Our projections also warn us about possible consequences in terms of health and security that such population movements could have on their hosting nations. Provided one is concerned about the security consequences of environmental migration, strengthening the buffering role of urban centers may constitute a policy option. In that respect, reducing congestion costs and improving transport infrastructure may enhance the absorption capacity of agglomeration centers.

References

Adebusoye, P. (2006). Geographic Labour Mobility in Sub-Saharan Africa. Technical report, IDRC Working Papers on Globalization, Growth and Poverty.

Andre, C. and Platteau, J.-P. (1998). Land relations under unbearable stress: Rwanda caught in the Malthusian trap. *Journal of Economic Behavior and Organization*, 34:1–47.

Angrist, J. and Pischke, J.-S. (2009). *Mostly Harmless Econometrics: An empiricist's companion*. Princeton University Press.

Barrios, S., Bertinelli, L., and Strobl, E. (2006). Climatic change and rural-urban migration: the case of sub-saharian Africa. *Journal of Urban Economics*, 60(357-371).

Barrios, S., Bertinelli, L., and Strobl, E. (2010). Trends in rainfall and economic growth in Africa: A neglected cause of the African growth tragedy. *The Review of Economics and Statistics*, 92(2):350–366.

Bean, C. (2010). Joseph schumpeter lecture the great moderation, the great panic, and the great contraction. *Journal of the European Economic Association*, 8(2-3):289–325.

Beauchemin, C. and Bocquier, P. (2004). Migration and Urbanization in Africa: An Overview of the Recent Empirical Evidence. *Urban Studies*, 41(11):2245–2272.

Black, R. (2001). Environmental refugees: Myth or reality? *UNHCR Working Paper*, 34.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R., and Yanda, P. (2007). Africa. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II. In Parry, M., Canziani, O., Palutikof, J., van der Linden, P. J., and Hanson, C.,

editors, *Fourth assesment report of the intergovernmental panel on climate change*, pages 433–467. Cambridge University press, Cambridge UK.

Bosker, M. and Garretsen, H. (2008). Economic Geography and Economic Development in Sub-Saharan Africa. CESifo Working Paper Series No. 2490.

Brunnermeier, M. (2008). Deciphering the 2007-08 liquidity and credit crunch. *Journal of Economic Perspectives*, 23(1):77–100.

Bundervoet, T. (2009). Livestock, land and political power: The 1993 killings in Burundi. *Journal of Peace Research*, 46(3):357–376.

Burke, M., Miguel, E., Satyanath, S., Dykema, J., and Lobell, D. (2009). Warning increases the risk of civil war in africa. *Proceedings of the National Academy of Sciences*, 106(49):20670–20674.

Card, D. (1990). The Impact of the Mariel Boatlift on the Miami labour markets. *Industrial and Labor Relations Review*, 43(2):245–257.

Cecchetti, S. (1995). Distinguishing theories of the monetary transmission mechanism. *Review-Federal Reserve Bank Of Saint Louis*, 77:83–83.

Cecchetti, S. (2009). Crisis and responses: The federal reserve in the early stages of the financial crisis. *Journal of Economic Perspectives*, 23(1):51–75.

Cheshire, P. and Magrini, S. (2000). Endogenous processes in european regional growth: Convergence and policy. *Growth and Change*, 31(4):455–479.

Christensen, J., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R., Kwon, W.-T., Laprise, R., Rueda, V. M., Mearns, L., Menndez, C., Rsissnen, J., Rinkeand, A., Sarr, A., and

Whetton, P. (2007). *Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Clark, W. (1986). *Human migration*. Sage Publications Beverly Hills.

Collier, P., Conway, G., and Venables, T. (2008). Climate Change and Africa. mimeo, forthcoming in The Oxford Review of Economic Policy.

Deaton, A. and Heston, A. (2010). Understanding PPPs and PPP-based National Accounts. *American Economic Journal: Macroeconomics*, 2(4):1–35.

Dell, M., Jones, B. F., and Olken, B. A. (2009). Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates. *The American Economic Review*, 99(2):198–204.

Deschenes, O. and Greenstone, M. (2007). The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather. *The American Economic Review*, 97(1):354–355.

Dillon, A., Mueller, V., and Salau, S. (2010). Migratory responses to agricultural risk in northern nigeria. *IFPRI discussion papers*.

Duranton, G. and Puga, D. (2004). Micro-foundations of urban agglomeration economies. In Henderson, V. and Thisse, J.-F., editors, *Handbook of Regional and Urban Economics*, volume IV, chapter 48, pages 2063–2117. Amsterdam: North Holland.

El-Hinnawi, E. (1985). Environmental Refugees. United Nations Environment Programme, Nairobi.

Fadul, A. A. (2006). Natural Resources Management for Sustainable Peace in Darfur. In King, M. E. and Osman, M. A., editors, *Environmental degradation as a cause of conflict in Darfur*. University for Peace, Addis Ababa, Ethiopia.

Falola, T. and Salm, S. J. (2004). *Globalization and Urbanization in Africa*. Africa World Press.

Feng, S., Krueger, A., and Oppenheimer, M. (2010). Linkages among climate change, crop yields and mexico–us cross-border migration. *Proceedings of the National Academy of Sciences*, 107(32):14257.

Findley, S. (1994). Does drought increase migration? a study of migration from rural mali during the 1983-1985 drought. *International Migration Review*, pages 539–553.

Fisher, A. C., Hanemann, W. M., Roberts, M. J., , and Schlenker, W. (2011). The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather: Comment. *The American Economic Review*, forthcoming.

Food and Agricultural Organization (2004). The State of Food and Agriculture 2003-2004. FAO Food and Agricultural Organization, Agriculture Series (SOFA).

Friedberg, R. and Hunt, J. (1995). The impact of immigration on host country wages, employment and growth. *Journal of Economic Perspectives*, 9(2):23–44.

Friedman, M. and Schwartz, A. (1971). *A monetary history of the United States, 1867-1960*, volume 12. Princeton University Press.

Gertler, M. and Bernanke, B. (1995). Inside the black box: the credit channel of monetary policy transmission. *Journal of Economic Perspectives*, 9(4):27–48.

Gleditsch, N. P., Wallensteen, P., Eriksson, M., Sollenberg, M., and Strand, H. (2002). Armed Conflict 1946-2001: A new Dataset. *Journal of Peace Research*, 39(5):615–637.

Gutmann, M. and Field, V. (2010). Katrina in historical context: environment and migration in the us. *Population & Environment*, 31(1):3–19.

Hance, W. (1970). *Population, migration, and urbanization in Africa*. Columbia University Press.

Harris, C. (1954). The market as a factor in the localization of industry in the United States. *Annals of the Association of American Geographers*, 64:315–348.

Hatton, T. J. and Williamson, J. G. (2003). Demographic and economic pressure on emigration out of Africa. *Scandinavian Journal of Economics*, 105(3):465–486.

Head, K. and Mayer, T. (2004). The Empirics of Agglomeration and Trade. In Henderson, V. and Thisse, J.-F., editors, *Handbook of Regional and Urban Economics*, volume IV. Amsterdam: North Holland.

Head, K., Mayer, T., and Ries, J. (2010). The erosion of colonial trade linkages after independence. *Journal of International Economics*, 81:1369–1401.

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

Hsiang, S., Meng, K., and Cane, M. (2011). Civil conflicts are associated with the global climate. *Nature*, 476:438–441.

Hunt, J. (1992). The Impact of the 1962 repatriates from Algeria on the French labor market. *Industrial and Labor Relations Review*, 45(3):556–572.

IPCC (2007). *Climate Change 2007 - Impacts, Adaptation and Vulnerability*. Cambridge University Press.

Jacobson, J. (1988). Environmental Refugees: a Yardstick of Habitability. *Bulletin of Science, Technology & Society*, 8(3):257.

Kasekende, L. and Brownbridge, M. (2011). Post-crisis monetary policy frameworks in sub-saharan africa. *African Development Review*, 23(2):190–201.

Kibreab, G. (1997). Environmental Causes and Impact of Refugee Movements: A Critique of the Current Debate. *Disasters*, 21(1):20–38.

Kiszewski, A., Mellinger, A., Spielman, A., Malaney, P., Sachs, S., and Sachs, J. (2004). A global index representing the stability of malaria transmission. *The American Journal of Tropical Medicine and Hygiene*, 70(5):486.

Krugman, P. (1991). Increasing returns and economic geography. *Journal of Political Economy*, 99:483–499.

Lach, S. (2007). Immigration and prices. *Journal of Political Economy*, 115(4):548–587.

Maddala, G. S. and Wu, S. (1999). A comparative Study of Unit Root Tests With Panel Data and A New Simple Test. *Oxford Bulletin of Economics and Statistics*, 61:631–652.

Marchiori, L. and Schumacher, I. (2011). When nature rebels: international migration, climate change, and inequality. *Journal of Population Economics*, 24(2):569–600.

Mayda, A. (2010). International migration: a panel data analysis of the determinants of bilateral flows. *Journal of Population Economics*, 23(4):1249–1274.

Mayer, T. and Zignago, S. (2006). Notes on CEPII's distances measures. CEPII distance data.

Maystadt, J.-F. and Verwimp, P. (2009). Winners and Losers Among a Refugee-Hosting Population. *CORE Discussion Paper*, 2009/34.

McGregor, J. (1993). Refugees and the environment. *Geography and Refugees: Patterns and Processes of Change*, pages 157–170.

Miguel, E., Satyanath, S., and Sergenti, E. (2004). Economic shocks and civil conflict : An instrumental variable approach. *Journal of Political Economy*, 112(4):725.

Miller, H. M. and Singh, R. N. (1994). Urbanization during the Postcolonial Days. In Traver, J. D., editor, *Urbanization in Africa*. Greenwood press, London.

Mishkin, F. (1996). The channels of monetary transmission: lessons for monetary policy.

Mitchell, T. D., Hulme, M., and New, M. (2002). Climate Data for Political Areas. *Area*, 31(2):109–112.

Montalvo, J. G. and Reynal-Querol, M. (2007). Fighting against Malaria: Prevent wars while waiting for "miraculous" vaccine . *The Review of Economics and Statistics*, 89(1):165–177.

Mueller, V. and Osgood, D. (2009). Long-term consequences of short-term precipitation shocks: evidence from brazilian migrant households. *Agricultural Economics*, 40(5):573–586.

Munoz-Diaz, D. and Rodrigo, F. (2004). Spatio-Temporal Patterns of Seasonal Rainfall in Spain

(1912-2000) Using Cluster and Principal Component Analysis: Comparison. *Annales Geophysicae,*, 22:1435–1448.

Munshi, K. (2003). Networks in the modern economy: Mexican migrants in the us labor market. *Quarterly Journal of Economics,* 118(2):549–599.

Myers, N. (1996). Environmentally-induced displacements: the state of the art. Technical report, Environmentally-Induced Population Displacements and Environmental Impacts Resulting from Mass Migration, International Symposium.

Naude, W. (2008). Conflict, disasters, and no jobs: Reasons for international migration from sub-saharan africa. WIDER Research Paper, 2008/85.

Nicholson, S. (1986). The Spatial Coherence of African Rainfall Anomalies: Interhemispheric Teleconnections. *Journal of Applied Meteorology*, 25(10):1365–1381.

Nicholson, S. (1992). An Overview of African Rainfall Fluctuations of the Last Decade. *Journal of Climate*, 6(7):1463–1466.

Njoh, A. J. (2003). Urbanization and development in sub-Saharan Africa. *Cities*, 20(3):167–174.

Nordhaus, W. (2008). *A question of balance: Weighing the options on global warming policies*. Yale Univ Pr.

Ortega, F. and Peri, G. (2009). The Causes and Effects of International Labor Mobility: Evidence from OECD Countries 1980-2005 . Human Development Research Paper 2009/06.

Ortega, F. and Peri, G. (2011). The Aggregate Effects of Trade and Migration: Evidence from OECD Countries . IZA Discussion Paper No. 5604.

Ottaviano, G. and Peri, G. (2011). Rethinking the effects of immigration on wages. *Journal of the European Economic Association*, forthcoming.

Piguet, E., Pecoud, A., and de Guchteneire, P. (2011). Migration and Climate Change. Cambridge University Press.

Rappaport, J. (2007). Moving to nice weather. *Regional Science and Urban Economics*, 37(3):375–398.

Rappaport, J. and Sachs, J. (2003). The united states as a coastal nation. *Journal of Economic Growth*, 8(1):5–46.

Ravenstein, E. (1885). The Laws of Migration. *Journal of the Statistical Society of London*, 48(2):167–235.

Redding, S. and Venables, A. J. (2004). Economic geography and international inequality. *Journal of International Economics*, 62:53–82.

Roberts, B. (2003). Comparative Systems: An Overview. In *Conference on African Migration in Comparative Perspective, Johannesburg, South Africa*, pages 4–7.

Saiz, A. (2007). Immigration and Housing Rents in American Cities. *Journal of Urban Economics*, 61:345–371.

Saldaña-Zorrilla, S. and Sandberg, K. (2009). Impact of climate-related disasters on human migration in mexico: a spatial model. *Climatic change*, 96(1):97–118.

Suhrke, A. (1994). Environmental Degradation and Population Flows. *Journal of International Affairs*, 47(2).

Taylor, E. and Martin, P. (2001). Human capital : migration and rural population change. In Gardner, B. and Rausser, G., editors, *Handbook of Agricultural economics*, pages 457–511. Elsevier Science B V.

Todaro, M. (1980). Internal Migration in Developing Countries : A Survey. In Easterlin, R., editor, *Population and Economic Change in Developing Countries*, chapter 6, pages 361–402. University of Chicago Press.

UNHCR (2009). *Statistical Online Population Database*. www.unhcr.org/statistics/populationdatabase, Data extracted: 01/03/2009, United Nations High Commissioner for Refugees (UNHCR), Geneva.

United Nations (2008). *Fighting climate change: Human solidarity in a divided world* .

United Nations (2009). Access on 28/11/2010, http://esa.un.org/unpp/, World Population Prospects: The 2008 Revision. Department of Economic and Social Affairs, United Nations.

US Census (2010). International Data Base: Population Estimates and Projections Methodology. http://www.census.gov/population/international/data/idb/estandproj.php, June 2010, US Census Bureau.

Warren, R., Arnell, N., Nicholls, R., Levy, P., and Price, J. (2006). Understanding the regional impacts of climate change. Technical report, Tyndall Centre for Climate Change Research Working Paper 90.

World Bank (2010). *World Development Report 2010: Development and Climate Change*. Washington, DC: World Bank.

Yap, L. (1977). The attraction of cities : A review of the migration literature. *Journal of Development Economics*, 4(3):239–264.

Zlotnik, H. (1999). Trends of International Migration since 1965: What Existing Data Reveal. *International Migration*, 37(1):21–61.

Zlotnik, H. (2003). Migrants' rights, forced migration and migration policy in Africa. *Migration in Comparative Perspective conference, Johannesburg*.

List of Figures and tables

Figure 1: Rural-urban and international migration

a. Rural sector b. Urban sector

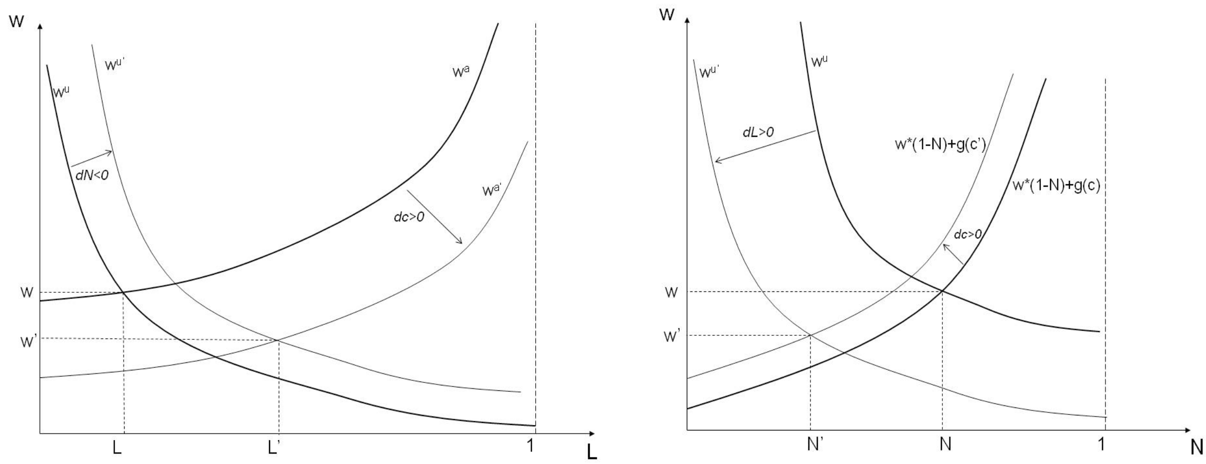


Table 1: Countries

Regions	Countries
Central	Burundi, Cameroon, Central African Republic, Chad, Congo Brazzaville, Congo Kinshasa, Gabon, Rwanda
East	Djibouti, Ethiopia, Kenya, Mauritius, Sudan, Tanzania, Uganda
South	Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Zambia, Zimbabwe
West	Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo

Table 2: 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 weigthed by distance.
WAR	War onset, value 1 for civil war onset
WAR^F	War onsets in other countries weigthed 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

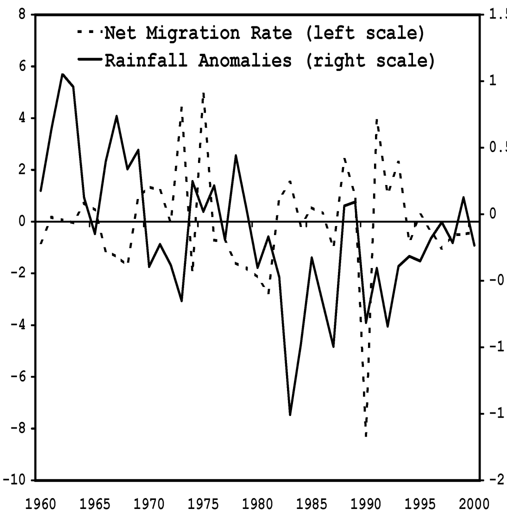
A more detailed variable description containing also the different sources for the data is provided in the supplementary material.

Table 3: Descriptive statistics

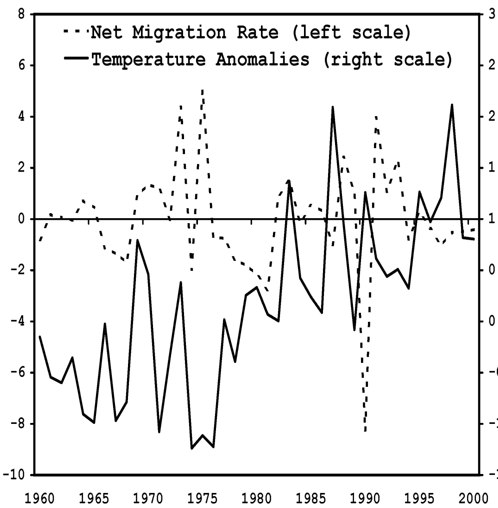
	Mean	Std Dev	Units
MIGR	0.1511	20.657	per 1’000 of population
$MIGR^a$	0.1581	8.930	per 1’000 of population
$RAIN_{level}$	1051.2470	578.741	mm
$TEMP_{level}$	24.4440	3.371	Celsius degrees
RAIN	-0.3688	0.975	anomalies
TEMP	0.5588	1.063	anomalies
AGRI	0.4347	0.496	1 if country’s agricultural share of GDP is above median in 1995, 0 otherwise
RAIN*AGRI	-0.1583	0.648	
TEMP*AGRI	0.2221	0.754	
WAR_{t-1}	0.0333	0.180	1 if more than 100 deaths, 0 otherwise
WAR^F_{t-1}	0.0298	0.059	
URB	28.5612	14.725	% of population
(log)URB	3.1931	0.616	
$\log(y/y^F)$	-1.1689	0.836	
Δ Money Supply	0.0277	0.140	in 10^{12} US dollars
New State	0.0053	0.073	1 if country is in 2 first years of independence, 0 otherwise
New State UK	0.0040	0.063	1 if country is in 2 first years of independence from UK, 0 otherwise
NetREF	$-6.69*10^{-5}$	18.528	per 1’000 of population

$MIGR^a$ stands for net migration rate without the correction for the refugee movement.

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



a. Rainfall and net migration



b. Temperature and net migration

Source: IPPC for rainfall and temperature data and US Census for net migration.

Table 4: Two-stage regressions

Regression	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Models	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS LIML	FE2SLS	FE2SLS	FE2SLS
SE	robust	robust	robust	robust	robust	robust	robust	robust	robust
Stage	1^{st}	2^{nd}	1^{st}	1^{st}	2^{nd}	2^{nd}	1^{st}	1^{st}	2^{nd}
Dependent Variable	log(y/y^F)	MIGR	log(y/y^F)	log(URB)	MIGR	MIGR	log(y/y^F)	log(URB)	MIGR
RAIN	-0.0222	1.277	-0.023	-0.00332	0.843	0.843	-0.0231	-0.0034	0.845
	[0.0140]	[0.978]	[0.0140]	[0.00832]	[0.832]	[0.832]	[0.0139]	[0.00830]	[0.833]
TEMP	-0.0457***	2.922**	-0.0432***	-0.0204**	2.841**	2.842**	-0.0432***	-0.0203**	2.849**
	[0.0153]	[1.366]	[0.0153]	[0.00876]	[1.239]	[1.240]	[0.0153]	[0.00875]	[1.252]
RAIN*AGRI	0.0484***	-2.608**	0.0494***	0.00162	-1.258	-1.258	0.0495***	0.0017	-1.26
	[0.0187]	[1.314]	[0.0187]	[0.00997]	[0.936]	[0.936]	[0.0187]	[0.00995]	[0.937]
TEMP*AGRI	0.00702	-1.382	0.00811	0.0455***	-4.253**	-4.254**	0.00807	0.0454***	-4.268**
	[0.0217]	[1.297]	[0.0218]	[0.00980]	[1.693]	[1.694]	[0.0217]	[0.00979]	[1.715]
WAR_{t-1}	-0.075	6.024	-0.0738	0.0104	2.997	2.997	-0.0738	0.0104	2.996
	[0.0877]	[7.611]	[0.0877]	[0.0259]	[5.709]	[5.710]	[0.0876]	[0.0259]	[5.715]
WAR^F_{t-1}	-0.183	7.869	-0.182	0.02	0.86	0.861	-0.182	0.02	0.861
	[0.150]	[9.281]	[0.150]	[0.0850]	[7.194]	[7.195]	[0.150]	[0.0849]	[7.210]
log(y/y^F)		52.30**			21.58***	21.59***			21.62***
		[20.57]			[7.216]	[7.219]			[7.286]
log(URB)					67.51***	67.53***			67.83***
					[24.14]	[24.15]			[24.55]
Instruments									
Δ Money	0.131**		0.131**	0.0596			0.130**	0.0591	
	[0.0556]		[0.0557]	[0.0350]			[0.0556]	[0.0349]	
New State UK			-0.641***	0.230***			-0.671***	0.194***	
			[0.0892]	[0.0484]			[0.0725]	[0.0323]	
New State			-0.0297	-0.0362					
			[0.0504]	[0.0338]					
HW-Dum[a]	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Region-Dum[a]	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Time-Dum[a]	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Region-Time[a]	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Observations	750	750	750	750	750	750	750	750	750
Number of countries	39	39	39	39	39	39	39	39	39
F-test	61.85***	23.23***	88.87***	65.79***	22.17***	22.17***	93.85***	66.36***	19.33***
F-test on excl. IV	5.51**		30.84***	12.99***			46.24***	19.43***	
Underid test		6.796***			7.595***	7.595***			7.124***
P-value Hansen					0.871	0.871			
Endo stat		12.98***			14.53***	14.53***			13.26***
Root MSE	.2288	13.04	.2283	.09746	10.82	10.82	.2281	.09738	10.84

** 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 5: IPCC projected changes in rainfall and temperature

	projected change in rainfall			projected change in temperature		
	best	median	worst	best	median	worst
Saharan	57%	-6%	-44%	2.6	3.6	5.4
West	13%	2%	-9%	1.8	3.3	4.7
East	25%	7%	-3%	1.8	3.2	4.3
South	6%	-4%	-12%	1.9	3.4	4.8

Columns "worst", "median" and "best" correspond to the less optimistic, medium and most optimistic weather changes of the IPCC's scenario A1B, i.e. 75%, 50%, and 25% quartile values for projected changes in precipitation (%) and to the 25%, 50%, and 75% quartile values for projected changes in temperature (°C) between the period 1980-1999 and the period 2080-2099.

Source: IPCC Fourth Assessment Report, Scenario A1B (Christensen et al., 2007).

Table 6: Weather-induced migration for the sub-Saharan Africa region

	1960-2000	**Projections for the end of the 21st century**		
		best	median	worst
Weather-driven migration				
Annual net (international) migration rate$^{(a)}$	**-0.30**	**-1.21**	**-3.40**	**-5.32**
Annual number of net international migrants$^{(b)}$	-128'414			
Annual number of *internal* migrants$^{(b,c)}$	4'206'729			
Total number of net international migrants	-5'136'569			
Total number of *internal* migrants$^{(c)}$	168'269'153			
Proj. ann. nb. of net int'l migr. (low fertility)$^{(d)}$		**-2'910'008**	-8'493'369	-13'332'808
Proj. ann. nb. of net int'l migr. (medium fertility)$^{(d)}$		-4'053'671	**-11'784'960**	-18'477'402
Proj. ann. nb. of net int'l migr. (high fertility)$^{(d)}$		-5'528'551	-16'014'948	**-25'080'975**
Contribution of rainfall and temperature anomalies to net international migration				
Temperature	47 %	162 %	103 %	92 %
Rainfall	53 %	-62 %	-3 %	8 %
Contribution of amenity and economic geography channel to net international migration				
Amenity channel	101 %	352 %	224 %	200 %
GDP per capita (econ. geog. channel)	120 %	170 %	145 %	140 %
Urban population (econ. geog. channel)	-121 %	-422 %	-269 %	-241 %

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.

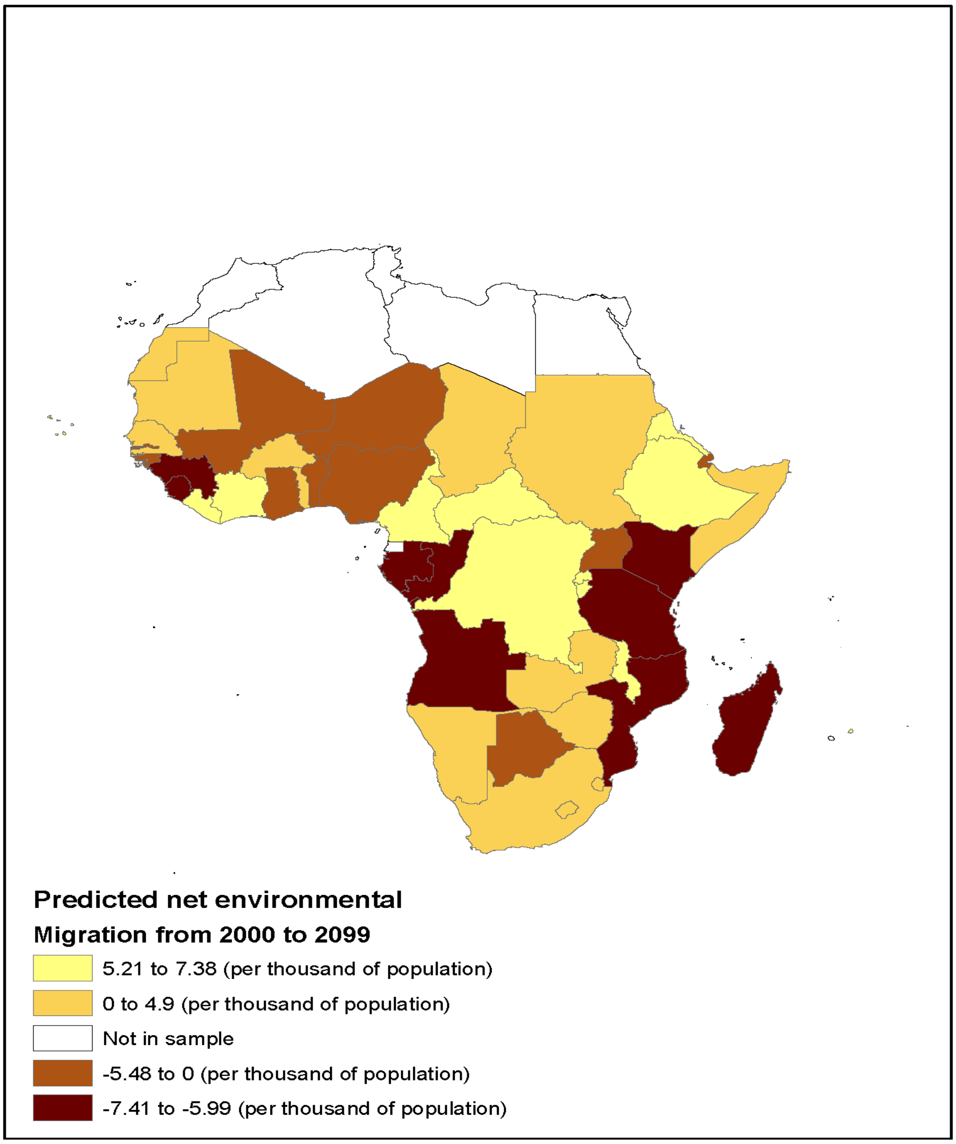
$^{(a)}$ Net migration rate is expressed in 1000 of population.

$^{(b)}$ Calculated using 1960-2000 population averages.

$^{(c)}$ Refers to rural-urban migration, i.e. increases in urbanization.

$^{(d)}$ *Proj. ann. nb. of net int'l migr.* stands for projected annual number of international migrants. In the cases (i) *1980-99 pop.*, (ii) low fertility, (iii) medium fertility and (iv) high fertility, projected migrants are obtained by multiplying the projected net migration rates of the first row with the (i) 1980-1999 population averages, (ii) 2080-2099 averages UN low fertility population projections, (iii) medium fertility projections and (iv) high fertility projections.

Figure 3: Projected net environmental migrants per thousand of population, 2000-2099



Supplementary material to

The Impact of Weather Anomalies on Migration in sub-Saharan Africa

Luca Marchiori * Jean-François Maystadt † Ingmar Schumacher ‡

October, 2011

1 Literature overview on environmentally-induced migration

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 sea level rises by one meter. In contrast to this claim, Black (2001)'s 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,

*Central Bank of Luxembourg, 2 Boulevard Royal, L-2983 Luxembourg, and IRES, Université catholique de Louvain. *E-mail:* luca.marchiori@bcl.lu.

†International Food Policy Research Institute (IFPRI), Washington DC. *E-mail:* J.F.Maystadt@cgiar.org. This author acknowledges financial support from the Fonds de la Recherche Scientifique (FNRS) and from the Belgian French-Speaking Community (convention ARC 09/14-019 on "Geographical Mobility of Factors").

‡Central Bank of Luxembourg, 2 Boulevard Royal, L-2983 Luxembourg, and Department of Economics, École Polytechnique Paris. *E-mail:* ingmar.schumacher@polytechnique.edu. The research presented here does not necessarily reflect the views and opinions of the Banque centrale du Luxembourg.

in this overview we constrain ourselves to hard evidence on environmental factors inducing migration based on either case studies or econometric analysis. An overview is provided in Table 1. Furthermore, we limit ourselves to evidence based on the last 60 years.

As Table 1 shows, 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) and Naude (2008)). Not controlling for these endogeneities may certainly 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 concludes 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), pp. 544) 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 questions 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.

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 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.

2 Additional tables: Variable description and unit root tests

Table 2 offers a detailed description of the main variables with an indication of the various sources used. Table 3 presents one-period lagged unit root tests for unbalanced panels.

3 The amenity channel

Columns (1)-(3) in Table 4 are estimated by means of a pooled estimation. We use this method as it is likely to capture the long-term relationship between our explanatory variables and net migration rates in sub-Saharan Africa, provided standard assumptions are fulfilled (see also Hatton and Williamson (2003)). Regressions (1) and (2) of Table 4 start by introducing the environmental, political and economic incentives to migrate, without any reference to our theoretical framework. We also correct our standard errors for heteroskedasticity and serial correlation. Using Pooled Ordinary Least Squares estimation (POLS), models (1) and (2) show that neither rainfall nor temperature seem to affect the incentives to migrate at the means.[1] Moreover, in model (3) we introduce an interaction term between the weather variables and the 'agricultural' dummy ($AGRI$). At least two reasons motivate the choice of such an explanatory variable. First, our theoretical model suggests that the effect of weather variations should be conditional on an exposure term, where a more dominant agricultural sector in the national economy implies a larger exposure. Second, this interaction term corresponds to the common sense view that agriculture-dependent countries will be particularly vulnerable to weather variability (Collier et al., 2008; World Bank, 2010). In regressions (1)-(3), weather variations appear not to affect net migration flows in neither of the three POLS regressions. The dummies proposed by Hatton and

[1] For consistency reasons, we also include temperature and rainfall anomalies separately, but the effect of these weather variables remains insignificant.

Williamson (2003) are significant and capture the policy-induced expulsion of Ghanaian migrants by the Nigerian government.

Nevertheless, it is well known that our POLS estimation may suffer from an endogeneity bias due to unobserved heterogeneity among the countries of our sample. For example, this would be the case if a long tradition of labor migration (Adepoju, 1995) affects the dependent variable and the GDP per capita ratio variable but does not follow the regional patterns captured by our regional-time dummies. A more promising approach is to get rid of the possible presence of a (time-constant) unobserved effect by using a fixed-effects estimation (FE). Like the POLS estimations, the FE models regressions (4)-(8) of Table 4 indicate that weather variables do not seem to have an impact on migration, even when introducing further lags as in regressions (7) and (8).

As pointed in the paper, it would, however, be hasty to conclude from this that weather variations do not impact migration behavior. For example, weather variables are known to affect GDP per capita as shown in Barrios et al. (2010) and Dell et al. (2009). Although no amenity effect from weather variations to migration is identified, our theoretical framework also suggests that weather variations may indirectly affect migration through the economic geography channel. Furthermore, our theoretical model also points to a possible endogeneity bias threatening the economic variables. The paper proposes an approach to consider both the amenity and the economic geography channel of weather variations on international migration and to deal with the endogeneity of the main economic variables.

4 Robustness tests: Additional tables

Robustness checks are not shown in the paper but are described in this supplementary material and are based on the baseline results, regressions (3) to (5) from Table 4 in the paper. These robustness checks relate to the use of alternative dependent variables (Table 5), alternative definition of the main explanatory variables of interest (Tables 6-8) and the addition or omission of control variables (Table 9) and the use of alternative bilateral migration data (Table 10).

First, in addition to robustness shown in the paper and based on bilateral migration data, Table 5 shows that our results do not depend on the refugee-related correction done to the net migration rate. Regressions (9) to (11) replicate the over-identified estimation of Table 4 in the paper without subtracting the net refugee flows from the migration rate but introducing them as an explanatory variable. Since now the dependent variable incorporates the movement of refugees, the net refugee flows (NetREF) exhibit a positive coefficient which is close to 1. Although it unduly increases the risk of endogeneity, our results are unaltered by this inclusion.

Second, we test the robustness of our findings to an alternative definition of our variables of interest, the weather-related variables. Regressions (12) to (14) of Table 6 indicate that similar results are obtained when rainfall and temperature are expressed in levels rather than in anomaly terms. The same results are obtained when the levels are transformed into logarithm. In regressions (15) to (20) of Table 6, the inclusion of a foreign-defined version or of lagged values for weather variables does not change our main results.[2] Nevertheless, most of these additional variables are far from being significant. Only temperature seems to have some lagging effects on the GDP per capita ratio and the level of urbanization. Even if we do not elaborate further on these results, the lagging effect of temperature is

[2] Note that the inclusion of foreign climatic variables is a particularly strong assumption about the capacity of the migrants to react to weather variations occurring in foreign countries.

consistent with evidence provided by Dell et al. (2008). Results are also robust to alternative definitions for the GDP per capita. Replacing GDP per capita by the GDP per worker (regressions (21) to (23) of Table 7), using the Chain transformation instead of the Laspeyres index in the real terms transformation (regressions (24) to (26) of Table 7) do not change the main results of the paper. We also test the results of the paper to alternative weighting in the computation of the Foreign wage. These alternative weights include other proxies than the distance for migration costs, including colonial link (regressions (27) to (29) of Table 7) a common colonial ruler (regressions (30) to (32) of Table 8) and linguistic proximity (regressions (36) to (38) of Table 8). [3] We could indeed assume that since African countries are more likely to have less migration restrictions with their former colonial ruler, the fact to have a colonial relationship is the distinction that matters for the foreign wage (Mcube et al., 2010). It has to be noted that it cannot be introduced as a control variable in the migration equation as it is time-constant. We could also assume that the fact to have experienced a similar colonial experiences is what matters because it will capture many similarities due to common colonial heritage (Acemoglu et al., 2001; La Porta et al., 1999; Huillery, 2009). According to Tables 7 and 8, results remain unaltered when the foreign wage is weighted by these alternative proxies for migration costs. These robustness checks remain valid when the colonial or linguistic proximity indicators are interacted with the distance between countries. Regarding the use of distance, we also test the robustness of our results to the assumption that only neighboring countries matter for migration (regressions (33) to (35) of Table 8). Our results remain robust to that more restrictive assumption on migration costs.

Third, we also test the robustness of our results to the addition or omission of some control variables. For example, one may think that the entry into the ACP agreements could also constitute another

[3] We use the linguistic proximity based on official or national languages and languages spoken by at least 20% of the population of the country in Table 8. However, similar results are obtained when we use mother tongue as a criteria. These variables are taken from the CEPII's distances measures (Mayer and Zignago, 2006).

determinant of international migration. Completing the data by Head et al. (2010) on the entry into ACP with data for Botswana and Namibia, adding the entry into ACP as an additional control variable does not alter the main results and shows a non-significant coefficient (with the exception of the effect on the GDP ratio). This can be seen in regressions (39) to (41) of Table 9. Furthermore, since the works by Miguel et al. (2004) and Burke et al. (2009), we cannot exclude that weather affects conflict and, hence, the inclusion of the conflict variable may wipe out some of the explanatory power of our weather variables. Therefore, the inclusion of the conflict-related variables may undermine our estimations of climate-induced migration. Although introducing a potential omitted variable bias, omitting the conflict-related variable does not alter the main results of this paper (regressions (42) to (44) of Table 9). As expected, the direct and indirect effects of weather variations on migration slightly increase as a result of this omission. Finally, Hatton and Williamson (2003) point out that demographic pressure is an important determinant of international migration. According to regressions (45) to (47) of Table 9, our main results remain valid when introducing such a demographic variable in our specification with the lagged value of population density, which is significant and affects net migration negatively. However, potential endogeneity issues induced by the introduction of population density require to be cautious with this specification and lead us to exclude this variable from our paper.

Fourth, one last robustness check deserves further attention. In Table 10, we test the robustness of our results to an alternative dependent variable, based on the OECD database on bilateral migration flows between our 39 SSA countries and 14 destination countries (Australia, Belgium, Canada, Denmark, France, Germany, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom and the United States). We should note that the research question becomes radically different as there are many reasons to believe that migration within Africa greatly differs from migration

movements outside Africa (see e.g. Mayda, 2010). Given the dyadic nature of these data and similar to Mayda (2010), our specification replaces our country fixed effect by a destination and origin countries' fixed effects, while the GDP ratio defined as the log of the origin country's (y) to the destination country's GDP per capita (y^F). Regression (48) of Table 10 first adopts a specification similar to Mayda (2010) but restricted to our sample. Like Mayda (2010), we use as dependent variable the emigration rate, i.e. immigrant inflow from origin to destination country (multiplied by 100'000), divided by origin country's population. The data is similar to Mayda (2010), but extended to more countries and years by Ortega and Peri (2009, 2011)[4] As expected by Mayda (2010), a negative coefficient is found for the GDP per capita ratio (significant at 10%). In regression (49) of Table 10, we introduce the weather-related incentives to migrate and proceed in regressions (50) to (56) to the same two-stage estimations than in our baseline results. We confirm our main results of table 4 in the article. Decreased rainfall anomalies increase the economic incentives to migrate from countries highly dependent on the agricultural sector, while temperature anomalies in turn increase that economic incentives. And this is true for migration outside Africa. However, we should acknowledge that the direct effects of weather anomalies on international migration and the buffer effect of the level of urbanization does not hold anymore. The impact of weather anomalies on the level of urbanization is confirmed but this last variable is not significant anymore in the second stage. Two explanations may be advanced. First of all, the fact that weather deviations do not directly affect international migration outside of Africa seems perfectly consistent with Mayda (2010) view that poverty constraints may be binding for some forms of international migration outside Africa. Second, the fact that agglomeration economies are

[4] Ortega and Peri (2009) and Ortega and Peri (2011) build on Mayda (2010) to extend the existing datasets on bilateral migration flows (gross and net) and stocks to more countries (14 OECD destinations and 74 countries of origin) and years (1980-2005) 1980-2007. Ortega and Peri's data offer different migration variables originating from different sources, but only the one based on UN data is going back until 1960 and is, according to Ortega and Peri, the most suitable for long-term analysis.

not sufficient to counter-balance at least partly the climate-related economic incentives to migrate outside Africa is consistent with the low levels of agglomeration forces within African cities at a global scale (de Brauw et al., 2011). Not jeopardizing our main results, this last robustness check certainly undermines the external validity of our results.

5 Details on the projections

Past movements. The annual average for any variable V over the period 1960-2000 is indicated by $\mu^{1960-2000}$(V). The average annual migration flow over the period 1960-2000, $\mu^{1960-2000}(\text{MIGR})$, due to variations in rainfall and temperature is computed as follows:

$$\mu^{1960-2000}(\text{MIGR}) = \text{ APE}_{RAIN}\ \mu^{1960-2000}(\text{RAIN}) + \text{ APE}_{TEMP}\ \mu^{1960-2000}(\text{TEMP}),$$

where $\mu^{1960-2000}(\text{RAIN})$ and $\mu^{1960-2000}(\text{TEMP})$ are the average annual rainfall and temperature anomalies, respectively, over the period 1960-2000. The average partial effects (APE) of rainfall anomalies and of temperature anomalies on net migration combine the direct effect and the indirect effects via the GDP per capita ratio and the level of urbanization of climate variations. We use for this computation the significant coefficients of the most precise results of regressions (3)-(5) of Table 4 in the paper. This means that we use the significant coefficients on TEMP and RAIN*AGRI of regression (3), on TEMP and TEMP*AGRI of regression (4), and on TEMP, TEMP*AGRI, log(y/y^F) and log(URB) of regression (5).[5]

[5] Our preferred specification (3)-(5) yields average partial effects (APE) of rainfall and temperature in agriculturally-dominated countries (Agri=1) and in countries with below median agricultural GDP share (Agri=0) taking on the following values: $\text{APE}_{\text{RAIN,Agri=1}}$=1.07, $\text{APE}_{\text{RAIN,Agri=0}}$=0, $\text{APE}_{\text{TEMP,Agri=1}}$=-0.65 and $\text{APE}_{\text{TEMP,Agri=0}}$=0.53. These values account for the amenity and economic geography channel of weather on migration.

Future movements. The IPCC projected future changes in climate for the 21st century are based on different atmosphere-ocean general circulation models and different climate scenarios. The scenarios are divided into four families (A1, A2, B1, B2), depending on assumptions on the future evolution of greenhouse gas pollution, land-use, technological development, economic growth, demographic changes, etc. Our projections of weather-driven migration are based on weather changes given by family A1 and in particular climate scenario A1B, described in detail in Chapter 11 of the IPCC report (Christensen et al., 2007). This scenario assumes, among other things, an increasing but moderate emission trajectory over the 21^{st} century (Global GHG emissions, i.e. CO2, CH4, N2O and F-gases, increase until 2050 and then slowly decrease until 2100), a more and more integrated world with rapid economic growth. This scenario choice is not an unreasonable choice for our projections, given that the world economy is marked by the rapid growth of China and India and that sub-Saharan Africa also experienced surprisingly high economic growth rates in the 2000s (Easterly, 2009).

The IPCC scenarios account also for future population evolution, assuming that world population in 2100 attaining 7.1 billion (families A1 and B1), 10.4 billion (family B2) or 15 billion (family A2) in 2100. In comparison, the United Nations' Population Division (United Nations, 2009) projects world population to attain either 6.2 (low fertility scenario), 10.1 (medium fertility scenario) or 15.8 (high fertility scenario). Scenario A1B assumes that world population peaks around 2050 and settles at 7.1 billion in 2100. This assumption thus comprised between the low and medium fertility scenarios of the UN.

The IPCC provides projections on the change in regional temperature and precipitation between the periods 1980-1999 and 2080-2099. Table 5 in the paper shows the best, median and worst long term climate changes in terms of temperature ($^{\circ}$C) and precipitation (%) for 4 African regions (Saharan,

Western, Eastern and Southern Africa). These changes stem from differences between the 1980-1999 period and the 2080-2099 period. To obtain these predictions, the IPCC relies on a multi-model data set which makes use of information from all available realisations for the 1980 to 1999 period and plots the evolution of projected changes for a specific scenario for the period 2080-2099. The best, median and worst cases - representing the 25%, 50% and 75% quartile values for changes in temperature ($^\circ$C) and the 75%, 50% and 25% quartile values for changes in precipitation (%) - are reported based on 21 models (Christensen et al., 2007, p.854). Since climatic predictions by the IPCC are based on realizations over the period 1980-1999, we computed the impact on net migration of a change in climatic variables with respect to the average climatic situation over the period 1980-1999. The predicted net numbers of migrants are calculated based on the average population over the period 1980-1999. Our calculations are described in what follows.

The projected *change* in net migration flows due to forecasted weather variations, ΔMIGR, can be computed by adopting the following strategy:

$$\Delta\text{MIGR} = \text{APE}_{RAIN}\ (\Delta\text{RAIN}) + \text{APE}_{TEMP}\ (\Delta\text{TEMP}) \tag{1}$$

where the APE's are computed as before. A change in any variable V refers to the change between the annual average value of V over the period 2080-2099 and the annual average over the period 1980-1999, $\Delta\text{V} = \mu^{2080-2099}(\text{V}) - \mu^{1980-1999}(\text{V})$. ΔRAIN and ΔTEMP are thus forecasted *changes* in weather variable anomaly and are directly based on the IPCC forecasted weather changes. The average annual rainfall and temperature *anomaly* over the period 2080-2099, $\mu^{2080-2099}(\text{RAIN})$, is given by the difference in the average rainfall *level* during period 2080-2099 and the one over the long-run period,

μ^{LR}, divided by the long-run standard deviation, σ^{LR}, in rainfall level:

$$\mu^{2080-2099}(\text{RAIN}) = \frac{\mu^{2080-2099}(\text{RAIN}_{level}) - \mu^{LR}(\text{RAIN}_{level})}{\sigma^{LR}(\text{RAIN}_{level})}.$$

The rainfall level during the period 2080-2099 corresponds to average level during the period 1980-1999 *plus* the future changes in the rainfall level as predicted by the IPCC:

$$\mu^{2080-2099}(\text{RAIN}_{level}) = \mu^{1980-1999}(\text{RAIN}_{level}) + \Delta\text{RAIN}^{\text{IPCC}}_{level}.$$

The future change in temperature anomalies, ΔTEMP, is calculated in an analogous way. We can then compute the additional net migration flows induced by future weather variations via equation (1) and by using our preferred estimates in regressions (3)-(5) of Table 4 in the paper for the APE's and the IPCC predictions for $\Delta\text{RAIN}^{\text{IPCC}}_{level}$ and $\Delta\text{TEMP}^{\text{IPCC}}_{level}$ (see Table 5 in the paper for the IPCC's weather forecasts).

Based on these projections, Table 11 ranks the countries of our sample according to highest *additional* net out-migration expected by future weather change in the median outcome of the IPCC projections. The numbers of net migrants are computed by using the medium-fertility population scenario of the UN Population Projections (United Nations, 2009). It also offers the *variation* in yearly net migration for the worst and best weather changes, and also as a comparison, the yearly average net migration induced by observed weather variations over the period 1960-2000 for every country in the sample.

References

Acemoglu, D., Johnson, S., and Robinson, J. A. (2001). The colonial origins of comparative development: An empirical investigation. *The American Economic Review*, 91(5):1369–1401.

Adepoju, A. (1995). Emigration dynamics in Sub-Saharan Africa. *International Migration*, 33(3-4):315–90.

Anselin, L. (2002). Under the hood : Issues in the specification and interpretation of spatial regression models. *Agricultural Economics*, 27(3):247–267.

Barrios, S., Bertinelli, L., and Strobl, E. (2010). Trends in rainfall and economic growth in Africa: A neglected cause of the African growth tragedy. *The Review of Economics and Statistics*, 92(2):350–366.

Bates, R., Feree, K., Habyarimana, J., Humphreys, M., and Singh, S. (2011). Dataset on africa: Economic data, controls data, other political data. Africa Research Program.

Black, R. (2001). *Environmental refugees: myth or reality?* UNHCR.

Burke, M., Miguel, E., Satyanath, S., Dykema, J., and Lobell, D. (2009). Warning increases the risk of civil war in africa. *Proceedings of the National Academy of Sciences*, 106(49):20670–20674.

Cheshire, P. and Magrini, S. (2000). Endogenous processes in european regional growth: Convergence and policy. *Growth and Change*, 31(4):455–479.

Christensen, J., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R., Kwon, W.-T., Laprise, R., Rueda, V. M., Mearns, L., Menndez, C., Rsissnen, J., Rinkeand, A., Sarr, A., and Whetton, P. (2007). *Regional Climate Projections. In: Climate Change 2007: The Physical Science*

Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Collier, P., Conway, G., and Venables, T. (2008). Climate Change and Africa. mimeo, forthcoming in The Oxford Review of Economic Policy.

de Brauw, A., Mueller, V., and Lee, H. (2011). The role of Rural-Urban Migration in the Structural transformation of sub-Saharan Africa. Paper presented at the IFPRI-University of Ghana Conference, "Understanding Economic Transformation in Sub-Saharan Africa" Accra, Ghana, May 10-11, 2011.

Dell, M., Jones, B., and Olken, B. (2008). Climate shocks and economic growth: Evidence from the last half century. *NBER Working Paper*, 14132.

Dell, M., Jones, B. F., and Olken, B. A. (2009). Temperature and Income: Reconciling New Cross-Sectional and Panel Estimates. *The American Economic Review*, 99(2):198–204.

Dercon, S. (2004). Growth and shocks: evidence from rural ethiopia. *Journal of Development Economics*, 74(2):309–329.

Dillon, A., Mueller, V., and Salau, S. (2010). Migratory responses to agricultural risk in northern nigeria. *IFPRI discussion papers*.

Easterly, W. (2009). How the Millennium Development Goals are Unfair to Africa. *World Development*, 37(1):26–35.

Ezra, M. and Kiros, G. (2001). Rural out-migration in the drought prone areas of ethiopia: A multilevel analysis1. *International Migration Review*, 35(3):749–771.

Fearon, J. D. and Latin, D. D. (2003). Ethnicity, Insurgency, and Civil War. *American Political Science Review*, 97(1):75–90.

Feng, S., Krueger, A., and Oppenheimer, M. (2010). Linkages among climate change, crop yields and mexico–us cross-border migration. *Proceedings of the National Academy of Sciences*, 107(32):14257.

Findley, S. (1994). Does drought increase migration? a study of migration from rural mali during the 1983-1985 drought. *International Migration Review*, pages 539–553.

Gutmann, M. and Field, V. (2010). Katrina in historical context: environment and migration in the us. *Population & Environment*, 31(1):3–19.

Halliday, T. (2006). Migration, risk, and liquidity constraints in el salvador. *Economic Development and Cultural Change*, 54(4):893–926.

Hammer, T. (2004). Desertification and migration: a political ecology of environmental migration in west africa. *Environmental Change and Its Implications for Population Migration*, pages 231–246.

Hatton, T. J. and Williamson, J. G. (2003). Demographic and economic pressure on emigration out of Africa. *Scandinavian Journal of Economics*, 105(3):465–486.

Head, K., Mayer, T., and Ries, J. (2010). The erosion of colonial trade linkages after independence. *Journal of International Economics*, 81:1369–1401.

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

Huillery, E. (2009). History matters: The long-term impact of colonial public investments in french west africa. *American Economic Journal: Applied Economics*, 1(2):176–215.

La Porta, R., Lopez-de Silanes, F., Shleifer, A., and Vishny, R. (1999). The quality of government. *Journal of Law, Economics, and Organization*, 15(1):222–279.

Leighton, M. (2006). Desertification and migration. *Governing global desertification: linking environmental degradation, poverty and participation*, page 43.

Maddala, G. S. and Wu, S. (1999). A comparative Study of Unit Root Tests With Panel Data and A New Simple Test. *Oxford Bulletin of Economics and Statistics*, 61:631–652.

Mayda, A. (2010). International migration: a panel data analysis of the determinants of bilateral flows. *Journal of Population Economics*, 23(4):1249–1274.

Mayer, T. and Zignago, S. (2006). Notes on CEPII's distances measures. CEPII distance data.

Mcube, M., Leyeka Lufumpa, C., and Ndikumana, L. (2010). Africans abroad: migration trends, patterns and determinants. *fDB Economic Brief* 1(6), 23 September 2010.

Miguel, E., Satyanath, S., and Sergenti, E. (2004). Economic shocks and civil conflict : An instrumental variable approach. *Journal of Political Economy*, 112(4):725.

Mortreux, C. and Barnett, J. (2009). Climate change, migration and adaptation in funafuti, tuvalu. *Global Environmental Change*, 19(1):105–112.

Munshi, K. (2003). Networks in the modern economy: Mexican migrants in the us labor market. *Quarterly Journal of Economics*, 118(2):549–599.

Myers, N. (1996). Environmentally-induced displacements: the state of the art. Technical report, Environmentally-Induced Population Displacements and Environmental Impacts Resulting from Mass Migration, International Symposium.

Naude, W. (2008). Conflict, disasters, and no jobs: Reasons for international migration from sub-saharan africa. WIDER Research Paper, 2008/85.

Ortega, F. and Peri, G. (2009). The Causes and Effects of International Labor Mobility: Evidence from OECD Countries 1980-2005 . Human Development Research Paper 2009/06.

Ortega, F. and Peri, G. (2011). The Aggregate Effects of Trade and Migration: Evidence from OECD Countries . IZA Discussion Paper No. 5604.

Paul, B. (2005). Evidence against disaster-induced migration: the 2004 tornado in north-central bangladesh. *Disasters*, 29(4):370–385.

Rappaport, J. (2007). Moving to nice weather. *Regional Science and Urban Economics*, 37(3):375–398.

Rappaport, J. and Sachs, J. (2003). The united states as a coastal nation. *Journal of Economic Growth*, 8(1):5–46.

Saldaña-Zorrilla, S. and Sandberg, K. (2009). Impact of climate-related disasters on human migration in mexico: a spatial model. *Climatic change*, 96(1):97–118.

Smith, K. and Petley, D. (2009). *Environmental hazards: assessing risk and reducing disaster*. Taylor & Francis.

UNHCR (2009). *Statistical Online Population Database*. www.unhcr.org/statistics/populationdatabase, Data extracted: 01/03/2009, United Nations High Commissioner for Refugees (UNHCR), Geneva.

United Nations (2009). Access on 28/11/2010, http://esa.un.org/unpp/, World Population Prospects: The 2008 Revision. Department of Economic and Social Affairs, United Nations.

World Bank (2009). *The World Bank (2009), World Development Indicators*. Washington, DC: World Bank.

World Bank (2010). *World Development Report 2010: Development and Climate Change*. Washington, DC: World Bank.

Table 1: Literature overview

Source	Study focuses on: Country/Place	Study focuses on: Period	Results
EVIDENCE FOR ENVIRONMENTAL IMPACTS ON MIGRATION			
Naude (2008)	sub-Saharan Africa	1965-2005	natural disasters induces conflicts which lead to out-migration
Barrios et al. (2010)	Sub-saharan Africa	1960-1990	lower rainfall induces urbanization
Hammer (2004)	Niger	1985	1 million migrated due to droughts (plus many more in the Sahel region during 1973 - 1999)
Smith and Petley (2009)	Bangladesh	1994	0.4% of households migrated from flooding
Henry et al. (2003)	Burkina Faso	1970-1998	odds of migrating are higher in dry regions vs. those with average rainfall
Dillon et al. (2010)	Nigeria	1988-2008	temperature affects incentives to migrate
Ezra and Kiros (2001)	Ethopia	1984-1994	vulnerability to food crisis induces migration
Dercon (2004)	Ethopia	1989-1997	rainfall affects consumption growth
Gutmann and Field (2010)	City of New Orleans	2005	four years after Hurricane Katrina population is still down by 23%
Gutmann and Field (2010)	southern South Sade County	1992	Hurricane Andrew led to reduction in population of 39%
Rappaport and Sachs (2003)	USA	2000	quality of life (measured through weather) effect leads to larger population concentration at coast
Rappaport (2007)	USA	1970-2000	population density affected by quality of life (measured through weather)
Feng et al. (2010)	Mexico	1995-2005	weather-driven changes in crop yields affect migration rate to the US
Leighton (2006)	North-East Brazil	1960-1980	drought and desertification induced 3.4 million migrants
Halliday (2006)	El Salvador	1997-2001	agricultural shocks induce international migration
Saldaña-Zorrilla and Sandberg (2009)	Mexico	1980-2005	natural disasters lead to internal migration
Munshi (2003)	Mexico	1982-1997	rainfall induces Mexico to US migration
Cheshire and Magrini (2000)	Europe	1980-2000	climatic variations impact urban population growth
EVIDENCE AGAINST ENVIRONMENTAL IMPACTS ON MIGRATION			
Findley (1994)	Mali	1982, 1989	droughts did not increase overall migration, but there was an increase in female and child as well as shorter-cycle migration
Paul (2005)	Bangladesh	2004	no migration (due to disaster aid)
Halliday (2006)	El Salvador	2001	earthquake reduced migration
Mortreux and Barnett (2009)	Tuvalu	2007	climate change no apparent reason for migration

Table 2: Variable definition and sources

CODE	**Definition**	**Characteristics**	**Source**
MIGR	Net migration flows	Difference between numbers of immigrants and emigrants per thousands of population from 1960 to 2000, on a yearly basis, corrected by the refugee movement	US Census Bureau and UNHCR (2009)
RAIN	Rain Anomalies	Deviations from the country's long-term mean, divided by its long-run standard deviation	Inter-Governmental Panel on Climate Change (IPCC)
TEMP	Temperature Anomalies	Deviations from the country's long-term mean, divided by its long-run standard deviation	Inter-Governmental Panel on Climate Change (IPCC)
y/y^F	GDP per capita over GDP per capita in other African countries weighted by the distance. To build this ratio, we excluded from the numerator the country for which there was a missing value for GDP per capita, and thus correspondingly also excluded its distance to country r in the denominator. (This is to keep the sum of rows in the weighting matrix equal to 1, see Anselin (2002)). The distance function used is $f(d) = 1/d^2$, where d is distance of other countries to country r	Available 1960-2000	Income per capita from Penn World Tables and World Bank data and data for d originates from CEPII (Mayer and Zignago, 2006).
WAR	war onset	1 for civil war onset	Fearon and Latin (2003)
WAR^F	War onsets in other countries weighted by distance	Value between 0 and 1; war onsets in another sub-Saharan African country weighted by a distance function	Fearon and Latin (2003) and CEPII
URB	Urban population	Share of urban population in total population	United Nations (2009)
AGRI	Whether a country has an agricultural value added above the median in 1995 (similar to Dell, 2009)	Dummy variable	World Bank (2009) for agricultural value added.
Δ Money	Money plus Quasi-Money	Absolute growth in money supply, available 1960-2000	Robert Bates' Database (Bates et al., 2011)
New State	Independence	1 if country is in the two first years of independence, available 1960-2000	Fearon and Latin (2003)
POPden	Population density	People per square meter, available 1960-2000	Robert Bates' Database (Bates et al., 2011)

Table 3: Panel unit root test (Maddala and Wu, 1999)

Variable	Panel Unit Root Test
MIGR	324.478***
MIGR^a	483.870***
RAIN	243.916***
TEMP	252.616***
RAIN*AGRI	123.067***
TEMP*AGRI	103.385**
WAR_{t-1}	133.281***
WAR^F_{t-1}	503.238***
Log(URB)	157.267***
$\text{Log}(y/y^F)$	183.103***
Δ Money	108.057***
NetREF	406.949***

** significant at 5%; *** significant at 1%.
MIGR^a stands for net migration rate without the correction for the refugee movement.
Fisher statistics are given by the test of Maddala and Wu (1999). Unit test with one period lag.

Table 4: Basic Regressions

Regression	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Models	POLS	POLS	POLS	FE	FE	FE	FE	FE
RAIN	-0.232	-0.21	-0.24	-0.223	-0.216	0.0168	-0.255	-0.00701
	[0.340]	[0.345]	[0.312]	[0.368]	[0.347]	[0.301]	[0.352]	[0.312]
TEMP	-0.33	-0.169	-0.00869	-0.216	-0.0631	0.000572	-0.142	-0.053
	[0.382]	[0.362]	[0.257]	[0.270]	[0.254]	[0.295]	[0.248]	[0.250]
RAIN*AGRI			0.0548			-0.593		-0.639
			[0.809]			[0.833]		[0.835]
TEMP*AGRI			-0.361			-0.183		-0.256
			[0.815]			[0.543]		[0.589]
RAIN$_{t-1}$							-0.0115	-0.0667
							[0.213]	[0.185]
TEMP$_{t-1}$							0.314	0.248
							[0.223]	[0.245]
RAIN$_{t-1}$*AGRI								0.167
								[0.504]
TEMP$_{t-1}$*AGRI								0.185
								[0.304]
log(y/y^F)		0.813	0.799		-0.385	-0.336	-0.29	-0.254
		[0.703]	[0.711]		[2.612]	[2.597]	[2.639]	[2.643]
log(URB)		0.78	0.794		-2.668	-2.633	-3.026	-3.011
		[0.713]	[0.750]		[3.711]	[3.692]	[3.794]	[3.782]
WAR$_{t-1}$		1.338	1.366		1.009	1.072	1.034	1.119
		[3.490]	[3.530]		[3.320]	[3.320]	[3.329]	[3.331]
WAR$^F_{t-1}$		-2.749	-2.815		-2.608	-2.68	-2.411	-2.29
		[3.997]	[4.026]		[5.208]	[5.169]	[5.090]	[5.105]
AGRI			0.289					
			[0.911]					
Constant	0.257	-1.327	-1.526	0.197	8.226	8.17	9.344	9.331
	[0.446]	[2.866]	[2.850]	[0.250]	[10.30]	[10.26]	[10.67]	[10.64]
Observations	750	750	750	750	750	750	750	750
R-squared	0.002	0.014	0.015	0.001	0.005	0.006	0.006	0.007
F-test	0.655	1.38	1.454	1.033	0.564	0.623	0.668	0.841
Number of coun	39	39	39	39	39	39	39	39

** significant at 5%; *** significant at 1%.
Robust standard errors are in square brackets. y stands for GDP per capita.

Table 5: Robustness to an alternative dependent variable

Regressions	(9)	(10)	(11)
Models	FE2SLS	FE2SLS	FE2SLS
SE	Robust	Robust	Robust
Stage	1^{st}	1^{st}	2^{nd}
Dependent Variable	log(y/y^F)	log(URB)	MIGR^a
RAIN	-0.0227*	-0.00323	0.854
	[0.0137]	[0.00834]	[0.862]
TEMP	-0.0437***	-0.0205**	2.934**
	[0.0154]	[0.00879]	[1.302]
RAIN*AGRI	0.0494***	0.00161	-1.293
	[0.0187]	[0.00997]	[0.994]
TEMP*AGRI	0.00879	0.0457***	-4.386**
	[0.0218]	[0.00984]	[1.814]
WAR$_t - 1$	-0.0755	0.00987	3.096
	[0.0880]	[0.0259]	[5.919]
WAR$^F_{t-1}t - 1$	-0.173	0.0224	0.581
	[0.149]	[0.0840]	[7.288]
NetRef	0.000334	9.70E-05	0.986***
	[0.000944]	[0.000254]	[0.0473]
log(y/y^F)			22.26***
			[7.763]
log(URB)			69.69***
			[26.19]
Instruments			
Δ Money	0.126**	0.0581*	
	[0.0580]	[0.0351]	
New State UK	-0.642***	0.230***	
	[0.0894]	[0.0484]	
New State	-0.0285	-0.0358	
	[0.0508]	[0.0338]	
HW-Dum^a	incl.	incl.	incl.
Region-Dum^a	incl.	incl.	incl.
Time-Dum^a	incl.	incl.	incl.
Region-Time^a	incl.	incl.	incl.
Observations	750	750	750
Number of countries	39	39	39
F-test	92.76***	67.94***	24.86***
F-Test on excluded IV	30.26***	12.96***	
Underid test			7.449**
Weak id stat			2.334
P-value Hansen test			0.862
Endo stat			13.08***
Root MSE	0.23	0.097	11.01

* significant at 10%; ** significant at 5%; *** significant at 1%. MIGR^a stands for net migration rate without the correction for the refugee movement. 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.

Table 6: Robustness to alternative climatic variables

Regression	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Models	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS
SE	robust	robust	robust	robust	robust	robust	robust	robust	robust
Stage	1^{st}	1^{nd}	2^{st}	1^{st}	1^{nd}	2^{nd}	1^{st}	1^{st}	2^{nd}
Dependent	log(y/y^F)	log(URB)	MIGR	log(y/y^F)	log(URB)	MIGR	log(y/y^F)	log(URB)	MIGR
Alternative 1	RAIN$_{level}$	RAIN$_{level}$	RAIN$_{level}$	RAIN^F	RAIN^F	RAIN^F	RAIN$_{t-1}$	RAIN$_{t-1}$	RAIN$_{t-1}$
Alternative 2	TEMP$_{level}$	TEMP$_{level}$	TEMP$_{level}$	TEMP^F	TEMP^F	TEMP^F	TEMP$_{t-1}$	TEMP$_{t-1}$	TEMP$_{t-1}$
Alternative 3	RAIN$_{level}$ *AGRI	RAIN$_{level}$ *AGRI	RAIN$_{level}$ *AGRI	RAIN^F *AGRI	RAIN^F *AGRI	RAIN^F *AGRI	RAIN$_{t-1}$ *AGRI	RAIN$_{t-1}$ *AGRI	RAIN$_{t-1}$ *AGRI
Alternative 4	TEMP$_{level}$ *AGRI	TEMP$_{level}$ *AGRI	TEMP$_{level}$ *AGRI	TEMP^F *AGRI	TEMP^F *AGRI	TEMP^F *AGRI	TEMP$_{t-1}$ *AGRI	TEMP$_{t-1}$ *AGRI	TEMP$_{t-1}$ *AGRI
RAIN				-0.0255*	-0.00431	0.936	-0.0202	-0.00164	0.615
				[0.0144]	[0.00838]	[0.845]	[0.0142]	[0.00806]	[0.883]
TEMP				-0.0404**	-0.0281***	3.146**	-0.0354**	-0.0164*	2.552*
				[0.0180]	[0.0101]	[1.444]	[0.0159]	[0.00885]	[1.350]
RAIN*AGRI				0.0539***	0.00504	-1.529	0.0448**	-0.00285	-0.656
				[0.0197]	[0.0101]	[1.023]	[0.0189]	[0.00977]	[1.023]
TEMP*AGRI				-0.00646	0.0606***	-4.566**	0.00572	0.0341***	-4.278**
				[0.0304]	[0.0140]	[2.305]	[0.0221]	[0.00965]	[1.925]
Alternative 1	-2.109**	0.175	37.87	0.106	0.0113	-3.063	-0.0151	0.0054	-0.0861
	[0.997]	[0.468]	[48.63]	[0.114]	[0.0587]	[5.754]	[0.0148]	[0.00792]	[0.911]
Alternative 2	-0.0919**	-0.0354	5.888**	0.0438	0.213	-18.84	-0.0345**	-0.0174**	2.282
	[0.0421]	[0.0255]	[2.980]	[0.279]	[0.148]	[15.52]	[0.0161]	[0.00861]	[1.468]
Alternative 3	3.068**	-0.609	-35.45	-0.125	-0.0696	11.19	0.025	-0.00652	0.221
	[1.338]	[0.621]	[58.57]	[0.171]	[0.0830]	[9.504]	[0.0191]	[0.00954]	[0.997]
Alternative 4	0.0319	0.109***	-11.00**	0.134	-0.153	3.934	0.0129	0.0325***	-2.586
	[0.0653]	[0.0317]	[4.410]	[0.229]	[0.0983]	[10.34]	[0.0221]	[0.00989]	[2.051]
WAR$_{t-1}$	-0.0716	0.0125	2.666	-0.0772	0.00976	2.987	-0.0765	0.0115	2.507
	[0.0859]	[0.0263]	[5.459]	[0.0877]	[0.0258]	[5.498]	[0.0877]	[0.0260]	[5.699]
	[0.405]	[0.633]	[0.625]	[0.379]	[0.706]	[0.587]	[0.383]	[0.659]	[0.660]
WAR$^F_{t-1}$	-0.181	0.0212	0.389	-0.202	0.00136	3.128	-0.175	0.0409	-1.649
	[0.153]	[0.0817]	[6.991]	[0.148]	[0.0847]	[7.405]	[0.154]	[0.0869]	[7.937]
	[0.239]	[0.796]	[0.956]	[0.172]	[0.987]	[0.673]	[0.255]	[0.638]	[0.835]
log(y/y^F)			19.22***			18.43***			17.27**
			[6.617]			[6.873]			[7.335]
			[0.00368]			[0.00733]			[0.0185]
log(URB)			67.25***			67.99***			87.89**
			[24.15]			[25.58]			[42.01]
			[0.00536]			[0.00787]			[0.0364]
Instruments									
Δ Money	0.127**	0.0639*		0.132**	0.0644*		0.131**	0.0506	
	[0.0560]	[0.0354]		[0.0555]	[0.0358]		[0.0537]	[0.0342]	
New State UK	-0.701***	0.233***		-0.672***	0.212***		-0.703***	0.140***	
	[0.0925]	[0.0488]		[0.0957]	[0.0510]		[0.109]	[0.0540]	
New State	-0.0395	-0.0393		-0.0235	-0.0367		-0.00312	-0.0279	
	[0.0499]	[0.0335]		[0.0499]	[0.0341]		[0.0553]	[0.0340]	
HW-Dum[a]	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Region-Dum[a]	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Time-Dum[a]	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Region-Time[a]	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Observations	750	750	750	750	750	750	750	750	750
Nbr of countries	39	39	39	39	39	39	39	39	39
Nbr of countries	39	39	39	39	39	39	39	39	39
F-test	39.33***	104.87***	42.27***	89.98***	62.65***	26.73***	88.87***	65.79***	22.17***
F-Test on excl. IV	31.51***	12.23***		27.76***	9.06***		22.42***	3.46***	
Underid test			7.899**			7.103**			3.985
Weak id stat			2.511			2.242			1.3
P-value Hansen test			0.764			0.973			0.933
Endo stat			14.33***			13.71***			14.42***
Root MSE	0.23	0.098	10.61	0.23	0.097	10.51	0.23	0.096	11.53

* significant at 10%; ** significant at 5%; *** significant at 1%. 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.

Table 7: Robustness to alternative economic variables (Part 1)

Regression	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)
Models	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS
SE	robust	robust	robust	robust	robust	robust	robust	robust	robust
Stage	1^{st}	1^{nd}	2^{st}	1^{st}	1^{nd}	2^{nd}	1^{st}	1^{st}	2^{nd}
Dependent	log(y/y^F)	log(URB)	MIGR	log(y/y^F)	log(URB)	MIGR	log(y/y^F)	log(URB)	MIGR
Alternative log(y/y^F)	GDP per worker	GDP per worker	GDP per worker	Chain Trans.	Chain Trans.	Chain Trans.	Colony	Colony	Colony
RAIN	-0.0203	-0.00332	0.944	-0.0229	-0.00332	0.846	-0.0197	-0.00332	0.899
	[0.0135]	[0.00832]	[0.894]	[0.0139]	[0.00832]	[0.834]	[0.0137]	[0.00832]	[0.957]
TEMP	-0.0416***	-0.0204**	3.095**	-0.0429***	-0.0204**	2.846**	-0.0384**	-0.0204**	3.221**
	[0.0149]	[0.00876]	[1.362]	[0.0153]	[0.00876]	[1.242]	[0.0149]	[0.00876]	[1.511]
RAIN*AGRI	0.0421**	0.00162	-1.437	0.0493***	0.00162	-1.264	0.0448**	0.00162	-1.33
	[0.0183]	[0.00997]	[1.027]	[0.0187]	[0.00997]	[0.939]	[0.0186]	[0.00997]	[1.095]
TEMP*AGRI	0.0177	0.0455***	-4.496**	0.00808	0.0455***	-4.262**	-0.00491	0.0455***	-4.782**
	[0.0212]	[0.00980]	[1.841]	[0.0218]	[0.00980]	[1.697]	[0.0216]	[0.00980]	[2.062]
$\text{WAR}_t - 1$	-0.0669	0.0104	3.413	-0.0746	0.0104	3.026	-0.0748	0.0104	3.055
	[0.0868]	[0.0259]	[6.238]	[0.0877]	[0.0259]	[5.723]	[0.0882]	[0.0259]	[6.091]
$\text{WAR}^F_{t-1}t - 1$	-0.137	0.02	1.054	-0.183	0.02	0.904	-0.205	0.02	1.611
	[0.142]	[0.0850]	[7.670]	[0.150]	[0.0850]	[7.213]	[0.147]	[0.0850]	[8.448]
Alternative			29.66***			21.75***			24.60**
log(y/y^F)			[10.29]			[7.269]			[9.575]
log(URB)			65.19***			67.69***			85.80**
			[24.59]			[24.17]			[34.82]
Instruments									
Δ Money	0.0987*	0.0596*		0.129**	0.0596*		0.0618	0.0596*	
	[0.0519]	[0.0350]		[0.0563]	[0.0350]		[0.0541]	[0.0350]	
New State UK	-0.428***	0.230***		-0.641***	0.230***		-0.616***	0.230***	
	[0.0820]	[0.0484]		[0.0891]	[0.0484]		[0.0872]	[0.0484]	
New State	-0.0451	-0.0362		-0.0258	-0.0362		-0.101**	-0.0362	
	[0.0554]	[0.0338]		[0.0505]	[0.0338]		[0.0480]	[0.0338]	
HW-Dum[a]	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Region-Dum[a]	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Time-Dum[a]	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Region-Time[a]	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Observations	750	750	750	750	750	750	750	750	750
Number of countries	39	39	39	39	39	39	39	39	39
F-test	95.46***	65.79***	270.96***	90.41***	65.79***	22.20***	32.49***	65.79***	13.71***
F-Test on excl. IV	23.31***	12.99***		30.59***	12.99***		35.13***	12.99***	
Underid test			11.82***			7.665**			8.265**
Weak id stat			0.00271			0.0217			0.016
P-value Hansen test			0.746			0.891			0.487
Endo stat			14.67***			14.56***			13.08***
Root MSE	0.23	0.097	11.75	0.23	0.097	10.85	0.23	0.097	12.1

* significant at 10%; ** significant at 5%; *** significant at 1%. 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.

Table 8: Robustness to alternative economic variables (Part 2)

Regression	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)
Models	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS
SE	robust	robust	robust	robust	robust	robust	robust	robust	robust
Stage	1^{st}	1^{nd}	2^{st}	1^{st}	1^{nd}	2^{nd}	1^{st}	1^{st}	2^{nd}
Dependent	log(y/y^F)	log(URB)	MIGR	log(y/y^F)	log(URB)	MIGR	log(y/y^F)	log(URB)	MIGR^a
Alternative log(y/y^F)	Common Colony	Common Colony	Common Colony	Contiguity	Contiguity	Contiguity	Linguistic proximity	Linguistic proximity	Linguistic proximity
RAIN	-0.0454***	-0.00332	1.512	-0.0292*	-0.00332	0.943	-0.0172	-0.00332	0.748
	[0.0151]	[0.00832]	[1.112]	[0.0173]	[0.00832]	[0.924]	[0.0152]	[0.00832]	[0.896]
TEMP	-0.0470***	-0.0204**	3.376**	-0.019	-0.0204**	2.471**	-0.0381**	-0.0204**	2.965**
	[0.0172]	[0.00876]	[1.610]	[0.0231]	[0.00876]	[1.249]	[0.0173]	[0.00876]	[1.408]
RAIN*AGRI	0.0575***	0.00162	-1.624	0.0497**	0.00162	-1.166	0.0446**	0.00162	-1.133
	[0.0192]	[0.00997]	[1.161]	[0.0227]	[0.00997]	[1.027]	[0.0198]	[0.00997]	[1.017]
TEMP*AGRI	-0.0096	0.0455***	-4.568**	-0.0314	0.0455***	-3.910**	-0.0125	0.0455***	-4.429**
	[0.0219]	[0.00980]	[2.015]	[0.0273]	[0.00980]	[1.734]	[0.0232]	[0.00980]	[1.919]
WAR$_t - 1$	-0.0225	0.0104	1.788	-0.0802	0.0104	2.853	-0.104	0.0104	3.408
	[0.0887]	[0.0259]	[6.147]	[0.0961]	[0.0259]	[5.714]	[0.0925]	[0.0259]	[5.813]
WAR$^F_{t-1}t - 1$	-0.145	0.02	0.152	-0.23	0.02	1.192	-0.221	0.02	1.231
	[0.163]	[0.0850]	[9.419]	[0.196]	[0.0850]	[7.884]	[0.154]	[0.0850]	[7.917]
Alternative			24.35**			19.30***			20.61**
log(y/y^F)			[9.572]			[7.225]			[8.007]
log(URB)			83.56**			77.16**			80.91**
			[34.38]			[30.38]			[32.96]
Instruments									
Δ Money	0.0685	0.0596*		0.116**	0.0596*		0.0974*	0.0596*	
	[0.0520]	[0.0350]		[0.0579]	[0.0350]		[0.0527]	[0.0350]	
New State UK	-0.608***	0.230***		-0.827***	0.230***		-0.804***	0.230***	
	[0.0906]	[0.0484]		[0.0901]	[0.0484]		[0.0906]	[0.0484]	
New State	-0.101**	-0.0362		-0.0204	-0.0362		-0.0248	-0.0362	
	[0.0488]	[0.0338]		[0.0572]	[0.0338]		[0.0487]	[0.0338]	
HW-Dum^a	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Region-Dum^a	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Time-Dum^a	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Region-Time^a	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Observations	750	750	750	750	750	750	750	750	750
Number of countries	39	39	39	39	39	39	39	39	39
F-test	285.58***	65.79***	50.79***	28.66***	65.79***	19.31***	65.24***	65.79***	25.55***
F-Test on excl. IV	31.88***	12.99***		55.21***	12.99***		41.87***	12.99***	
Underid test			8.455**			7.548**			6.933**
Weak id stat			0.0146			0.023			0.0312
P-value Hansen test			0.5			0.857			0.803
Endo stat			13.001***			14.34***			14.4***
Root MSE	0.239	0.097	12.48	0.27	0.097	11.36	0.241	0.097	11.48

* significant at 10%; ** significant at 5%; *** significant at 1%. 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.

Table 9: Robustness to the addition or omission of control variables

Regression	(39)	(40)	(41)	(42)	(43)	(44)	(45)	(46)	(47)
Models	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS
SE	robust	robust	robust	robust	robust	robust	robust	robust	robust
Stage	1^{st}	2^{nd}	1^{st}	1^{st}	2^{nd}	2^{nd}	1^{st}	1^{st}	2^{nd}
Dependent Variable	log(y/y^F)	log(URB)	MIGR	log(y/y^F)	log(URB)	MIGR	log(y/y^F)	log(URB)	MIGR
Addition	ACP	ACP	ACP				Density	Density	Density
Omission				No Conflict	No Conflict	No Conflict			
RAIN	-0.0232*	-0.0033	0.882	-0.0229	-0.00332	0.849	-0.00819	-0.00133	0.484
	[0.0137]	[0.00831]	[0.822]	[0.0141]	[0.00831]	[0.844]	[0.0143]	[0.00797]	[0.828]
TEMP	-0.0426***	-0.0204**	2.851**	-0.0435***	-0.0203**	2.858**	-0.0387**	-0.0200**	2.636**
	[0.0152]	[0.00877]	[1.228]	[0.0153]	[0.00876]	[1.244]	[0.0155]	[0.00875]	[1.221]
RAIN*AGRI	0.0498***	0.00159	-1.367	0.0473**	0.00191	-1.187	0.0378**	-0.000235	-1.271
	[0.0185]	[0.00996]	[0.927]	[0.0184]	[0.00999]	[0.908]	[0.0188]	[0.0101]	[0.980]
TEMP*AGRI	0.0106	0.0452***	-4.161**	0.00614	0.0458***	-4.219**	0.0134	0.0480***	-4.118**
	[0.0214]	[0.00983]	[1.652]	[0.0217]	[0.00975]	[1.696]	[0.0219]	[0.0101]	[1.660]
WAR$_t - 1$	-0.0742	0.0104	3.211				-0.0947	0.0039	5.013
	[0.0877]	[0.0259]	[5.818]				[0.0904]	[0.0251]	[6.421]
WAR$^F_{t-1\,t} - 1$	-0.182	0.02	1.355				-0.26	0.00357	6.48
	[0.150]	[0.0851]	[7.177]				[0.164]	[0.0829]	[7.486]
Addition	0.177*	-0.0163	-3.697				0.00310***	0.000668	-0.140**
	[0.1000]	[0.0354]	[2.936]				[0.000754]	[0.000590]	[0.0606]
log(y/y^F)			23.86***			21.63***			31.00***
			[8.079]			[7.243]			[10.05]
log(URB)			63.82***			68.50***			55.82***
			[22.78]			[24.37]			[19.37]
Instruments									
Δ Money	0.128**	0.0598*		0.129**	0.0598*		0.119**	0.0567	
	[0.0541]	[0.0350]		[0.0557]	[0.0350]		[0.0533]	[0.0358]	
New State UK	-0.615***	0.228***		-0.646***	0.231***		-0.408***	0.275***	
	[0.0929]	[0.0489]		[0.0897]	[0.0481]		[0.0975]	[0.0613]	
New State	0.0843	-0.0467		-0.0292	-0.0362		-0.0469	-0.0395	
	[0.0892]	[0.0380]		[0.0508]	[0.0337]		[0.0514]	[0.0342]	
HW-Dum^a	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Region-Dum^a	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Time-Dum^a	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Region-Time^a	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.	incl.
Observations	750	750	750	750	750	750	750	735	735
Number of countries	39	39	39	39	39	39	39	39	39
Number of countries	39	39	39	39	39	39	39	39	39
F-test	85.57***	68.72***	56.11***	64.18***	64.98***	595.00***	61.10	54.18***	3512.28***
F-Test on excl. IV	17.56***	9.22***		31.07***	13.18***		14.25***	9.06***	
Underid test			7.773**			7.661**			13.59***
Weak id stat			2.56			2.449			4.822
P-value Hansen test			0.535			0.869			0.731
Endo stat			13.94***			14.41***			14.45***
Root MSE	0.23	0.097	10.87	0.23	0.097	10.89	0.23	0.098	11.3

* significant at 10%; ** significant at 5%; *** significant at 1%. 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.

Table 10: Robustness with alternative OECD dataset

Regression	(48)	(49)	(50)	(51)	(52)	(53)	(54)	(55)	(56)
Models	FE	FE	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS
SE	robust	robust	robust	robust	robust	robust	robust	robust	robust
Stage			1^{st}	2^{nd}	1^{st}	2^{st}	1^{nd}	1^{st}	2^{st}
Dependent Variable	MIGR	MIGR	log(y/y^F)	MIGR	log(y/y^F)	MIGR	log(y/y^F)	log(URB)	MIGR
log(y/y^F)	-2.863**	-2.824**		-19.73*		-12.67*			-10.06**
	[1.354]	[1.357]		[10.88]		[7.540]			[5.022]
RAIN		0.00869	-0.0247***	-0.463	-0.0232***	-0.00424	-0.0232***	-0.00683**	0.0459
		[0.239]	[0.00570]	[0.410]	[0.00576]	[0.281]	[0.00577]	[0.00316]	[0.232]
RAIN*AGRI		-0.155	0.0205***	0.377	0.0173**	-0.0885	0.0186**	0.00509	-0.126
		[0.236]	[0.00739]	[0.404]	[0.00738]	[0.241]	[0.00740]	[0.00421]	[0.198]
TEMP		0.349	-0.0394***	-0.286	-0.0349***	-0.0717	-0.0336***	-0.0133***	-0.00111
		[0.292]	[0.00584]	[0.559]	[0.00603]	[0.388]	[0.00602]	[0.00336]	[0.347]
TEMP*AGRI		-0.383	-0.00396	-0.426	-0.00637	-0.386	-0.00823	0.0236***	-0.333
		[0.345]	[0.00772]	[0.396]	[0.00772]	[0.333]	[0.00771]	[0.00406]	[0.323]
log(Distance)	-2.143	-2.143	-0.00791	-2.568					
	[2.368]	[2.365]	[0.0445]	[2.580]					
WAR_{t-1}	0.631	0.653	0.00466	0.886	-0.00294	0.511	-0.00229	0.00715	0.529
	[1.225]	[1.216]	[0.0231]	[1.221]	[0.0238]	[1.144]	[0.0237]	[0.00857]	[1.149]
log(URB)									-1.543
									[2.511]
Instruments									
Δ Money			0.0277***		0.0296***		0.159***	0.0612***	
			[0.00906]		[0.0110]		[0.0283]	[0.0137]	
New State							-0.00957	-0.00399	
							[0.0332]	[0.0179]	
Constant	22.93	22.84							
	[22.83]	[22.83]							
α_i	Incl.	Incl.	Incl.	Incl.			Incl.	Incl.	Incl.
α_j	Incl.	Incl.	Incl.	Incl.			Incl.	Incl.	Incl.
$\alpha_i j$					Incl.	Incl.			
HW-Dum[a]	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Region-Dum[a]	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Time-Dum[a]	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Region-Time[a]	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Observations	4'959	4'959	4'503	4'503	4'463	4'463	4'463	4'463	4'463
F test			9172***	37774***	599***	3.90***	593***	228***	151***
F-Test on excl. IV			9.33***		7.31***		13.85***	39.27***	
P-value Hansen									0.0989
Underid test				14.75***		11.49***			26.32***
Root MSE	7.621	7.622	0.210	8.293	0.203	5.834	0.203	0.0911	5.742

* significant at 10%; ** significant at 5%; *** significant at 1%. Robust standard errors are in square brackets. y stands for GDP per capita in migrants' origin countries, y^F stands for GDP per capita in destination countries. "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. Efficiency of regressions (16)-(18) have been strengthened by introducing the square of the money supply to make the instruments stronger. Otherwise, the second-stage is less precise due to the instrument weakness in such a setting. Angrist-Pischke multivariate F test of excluded instruments for regression (54)-(56). R-squared 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 11: Projected changes in net migration, by country

A. Annual net migrants (numbers)					B. Annual net migrants (per thousand of population)				
	(1)	(2)	(3)	(4)		**(5)**	(6)	(7)	(8)
		2080-2099		**1960-2000**			**2080-2099**		**1960-2000**
Country	**median**	best	worst		Country	**median**	best	worst	
Nigeria	-4046790	-1352539	-6614062	-22000	Congo Brazz.	-9.25	-3.52	-14.69	-0.01
Tanzania	-2255926	-781905	-3318285	-13119	Gabon	-8.64	-3.53	-13.49	0.23
Kenya	-1288887	-513725	-1856386	-14732	Mozambique	-8.63	-4.12	-12.72	-0.67
Uganda	-830091	-216471	-1262958	-7688	Tanzania	-8.60	-2.98	-12.65	-0.55
Niger	-642116	-156446	-1138538	-4788	Angola	-8.23	-3.97	-12.10	-0.84
Mozambique	-640826	-306091	-944822	-10330	Sierra Leone	-7.97	-3.21	-12.48	-1.34
Angola	-489114	-236036	-719281	-9761	Kenya	-7.66	-3.05	-11.03	-0.55
Ghana	-427738	-162675	-679480	-9079	Guinea	-7.50	-3.01	-11.76	-1.44
Mali	-350832	-10878	-664631	-12698	Ghana	-6.84	-2.60	-10.87	-0.71
Guinea	-268202	-107505	-420574	-9487	Djibouti	-6.51	-3.01	-9.13	-0.82
Benin	-167796	-58263	-272076	-3786	Nigeria	-6.35	-2.12	-10.39	-0.28
Sierra Leone	-135132	-54472	-211598	-5971	Uganda	-5.93	-1.55	-9.02	-0.55
Congo Brazz.	-128248	-48850	-203652	-32	Niger	-5.83	-1.42	-10.34	-0.66
Gabon	-34191	-13955	-53367	201	Guinea-Bissau	-5.47	-2.32	-8.44	-1.34
Guinea-Bissau	-28727	-12205	-44360	-1446	Benin	-5.43	-1.88	-8.80	-0.84
Gambia	-27136	-12568	-40871	-1508	Mali	-5.27	-0.16	-9.97	-1.56
Djibouti	-12569	-5806	-17635	-443	Gambia	-4.86	-2.25	-7.32	-1.63
Botswana	-10640	-3282	-14824	-1548	Botswana	-4.66	-1.44	-6.49	-1.23
Swaziland	6065	3389	8563	359	Lesotho	3.67	2.05	5.19	0.48
Mauritius	9378	5241	13240	65	Swaziland	3.89	2.18	5.50	0.53
Lesotho	11086	6195	15651	830	Mauritania	4.02	2.90	6.03	0.46
Namibia	21194	11844	29921	1072	Sudan	4.16	3.01	6.24	0.59
Mauritania	42948	31018	64423	1021	Senegal	4.18	2.28	5.96	0.57
Togo	64297	35071	91575	1160	Burkina Faso	4.31	2.35	6.14	0.24
Centr. Afr. Rep.	74061	40397	105480	688	Zimbabwe	4.60	2.57	6.49	0.48
Burundi	84430	47492	113453	2790	Togo	4.79	2.61	6.83	0.31
Liberia	98117	53518	139743	361	Chad	5.18	3.74	7.78	0.11
Zimbabwe	99245	55460	140111	4620	Namibia	5.24	2.93	7.40	0.69
Senegal	193226	105396	275201	4123	Zambia	5.34	2.98	7.54	0.49
Chad	190440	137540	285661	549	Rwanda	5.47	3.07	7.35	0.62
Rwanda	212874	119742	286050	3858	Burundi	5.64	3.17	7.58	0.56
Cameroon	326530	178107	465057	171	Ethiopia	5.84	3.28	7.84	0.30
Côte d'Ivoire	327375	178568	466261	1081	Malawi	6.16	3.44	8.70	0.44
Burkina Faso	336579	183589	479371	2029	Liberia	6.36	3.47	9.05	0.16
Sudan	469210	338874	703815	14567	Côte d'Ivoire	6.62	3.61	9.43	0.10
Zambia	592775	331257	836859	3639	Cameroon	6.90	3.77	9.83	0.02
Malawi	677564	378639	956561	3759	Centr. Afr. Rep.	7.11	3.88	10.12	0.24
Congo Ksh.	1316591	740582	1769168	5241	Congo Ksh.	7.14	4.01	9.59	0.16
Ethiopia	1544354	868699	2075226	14636	Mauritius	7.99	4.46	11.27	0.07

The countries of our sample are ranked according to highest *additional* net out-migration expected by the IPCC's scenario A1B *median* weather forecast. Columns (1) to (3) display future changes in the *number* of net migrants as a consequence of IPCC's scenario A1B projected weather variations. They account for population increase between 1980-1999 and 2080-2099 as estimated by the medium-fertility scenario of the UN population forecasts. Columns (5) to (7) show projections for net migration *rates* induced by weather changes. Column (4) displays the yearly average number of net migrants induced by weather variations over the period 1960-2000. Column (8) shows the yearly average net migration rate due to weather variations over the same period. Columns (1) to (3) evaluate the additional number of net migrants compared to the average population for the period 1980-1999.

Institut de Recherches Économiques et Sociales
Université catholique de Louvain

Place Montesquieu, 3
1348 Louvain-la-Neuve, Belgique

ISSN 1379-244X D/2011/3082/034