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Is environmentally-induced income variability a driver of migration? A macroeconomic perspective*

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Abstract

It was recently suggested that the role of environmentally-induced income variability as a determinant of migration has been studied little to none. We provide a theoretical discussion and an overview of the empirical literature on this. We also extend a previous empirical study of ours by including income variability. Our findings lead us to acknowledge that income variability is a negligible driver of migration decisions at the macroeconomic level.

Keywords: Income variability, international migration, rural-urban migration, weather anomalies, sub-Saharan Africa.
JEL Classification: F22, Q54, R13.

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1 Introduction

The widely-known predictions for environmental migration in Black (2001) or the Stern Review (Stern et al. 2006) have attracted a growing number of academic studies that investigate in how far these largely back-of-the envelop predictions stand the test of academic scrutiny. These academic studies have mainly focused on environmentally-induced income differences between urban or rural regions or receiving and sending countries as drivers of migration decisions. By environmentally-induced migration decisions we shall, henceforth, mean any impact from environmental conditions, like weather variability or natural disasters, on migration decisions, either directly or indirectly through other variables. As a general result from this literature, environmental effects like weather variability have been shown to drive national and international migration through income differences (Marchiori, Maystadt and Schumacher, 2011). Some of the studies on environmentally-induced drivers of migration have been reviewed, among others, in a recent article by Lilleør and Van den Broek (2011). One of the main questions that came out of the readings of the literature was whether only income differences play a role in determining migration, or whether there is also a role for income variability. In this article we investigate whether environmental conditions drive migration through their impact on income variability. We do this in three steps.

In section 2 we describe a theoretical model that we introduced in Marchiori, Maystadt and Schumacher (2012) and that captures the primary links between weather variability, rural-urban and international migration. The two channels through which the environment may drive migration are the 'amenity channel', which impacts migration decisions directly through non-market costs, and the 'economic geography channel', which works through wage and agglomeration effects. Based on this model we find little reason to believe that income variability may play a crucial role for environmental-induced migration decisions.

In the next section 3 we go through a close to exhaustive list of the migration literature and investigate, in which approaches income variability has been shown to play a significant role for environmentally-induced migration. In our reading of the literature we find that income variability has only been emphasized in one microeconomic study, and only in a rather specific setting. We find income variability to be missing from all macroeconomic studies.

As a result, in section 4 we extend a previous macroeconomic study of ours (Marchiori, Maystadt and Schumacher, 2012) to include income variability as an additional explanatory variable. We argue for different ways in which income variability should be modeled in a macroeconomic setting and test several different specifications.

Though our empirical results suggest that there is no significant role for environmentally-induced income variability as a driver of migration decisions, we would like to emphasize to the reader that our approach should be understood as a preliminary step in the analysis of the role of income variability. We conclude with some further remarks in section 5 on why income variability could nevertheless play a role and how future studies could try addressing vital links.

2 A theoretical discussion

In a recent article of ours (Marchiori, Maystadt and Schumacher, 2012), henceforth MMS, we analyze the effects of weather anomalies[1] on migration in sub-Saharan Africa. We propose a two country, two sector model, where the motivation to migrate depends on the difference in standards of livings (i.e. indirect utility) between rural and urban areas, as well as domestic and foreign countries. The model predicts that i) weather anomalies have a direct effect on migration via amenities; ii) weather anomalies have indirect effects on migration through changes in income and urbanization; iii) the environmental impact is stronger in economies that depend heavily on the agricultural sector; iv) the weather-induced change in income is endogenous to migration; v) the weather-induced change in urbanization is endogenous to migration.

The mechanism of the model is as follows. Assume we are in an equilibrium where nobody wants to migrate. Further, assume migration decisions are taken based on indirect utility comparisons, where indirect utility is depending on wages and amenity conditions. Finally, assume climatic conditions worsen in one country. Since it is well-known that a worsening of climatic conditions has the strongest impact on the rural sector, then this reduces wages in the rural sector, leading to a gap between rural and urban wages. As a consequence, rural workers have now

[1] Weather anomalies are calculated as the deviations from a country's long-run mean, divided by its long-run standard deviation.

an incentive to migrate to the urban sector. Consequently, a worsening of climatic conditions in one country leads to a rural-urban migration.

In the urban sector, there are now two opposing forces at play. One is that an increase in the urban population has a so-called agglomeration effect. It is a kind of Marshallian externality that increases local wages due to e.g. labor sharing. Since this agglomeration effect has a positive impact on wages, it is expect to further attract migrants from the rural sector, but also now from abroad, since there are higher wages in the urban sector compared to other countries. However, decreasing returns to labor in the production function suppress wages in the urban sector. As a result, if decreasing returns to scale outweigh the agglomeration effect, then the worsening of the climatic condition leads first to rural-urban migration, and then to international migration. We dubbed this channel the *economic geography channel*. To be precise, it is comprised of an income channel and an agglomeration channel, both working in opposite directions.

Finally, there is the *amenity channel*. It is, for example, well known that illnesses like malaria or dengue increase substantially in some countries with worsening climatic conditions. In this case, migratory decisions might not be based on income differentials but simply be due to quality of life considerations.[2]

This is the starting point, and we now have to figure out how environmentally-induced income variability influences the mechanisms introduced above. Our assumption is that income variability is disliked by agents because of risk aversion. Leaving the amenity channel aside and assuming we are in a two country setting, it is clear that environmental variables affect both income levels and income variability. Assume we start from a situation where weather variability is driving income to a significant extent, and assume that there was no important weather variability during the past years in both countries. If country A has the more favorable weather conditions, then it will have a higher income level and there will be migration from country B to country A based on the economic geography channel. Thus, if weather variability is sufficiently low, then environmentally-induced income differences are the drivers of migration. Assume now that income variability increases in country A. This can arise in basically three different ways.

Firstly, assume weather conditions in country A worsen over consecutive years,

[2]The amenity channel has been shown to exist for the case of the US by Rapapport (2007) and also discussed in the Wold Development Report (World Bank, 2010).

thus reducing income levels and increasing income variability. In this case, worsening living conditions, especially in already poor regions, are driving migration decisions to country B. Here, the increase in income volatility will have the desired sign in an econometric study, namely it is going to affect out-migration positively. However, the reduction in income levels will also increase out-migration. Consequently, we will again not have the effect that an increase in income variability affects migration because of an increase in variability, but simply due to the worsening trend in income levels.

Secondly, income variability may arise due to over consecutive improvements in weather conditions in country A, which then raise income levels but also increases income variability. The increase in income levels will lead to an inflow of migrants, while the increase in income variability should lead to an outflow of migrants due to risk aversion. In our opinion, agents need to be extremely forward looking in order to associate the current improvements in weather conditions with an increased variability that may lead to worsening weather conditions later. The problem, clearly, comes from the fact that the increase in weather variability here has been beneficial for country A. Thus, agents are more likely to migrate based on the improvement in income levels than the increased variability. Furthermore, income variability is likely to have the wrong sign in an econometric study, since the increase in income variability will result in in-migration.

Thirdly, income variability can arise due to a so-called mean preserving increase in weather volatility. Let us assume that at time $t = 1$ the weather improves, while at time $t = 2$ it worsens relative to the status quo. This leads first to an increase in income at time $t = 1$, then to a reduction at time $t = 2$, and thus to an increase in income variability over the periods $t = 0$ to $t = 2$. Assuming migration to be reasonably responsive to changes in the determinants of migration, then, based on the increase in income at $t = 1$ we would expect inwards migration to country A, and outwards migration in $t = 2$ due to the worsening of income levels. A risk averse agent would now prefer to migrate because his utility is likely to worsen based on the larger variability. Consequently, in this case weather-induced income variability may lead to migration, but only based on a 'risk aversion channel'.

It is then important to know how relevant such a risk aversion channel is likely to be. For example, it should be expected that the risk aversion channel is mediated by savings in good years which may be used to compensate income reductions in bad years. Also, it is well-known that weather conditions play the largest role in the agricultural sector of the developing countries. However, weather variability is the rule rather than the exception, and consequently income variability is well-known to agricultural workers. It is more reasonable to expect constraints to matter the most. For example, it is unlikely that a farmer who spent years and years cultivating his land will simply migrate somewhere else because of an increase in weather variability. Instead, migration will be considered a necessary option in case income levels have reduced to below subsistance levels, or to levels that are far worse than in other countries. Also, discount rates in less developed countries are very high such that current living conditions tend to matter more than potential future ones. Finally, recent contributions by Barro (2009) suggest that the welfare costs of smaller income variability are rather low. If that is the case, then it is reasonable to believe that this point also extends to migration decisions.

Based on the framework above, it is difficult to acknowledge an important role to income variability itself as a driver of migration decisions, at least from a theoretical perspective.

3 Empirical evidence on income variability and environmental migration

To see whether income variability is really an important driver of environmentally-induced migration decisions, we revisit the empirical evidence on the effects of income variability on environmental migration.

In effect, we only know about two microeconometric studies that investigate the impact of income variability as a driver of migration decisions (c.f. Lilleør and Van den Broek, 2011), namely Rosenzweig and Stark (1989) as well as Yang and Choi (2007). Rosenzweig and Stark (1989) investigates how marriage is used as a risk-mitigating devise by Indian households and find that profit variability has an impact on marriage-related migration of household members. Yang and Choi (2007) use household data from the Philippines and find that the change in household income (as a share of initial household income) increases the likelihood of a household having a migrant, but only for non-migrant households. Thus, both articles predict that household migration is used to smooth consumption expenditure.

In the macroeconomic literature, we have not come across a single article that studied the role of income variability for migration decisions. Our subsequent discussion is partly based on the review in Lilleør and Van den Broek (2011), and also extends this to new articles. Even assuming that climate variability drives income variability to a substantive extent, the evidence is not supportive of the assertion that environmentally-induced income variability is a major determinant of migration. Among the papers referred by Lilleør and Van den Broek (2011)[3], almost none of them shows that climate variability (assumed to proxy for income variability) affects migration.[4] As far as we know (see Table 4, with changes and updates compared to Lilleør and Van den Broek (2011) in bold), the only other articles that directly investigate the role of climate variability as a factor of migration - but not referenced in the review of Lilleør and Van den Broek (2011) - are Mueller and Osgood (2009), Dillon et al. (2011), Lewin et al. (2012) and Kavi Kumar and Viswanathan (2012). Mueller and Osgood (2009) observe greater migration rates in Brazil from areas with lower precipitation variance. The same authors indicate that such a variance has a detrimental impact on household income. As acknowledged by the authors, that result is not robust to the inclusion of household characteristics (number of household members in a given age category, or the household head educational attainment) while the authors do not assess the impact on income variability. The most robust finding in their income equation relates to their measure of precipitation shocks, proxied as the difference between the precipitation mean and the level of precipitation the year the household migrated. Dillon et al. (2011) use climate variability to measure agricultural income variability and assess its importance in determining migration in Nigeria. However, these authors rightly suggest that, based on their econometric method, their results rather imply that climate variability is associated with low income *levels*, but not necessarily income variability. If one were to extrapolate this result, then we should conclude that climatic shocks should increase migration, at the household level, for reasons of consumption smoothing. Lewin et al. (2012) also

[3]See panel C of Table 1 in Lilleør and Van den Broek (2011) and reproduced as part of Table 4.

[4]The definition of rainfall variability in Henry et al. (2003, 2004) is close to the rainfall anomalies used in Marchiori et al. (2012), as it is expressed as the frequency of deviations from the long-term mean. More specifically, Henry et al. (2003) compute the number of decades during the rainy season of 1983-1984 with a deviation from the mean rainfall of more than 50 percent compared to the 1960-1998 mean rainfall for the corresponding decade. Henry et al. (2004) define rainfall deficits based on the ratio of the mean rainfall over the three preceding years to the mean rainfall over the 1960-1998 periods.

introduce a measure of climate variability, defined as the average for the last 10 rainy seasons of the coefficient of variations of daily rainfall. Contrary to Mueller and Osgood (2009) and Dillon et al. (2011), the authors find that such a proxy is negatively associated with the fact to have migrated. That result seems to be in contradiction with the mechanism asserted by Lilleør and Van den Broek (2011). However, the fact they use the mean (and not the change) of the standard deviation in a cross-sectional setting limits their ability to draw causal inference. Finally, a recent paper by Kavi Kumar and Viswanathan (2012) directly introduce the standard deviation of annual rainfall over the past 20 years to explain migration between Indian districts. Such variable has a significant impact on short-term migration (defined as within 6 months) and no impact on long-term migration (larger than 6 months). The same authors then identify the link between weather variability and migration, through changes in crop yields (in particular of wheat) but not on crop yields (or income) variability. The paper applies the method proposed by Feng et al. (2010) who only investigate the role of changes (not variability) in annual precipitation and temperature. So even extending the literature review of Lilleør and Van den Broek (2011), we find very little support, with the exception of the special case of marriage-related female migration in India (Rosenzweig and Stark 1989), for a role of income variability.[5]

Naturally, the fact that neither of the articles (apart from microeconometric study mentioned above) in our review of articles in Table 4 includes income variability as a driver of migration does not preclude the possibility that it may, nevertheless, be a driver of migration decisions. This holds especially true since most of the articles only investigate a reduced-form relationship between migration and climate variables, without studying further through which channels these climate variables drive migration. Indeed, the microeconometric study of Rosenzweig and Stark

[5]Reviewing the papers who have used climatic variations as an instrument for income is outside the scope of this review as it would touch upon a wide variety of fields such as issues related to democratization (Brückner and Ciccone 2011, Burke and Leigh 2010), conflict (Miguel et al. 2004, Brückner 2010, Miguel and Satyanath 2011, or Ciccone 2011), health (Hoddinott and Kinsey 2001 , Burke et al. 2012), financial flows (Yang and Choi 2007, Arezki and Brückner 2011), labor (Rose 2001), etc. More fundamentally, the search for a source of exogenous variation (for the sake of finding a valid instrument for income shocks) in these related papers means that researchers legitimately only show the significant relationship between certain types of weather shocks and income, while a review should not exclude by construction studies that would not find any relationship between weather shocks and economic outcomes. We thus limit the review to quantitative papers that ensure some degrees of comparability.

(1989) suggests that income variability plays a role at the micro-level. However, it is not clear a priori whether the result of Rosenzweig and Stark (1989) really applies further than simply to a couple of villages in rural India and beyond a particular institutional setting, marriage arrangements in South Asia. The question, thus, is, whether their result is sufficiently important also at the macroeconomic level. We thus go back to our original empirical study and add income variability in order to know whether this variable turns out to be an important driver of migration or not.

4 Empirical study

The empirical model adopted by Marchiori et al. (2012) is based on the theoretical framework that we described above. Such a standard framework has been equally adopted by related papers on the issue of environmental migration such as Barrios et al. (2006), Naudé (2010) or Beine and Parsons (2012). Naturally, we adapt this basic framework in order to understand how weather variations may affect the internal and international migration and also shed light on the sources of multiple endogeneities.

$$\begin{aligned}\mathrm{MIGR}_{r,t} = {} & \beta_0 + \beta_1\,\mathrm{WeatherA}_{r,t} + \beta_2\,(\mathrm{WeatherA}_{r,t} * \mathrm{AGRI}_r) + \beta_3 \log\left(\frac{\mathrm{GDPpc}_{r,t}}{\mathrm{GDPpc}_{-r,t}}\right) \\ & + \beta_4 \log(\mathrm{URB}_{r,t}) + \beta_5 \log(\mathrm{GDPpcVariability}_{r,t}) + \beta\,\mathrm{X}_{r,t} + \beta_{R,t} + \beta_r + \epsilon_{r,t}\end{aligned}$$

Based on a dataset of 39 sub-Saharan African countries with yearly data from 1960 to 2000, the empirical model seeks to explain the average net migration rates ($MIGR_{r,t}$) defined for each country r at year t by variables describing the weather characteristics ($WeatherA_{r,t}$), the economic and demographic situations (e.g. the income differential $\frac{\mathrm{GDPpc}_{r,t}}{\mathrm{GDPpc}_{-r,t}}$ or the level of urbanization $\mathrm{URB}_{r,t}$), as well as several country-specific variables (e.g. $\mathrm{X}_{r,t}$) . To reduce the threat of endogeneity biases (due to simultaneity, omitted variable, measurement errors or spurious trends), we also control for any time-constant source of country heterogeneity by the use of a country fixed effect α_r, for phenomena common to all countries across time through the introduction of time dummies, α_t, and for changes in the regional patterns of migration with time-region fixed effect, $\alpha_{R,t}$. We also adopt an instrumental approach to induce some exogenous variations in our variables of interest and be able to draw causal inference. More explanations are given in Marchiori et al. (2012).

The only change compared with marchiori et al. (2012) is the addition of one proxy for income variability, $(\text{GDPpcVariability}_{r,t})$. Like Rosenzweig and Stark (1989), we use the standard deviation of income as a measure of the intertemporal variability in income (per capita). The average income over a certain period N is simply

$$\widehat{y}_t^N = \frac{1}{N} \cdot \sum_{k=t-n+1}^{N} y_k, \tag{1}$$

where $n \geq 1$. The intertemporal variance of income ($(s_t^N)^2$), over N periods, is given by

$$(s_t^N)^2 = \frac{1}{N} \cdot \sum_{k=t-n+1}^{N} (y_k - \widehat{y}_t^N)^2, \tag{2}$$

where the standard deviation of income (s_t^N) is simply the square root of the variance. It is denoted by s_{it}^N and it varies across countries i and over time t, where again N denotes the number of periods over which the standard deviation is defined.

The coefficient of variation is then simply defined as

$$cv_t^N = \frac{s_t^N}{\widehat{y}_t^N}.$$

One comment that we have for future works investigating the role of climate variability is that similar concerns should apply to income variability as to income differences. It would not make sense for a migrant to move from an origin country because of high income variability to another country with even higher income variability. As a consequence, any study should take the income variability differences between origin and destination country into account. However, simply considering income variability at the origin and destination country is also not enough. Imagine a country with low income compared to one with high income. Even though the income variability in the low income country is high, it may be that a lower income variability in the high income country has a higher relative value. This arises because income levels are having a scale effect on the standard deviation. To properly take this scale effect into account one would have to use the coefficient of variation, which adjusts the standard deviation by the mean. Finally, it goes without saying that if one believes income levels to be endogenous like we showed it to be the case in MMS, then one will directly accept that also income variability is endogenous. As a consequence, one has to control for this endogeneity.

Table 1 offers a short description of the main variables used in MMS (sources in there). Table 2 presents, in columns 1 to 3, the results of MMS' preferred specification (i.e. columns 3-5 of Table 6 in MMS 2012). The other columns show how these results change when income variability ((s^N)) is introduced. Similar results are obtained for $N = 2, 3, 4, 5$, we present the results for $N = 3$. As a quick reminder, our theoretical framework predicts that wages and the level of urbanization should be treated as endogenous variables in any empirical framework. Thus, regressions (1) and (2) give the first stage regressions, where both the income differential and the level of urbanization are treated endogenously, with the instruments being the change in money supply ("Δ Money"), and whether the country has recently become independent ("New State" as well as "New State UK" from British colonial rule). Regression (3) then presents the results with migration as the dependent variable, the two instrumented variables and the climate controls. We find that both the income differential and the level of urbanization are affected by the climate variables, and both are also explaining migration. Furthermore, we have a direct effect from the climate variables on migration, which we - based on the theoretical model - can ascribe to the amenity affect.

We now include income variability into our specification. To minimize potential future criticism we do this in three steps. Firstly, we include income variability as an exogenous variable, which we suggested above should be problematic due to its potential endogeneity, and also because it should be measured relative to the income variability in the foreign countries. In any case, including income variability ($(s)^3$) into the model gives regressions (4) to (6). We see that income variability has no effect on income or urbanization, and that it has a marginally negative effect on migration. Looking at the coefficients, we find no differences that are worth mentioning. Consequently, we could stop here and dismiss income variability as the omitted variable that might be responsible for what we called the amenity effect.

However, in order to do things properly, we suggested that we would have to treat income variability as being endogenous. Not only that, but it must also be viewed relative to income variability in the country where the migrants might want to move to. Clearly, what use would there be in migrating to a country with a higher income variability, when the reason for migrating is the income variability in the origin country in the first place. Thus, in Table 3 we include the relative income variability $(s/s^F)^3$ and the relative coefficient of variation $(cv/cv^F)^3$ as endogenous regressors. As a first remark, we find that they pass the instrument validity tests. Thus, based on the standard overidentification and weakness tests, we have some confidence about the validity of the instruments for these variables. First-stage regressions for the income differential y/y^F and for urbanization URB stay the same. Regression (4) shows the model (1) to (3) with the income variability differential ($(s/s^F)^3$) as being treated as an additional endogenous variable. We see that this has no impact on the results, which are now presented in regression (5). In regression (6) we use the measure that we view as more appropriate, namely the coefficient of variation differential ($(cv/cv^F)^3$. The new regression results for migration are presented in regression (7). Again, we find no changes to the previous results.

We conclude that our previous results are robust to the inclusion of income variability in different ways i.e. measuring it by the standard deviation or by the coefficient of variation of income over time, treating it as being exogenous or endogenous and using its level or its difference with respect to other countries.

5 Some further comments

In several empirical studies it has been suggested to discriminate between the effects of 'climate change', which is a shift in the average climate, and the effects of 'climate variability', which is a change in the variance of the climate. Given the time scale that we have, it is barely impossible to know whether changes in temperature or rainfall are actual level changes or simply changes in variability. For example, climatologists work with climate data extending over thousands of years, whereas economists tend to look at data from 30 to at maximum 50 years back. Obviously, at this range, we can never know whether the data that we have is due to climate change or due to a short-run climate variability. Consequently, it is impossible to discriminate between the two since we can actually only observe climate variability on this short time scale.

As another concern, and this is also a problem in our robustness study, one problem with income variability at the macro-level is clearly that a lot of micro-variability is simply washed out. For example, assume a country is consisting of two individu-

Table 1: Short description of main variables

CODE	Definition/Description
MIGR	Net migration rate: Difference between numbers of immigrants and emigrants per thousands of population, corrected by the refugee movement
RAIN	Rain Anomalies, deviations from the country's long-term mean, divided by its long-run standard deviation
TEMP	Temperature Anomalies: deviations from the country's long-term mean, divided by its long-run standard deviation
y/y^F	GDP per capita over GDP per capita in other African countries weighted by distance.
WAR	War onset, value 1 for civil war onset
WAR^F	War onsets in other countries weighted by distance
URB	Share of urban population in total population
AGRI	Whether a country has an agricultural value added above the median in 1995 (similar to Dell, 2009)
Δ Money	Money plus Quasi-Money: Absolute growth in money supply
New State	Independence: value 1 if country is in the two first years of independence
$MIGR^a$	Original net migration rate, without refugee movement correction
NetREF	Net refugee movement per thousands of population
Variability variables	
$(s/s^F)^N$	Intertemporal standard deviation of GDP per capita over intertemporal standard deviation of GDP per capita in other African countries weighted by distance. The number of periods to calculate the standard deviation were 3 (i.e. $N = 3$).
$(cv/cv^F)^N$	Intertemporal coefficient of variation in GDP per capita over intertemporal coefficient of variation in GDP per capita in other African countries weighted by distance. The number of periods to calculate the coefficient of variation were 3 (i.e. $N = 3$).

A more detailed description of variables containing the different sources for the data is provided in the supplementary material of MMS (2012) or of MMS (2011).

als. During the past three years, individual A had an income of 1, 2 and 3, whereas individual B had an income of 3, 2, and 1. Total income at the country-level was 4 in each period. Thus, at the macro-level we would believe there to be no income variability. In contrast, it is clear that there is income variability at the household level. If that variability is then the source of migration decisions at the household level, it would be impossible to find the same feedbacks at the macro-level. As a consequence, it is more likely to find income variability as a driver of migration decisions at the micro-level. However, and as we argued above, this income variability must be viewed relative to the variability in the destination region. This is certainly a problem for cross-individual datasets that very often do not observe the income variability, at the household level, of the destination region. It is clear that, to arrive at a good measure of income variability at the macro-level, one would not want to start with aggregate income per se, but one would need to look at the income variability of individuals over time and then aggregate this over the region in question.

6 Conclusions

The results that we present in this article point more towards the importance of the level of income than income variability as a driver of migration at the macroeconomic level. Not only is this suggested through our theoretical model, but also based on our empirical results. However, we also believe that this should not necessarily be the final say yet on income variability versus income levels. As we suggested from the beginning, our approach should be understood as a preliminary step in the analysis of the role of income variability.

For example, one reason for which income variability may not show up as a significant explanatory variable in macroeconomic studies is simply because it is being washed out in the country-aggregate measures. Based on the currently-available datasets, it will be very difficult, if not impossible, to construct a better cross-country or within-country aggregate measure of income variability. One objective for future research should thus be to take the household-level result on income variability and aggregate this to the country-level to see whether the effect is significant. Much more can also be done to better measure the impact of weather shocks on agricultural outputs. In that respect, the recent papers by Beine and Parsons (2012) or Schlenker and Lobell (2010) pave the way for key improvements in assessing the relationship between weather variations and migration in Sub-Saharan Africa.

Most importantly, in future work one has to dig a little deeper and really try to understand under which circumstances income variability may play a crucial role and why this role may not be captured by the level of income itself. For example, income variability itself may not be a problem, but the problem comes from negative income shocks. However, these shocks may be better captured via lags of income in the empirical studies.

Also, recent contributions by Barro (2009) suggest that rare disasters induce much larger welfare costs than smaller variability. This suggests that future work should take further moments of the climate or income distribution into account when studying migration decisions. Nevertheless, even small shocks can have large impacts when societies live close to thresholds like subsistance consumption levels. Thus, future works should investigate the role of non-linearities like thresholds.

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Table 2: Two-stage regressions

Regression	(1)	(2)	(3)	(4)	(5)	(6)
Models	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS
SE	robust	robust	robust	robust	robust	robust
Stage	1^{st}	1^{st}	2^{nd}	1^{st}	1^{st}	2^{nd}
Dependent Variable	log(y/y^F)	log(URB)	MIGR	log(y/y^F)	log(URB)	MIGR
RAIN	-0.023	-0.00332	0.843	-0.0229	-0.00336	0.834
	[0.0140]	[0.00832]	[0.832]	[0.0140]	[0.00831]	[0.872]
TEMP	-0.0432***	-0.0204**	2.841**	-0.0433***	-0.0203**	3.040**
	[0.0153]	[0.00876]	[1.239]	[0.0153]	[0.00880]	[1.305]
RAIN*AGRI	0.0494***	0.00162	-1.258	0.0494***	0.00169	-1.227
	[0.0187]	[0.00997]	[0.936]	[0.0187]	[0.00996]	[0.980]
TEMP*AGRI	0.00811	0.0455***	-4.253**	0.00836	0.0452***	-4.869***
	[0.0218]	[0.00980]	[1.693]	[0.0222]	[0.0101]	[1.816]
log(y/y^F)			21.58***			22.36***
			[7.216]			[7.647]
log(URB)			67.51***			73.25***
			[24.14]			[25.75]
$(s)^3$				0.00000848	-0.0000103	-0.0118*
				[9.87e-05]	[5.15e-05]	[0.00638]
Instruments						
Δ Money	0.131**	0.0596*		0.130**	0.0600*	
	[0.0557]	[0.0350]		[0.0558]	[0.0351]	
New State UK	-0.641***	0.230***		-0.641***	0.230***	
	[0.0892]	[0.0484]		[0.0897]	[0.0485]	
New State	-0.0297	-0.0362		-0.0307	-0.035	
	[0.0504]	[0.0338]		[0.0520]	[0.0345]	
War	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
HW-Dum	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Region-Dum	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Time-Dum	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Region-Time	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Observations	750	750	750	749	749	749
Number of countries	39	39	39	39	39	39
F-test	88.87***	65.79***	22.17***	54.17***	56.06***	29.19***
F-test on excl. IV	30.84***	12.99***		30.99***	13.02***	
Underid test			7.595***			7.668**
P-value Hansen			0.871			0.5766
Endo stat			14.53***			12.296***
Root MSE	0.2283	0.09746	10.82	0.2285	0.09754	11.19

*** p<0.01, ** p<0.05, * p<0.1

** 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. “War” includes controls for war at home and war in other countries (not significant and not shown to save space), “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. $t-1$ indicates a one period lagged variable. R-squared is not shown, because, in the case of 2SLS/IV, it is not an appropriate measure of the goodness of fit and has no statistical meaning (see www.stata.com).

Table 3: Two-stage regressions

Regression	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Models	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS	FE2SLS
SE	robust	robust	robust	robust	robust	robust	robust
Stage	1^{st}	1^{st}	2^{nd}	1^{st}	2^{nd}	1^{st}	2^{nd}
Dependent Variable	log(y/y^F)	log(URB)	MIGR	log($(s/s^F)^3$)	MIGR	log($(cv/cv^F)^3$)	MIGR
RAIN	-0.023	-0.00332	0.843	-0.0602	0.842	-0.0372	0.841
	[0.0140]	[0.00832]	[0.832]	[0.0517]	[0.817]	[0.0532]	[0.818]
TEMP	-0.0432***	-0.0204**	2.841**	0.0334	2.758**	0.0747	2.758**
	[0.0153]	[0.00876]	[1.239]	[0.0625]	[1.229]	[0.0634]	[1.228]
RAIN*AGRI	0.0494***	0.00162	-1.258	0.0972	-1.259	0.0455	-1.256
	[0.0187]	[0.00997]	[0.936]	[0.0693]	[0.915]	[0.0711]	[0.916]
TEMP*AGRI	0.00811	0.0455***	-4.253**	-0.0214	-4.127**	-0.0374	-4.127**
	[0.0218]	[0.00980]	[1.693]	[0.0768]	[1.700]	[0.0804]	[1.700]
log(y/y^F)			21.58***		21.10***		21.38***
			[7.216]		[7.078]		[6.921]
log(URB)			67.51***		64.96**		65.03**
			[24.14]		[26.24]		[26.08]
log($(s/s^F)^3$)					0.318		
					[1.899]		
log($(cv/cv^F)^3$)							0.315
							[1.884]
Instruments							
Δ Money	0.131**	0.0596*		0.735***		0.612***	
	[0.0557]	[0.0350]		[0.203]		[0.216]	
New State UK	-0.641***	0.230***		-0.534		-0.016	
	[0.0892]	[0.0484]		[0.391]		[0.400]	
New State	-0.0297	-0.0362		1.173***		1.219***	
	[0.0504]	[0.0338]		[0.317]		[0.317]	
War	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
HW-Dum	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Region-Dum	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Time-Dum	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Region-Time	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.	Incl.
Observations	750	750	750	749	749	749	749
Number of countries	39	39	39	39	39	39	39
F-test	88.87***	65.79***	22.17***	79.27***	17.01***	42.92***	17.07***
F-test on excl. IV	30.84***	12.99***		13.19***		17.01***	
Underid test			7.595***		1.549		1.561
P-value Hansen			0.871				
Endo stat			14.53***		14.389***		14.301***
Root MSE	0.2283	0.09746	10.82	0.8	10.66	0.8233	10.67

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

** significant at 5%; *** significant at 1% (significance at 10% not highlighted). Robust standard errors are in square brackets. y and y^F stand for domestic and foreign GDP per capita, respectively. s and s^F stand for domestic and foreign standard deviation in income, respectively. cv and cv^F stand for domestic and foreign coefficient of variability in income, respectively. "War" includes controls for war at home and war in other countries (not significant and not shown to save space), "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. $t-1$ indicates a one period lagged variable. 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 4: *Updated Table 1 of LVdB (Lilleør and Van den Broeck, 2011)*

Papers describing empirical evidence of climate effects on (A) income, (B) income variability, (C) migration, but not tested through an explicit driver (reduced form), (D) migration through the income differential driver and (E) migration through the income variability driver. In bold, changes compared to LVdB.

	Paper	Country (data sets)	Finding	Migration type	Origin	Environmental measure	CC[a]
(A)	Papers describing empirical evidence of climate effects on *income*						
1	Amhed et al. (2011)	Tanzania (Ministry of Agriculture/Agro MAPS/CRU TS3.0)	Temperature has a significant negative effect on yields, while precipitation has a significant positive effect			Precipitation and temperature levels (not panel data)	Yes
2	Barrios et al. (2010)	Developing countries (IPCC/World Penn Tables)	Rainfall is a significant positive determinant of poor economic growth in African developing countries, but not in others			Rainfall anomalies[b]	Yes
3	**Blanc (2012)**	**FAO data on area harvested and yields, CRU TS 2.1 weather dataset and other data (CO2, crop growing areas) available for the period 1961-2002 for 37 SSA countries**	**Temperature and precipitation do not affect cassava yields but floods are detrimental to cassava yields; Excessive precipitation negatively affect maize yields (concave relationship between precipitation and maize yield); temperature is detrimental to millet and sorghum yields while precipitation show a concave relationship to yields of these two crops**		**Rural**	**Temperature and precipitation (with quadratic terms and interactions terms with a dummy for less favorable agricultural conditions) as well as measures of evapotranspiration and the standardized precipitation Index**	**Yes**
4	Dell et al. (2009)	Americas - 12 countries (household surveys)	Negative relationship between income and temperature, both between and within countries (taking country fixed effect into account). Suggest that half of the strong negative short-term effects are offset in the long run through adaptation			Mean temperature and precipitation (artificial panel data)	Yes
5	**Dell et al. (2012)**	World (Penn World Tables/WDI)	Higher temperatures reduce economic growth (levels and rates) in poor,but not in rich, countries through reductions in both agricultural and industrial output, aggregate investment and political stability			Variations in rainfall and temperature levels over 50 years	Yes
6	Dercon (2004)	Rural Ethiopia (household survey)	Negative and persistent effects of rainfall shocks on consumption growth at household level			Rainfall shocks defined as change in the log(rainfall) at t relative to $t-1$	No

Continued on next page

	Paper	Country(data sets)	Finding	Migration type	Origin	Environmental measure	CC[a]
7	Deschênes and Greenstone (2007)	USA (Census of Agriculture)	The effect of climate change on agriculture outcomesprofit in the US may prove to be much smaller than that found in other studies, when the adaptive responses of farmers are taken into account			Variations in rainfall and temperature levels **(degree days)**	Yes
8	**Fisher et al. (2012)**	**USA (Census of Agriculture)**	**Replicating and correcting Deschênes and Greenstone (2007) empirical analysis, adverse potential impact on US agriculture (corn and soybeans yields and profits) by the end of the century**			**Variations in rainfall and temperature levels (degree-days)**	**Yes**
9	Jayachandran (2006)	India (WB India Agriculture & Climate Dataset)	Rainfall shock is used in the first stage as an instrument for agricultural productivity. A positive rainfall shock increases crop yields by 7%			Rainfall shock (= level $\leq$ 80th percentile of a district's normal rainfall)	No
10	Kazianga and Udry (2006)	Rural Burkina Faso (ICRISAT)	Short-term negative rainfall deviations result in negative income shocks, which translate into negative consumption shocks with little evidence of smoothing or insurance			Rainfall deviations from long-run mean at village level	No
11	**Kumar and Viwanathan (2012)**		See Panel D below				
12	**Lewin et al. (2012)**		See Panel C below				
13	**Marchiori et al. (2012)**		see Panel D below				
14	Rowhani et al. (2011)	Tanzania (national crop & climate data)	Both inter- and intra- seasonal changes in precipitation and temperature are associated with changes in crop yields. Increased precipitation variability reduces yields			Temperature and precipitation levels, and variability (not panel data)	Yes
15	**Schlenker and Roberts (2009)**	**USA (Census of Agriculture)**	**Based on an hedonic approach, adverse impact (in a non-linear way) on corn soybeans, and cotton yields in the US**			**Variations in rainfall and temperature levels (degree-days)**	**Yes**
16	**Schlenker et al. (2006)**	**USA (Census of Agriculture)**	**Based on an hedonic approach, adverse impact on US agriculture (farm land value per acre) and potential detrimental impact by the end of the century**			**Variations in rainfall and temperature levels (degree-days)**	**Yes**
17	**Shlenker and Lobell (2010)**	**FAO dataset on crop yields from 1961 to 2006**	**Detrimental impact on crop yields for maize, sorghum, millet, groundnut and cassava**			**Variations in rainfall and temperature levels (degree-days)**	**Yes**

Continued on next page

	Paper	Country(data sets)	Finding	Migration type	Origin	Environmental measure	CC[a]
18	Yang and Choi (2007)		See Panel D below				
(B)	Papers describing empirical evidence of climate effects on *income variability*						
19	Rosenzweig and Stark (1989)		See Panel E below				
(C)	Papers describing empirical evidence of climate effects on *migration*, but not tested through an explicit driver (reduced form)						
20	Barrios et al. (2006)	SSA and non-SSA (78 countries - 1960 - 1990)	Climate change (proxied by rainfall) was a significant determinant of urbanization in Sub-Saharan Africa but not in other developing countries	Internal	Rural	Rainfall (level, normalised by LT mean)	Yes
21	Beegle et al. (2011)	Tanzania (KHDS)	In an auxiliary regression, the authors find a positive effect of rainfall shock when a child on migrating as adult	Internal	Rural	Rainfall shock[c]	No
22	**Beine and Parsons (2012)**		See Panel D below				
23	**Bettin and Nicolli (2012)**	**Bilateral panel migration data for 231 origin and 231 destination countries between 1960 and 2000**	**Significant direct impact of different climate change proxies on international migration. In particular, disasters on outmigration flows are statistically significant in Asian countries.**	**International**		**Rainfall and temperature deviations from the long-run average (Dummy taking value 1 if above the 90th percentile); Natural disasters**	**Yes**
24	**Bohra-Mishra and Massey (2011)**	**Chitwan Valley Family Study (CVFS) for Nepal from February 1997 to January 2006**	**Using a (pooled) multinomial logit, local migration is associated with increase in the time to collect fodder, time required to collect firewood, a perceived decrease in crop production and an increase in population density but not with a change in water quality. Only time to collect fodder is associated with longer-distance migration.**	**Internal and international**	**Rural**	**Indirect measurements: Change in time to collect animal fodder; change in time to collect firewood for fuel; change in agricultural productivity, change in the quality of drinking water; and population density**	**Yes**
25	Carvajal and Pereira (2009)	Nicaragua (LSMS)	Wealth, and whether the sector of origin is rural or urban, are correlated with the likelihood of migration.	Internal and international	Rural Urban	Hurricane Mitch (1998)	Yes

Continued on next page

	Paper	Country(data sets)	Finding	Migration type	Origin	Environmental measure	CC[a]
26	**Deschênes and Moretti (2009)**	**2002 US Census**	**Evidence on detrimental impact on mortality but also decreasing impact of the number of extreme cold days on the probability to move to another (warmer) US state than the one the individual is born in**			**Differences in cold days between locations for the migration models**	
27	**Dillion et al. (2011)**	**Household survey in Northern Nigeria**	**Suggestive evidence of household response to ex ante risk (unfortunately cannot be tested with household fixed effect, see text) and robust findings that male migrate in response to ex-post risk**		**Rural**	**Ex-ante risks proxied by the coefficient of variation of temperature degree days over the growing period, interacted with land holding and ex-post risk proxied by the lagged number of standard deviations of temperature degree days interacted by land holding**	**Yes**
28	**Drabo and Mbaye (2011)**	**Bilateral migration from 88 developing countries to 6 OECD countries, 1950-2010**	**Disasters drive international migration of highly educated**	**International**		**no. of disasters (meteorological , hydrological, drought, wildfire and climatological disasters)**	**Yes**
29	**Ezra and Kiros (2001)**	**Ethopia, 1984-1994**	**fertility of land and vulnerability to food crisis affect out-migration**	**International**	**Rural**	**community vulnerability to food crisis**	**Yes**
30	Findley (1994)	Mali (CERPOD)	There is a positive correlation between drought and internal migration and a negative correlation between drought years and international migration, but without controlling for individual or household characteristics	Internal and international	Rural	Drought[d]	Yes
31	Gray (2009)	Ecuador (own data)	Less precipitation is associated with more internal and international rural out-migration, while an unusual harvest in period $t-1$ is associated with more local and internal migration	Local Internal International	Rural	Mean annual community precipitation	Yes
32	Halliday (2006)	El Salvador (BASIS)	agricultural loss leads to international migration while earthquakes reduce out-migration	International (to US)	Rural	Earthquake and agricultural loss	Yes

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	Paper	Country(data sets)	Finding	Migration type	Origin	Environmental measure	CC[a]
33	Henry et al. (2003)	Burkina Faso (Population Census Survey)	Environmental variables are significant in explaining inter-provincial migration, but their contribution was slightly lower than that of the socio-demographic variables	Internal, mainly R-R	Rural	Drought frequency, decade-to-decade rainfall variability	Yes
34	Henry et al. (2004)	Burkina Faso (EMIUB)	People from drier regions are generally more likely to migrate. Short-term rainfall deficits increase long-term rural-rural migration, but decrease short-term international migration	Internal, mainly R-R	Rural	Rainfall from global monthly precipitation data (annual mean and short-term deviations)	Yes
35	**Kumar and Viwanathan (2012)**		See Panel D below	International			
36	**Lewin et al. (2012)**	**Malawi's 2004/05 Integrated Household Survey (IHS2)**	**Rainfall shocks have a negative association with rural out-migration and migrants choose to move to communities where rainfall variability and drought probability are lower.**	**Internal**	**Rural**	**Rainfall variability measured by reported damages due to a drought or a flood, similar shocks reported at the community level, average for the last 10 rainy seasons of the coefficient of variation of daily rainfall and ratio of the average annual rainfall for the last 10 years rainy seasons over a 30-year period (not panel data)**	**Yes**
37	**Massey et al. (2010)**	**Chitwan Valley Family Study (CVFS) for Nepal in 1996**	**Short-distance mobility affected by perceived declines in productivity, declining land cover and increasing time required to collect firewood. Long-distance mobility is predicted by perceived declines in productivity**	**Internal**	**Rural**	**Indirect measurements (declining land cover, times to gather organic inputs, increasing population density and perceived declines in agricultural productivity)**	**Yes**
38	**Meze-Hausken (2004)**	**Ethopia**	**droughts lead to migration but adaption reduces migration**	**both**	**Rural**	**drought**	**Yes**

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	Paper	Country(data sets)	Finding	Migration type	Origin	Environmental measure	CC[a]
39	Munshi (2003)	Mexico-US (MMP)	Uses rainfall history in origin community to instrument US destination network size. The auxiliary regression shows a negative effect of past rainfall on the number of migrants in the destination network, implying that lower-than-average rainfall induces more out-migration	International	Rural	Community rainfall levels with up to six-year lags	No
40	**Naudé (2010)**	**45 Sub-Saharan African (SSA) countries over the period 1965-2005**	**Environmental pressures are found to have a less important direct impact (compared to conflict and incomme differential), although they may have an indirect impact on migration through conflict and job opportunities**	**International**	**Rural**	**Water scarcity proxied by the percentage of land under irrigation and Natural hazard disasters**	**Yes**
41	Paul (2005)	Bangladesh (own data)	No evidence of out-migration in the aftermath of a tornado	Internal	Rural	Tornado (not panel data)	Yes
42	Rappaport (2007)	US (Census Bureau and Bureau of Economic Analysis) counties from 1970 to 2000	Association between increased variation of nice weather (as a consumption amenity) and changes in population density, interpreted as weather-related internal migration	Internal	Both rural & urban	January average maximum temperature, July daily maximum heat index, July average mean relative humidity and average number of rainy days	Yes
43	**Reuveny and Moore (2009)**	**OECD dyadic migration flows to 14 developped countries and migration to the US (Statistical Yearbooks)**	**Environmental decline plays a significant role in out-migration, pushing people to leave their homes towards OECD countries**	**International**		**Indirect measurements (land farmed with permanent crops, arable land) and weather-related natural disasters**	**Yes**
44	**Saldaña-Zorrilla and Sandberg (2009)**	**Mexico, 1990-2000**	**household study where higher disaster frequency increases migration rates**	**unknown**	**Rural**	**disaster frequency**	**Yes**
45	**Strobl and Valfort (2012)**	**Uganda (2002 Uganda census and IPCC datasets)**	**Weather-induced internal migrants have a negative impact on the probability for non-migrants living in destination regions to be employed.**			**Standardized Precipitation Index**	**No**
46	Warner (2010)	Mozambique, Vietnam, Egypt (EACH-FOR)	Environmental factors (flooding in Mozambique and Vietnam, desertification and sea-level rise in Egypt) contribute to migration, especially via their effect on livelihoods			Flooding, Desertification, sea-level rise (not panel data)	Yes

(D) Papers describing empirical evidence of climate effects on *migration through the income differential driver*

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	Paper	Country(data sets)	Finding	Migration type	Origin	Environmental measure	CC[a]
47	**Beine and Parsons (2012)**	**Bilateral panel migration data for 137 origin and 166 destination countries between 1960 and 2000**	**Little direct impact of climate change on international migration. Indirect impact of natural disasters through wage differentials in LDC countries only.**	**Internal and international**	**Rural**	**Natural disasters; rainfall and temperature deviations from the long-run average**	**Yes**
48	**Feng et al. (2010)**	**Census data from mexico between 1995 and 2005**	**Significant effect of climate-driven changes in crop yields on the rate of emigration to the United States**	**International**	**Rural**	**Annual precipitation, annual average temperature and summer temperature**	**Yes**
49	Marchiori et al. (2012)	43 SSA countries	Climate variations increase the incentives to migrate internationally via changes in the wage ratio, but urbanization mitigates the effect on international migration	International (+R+U)	Rural	Precipitation and temperature anomalies	Yes
50	Yang and Choi (2007)	Philippines (LFS, SOF, FIES, APIS)	Rainfall deviations are used to instrument income changes. Positive income shocks increase international migration, while negative shocks increase receipts of remittances	International	Both rural & urban	Rainfall shocks (season specific)[e]	No
(E)	Papers describing empirical evidence of climate effects on *migration through the income variability driver*						
51	Rosenzweig and Stark (1989)	India (ICRISAT)	Rainfall means and variances are used to instrument agricultural profit means and variances, which in turn are used to explain household consumption smoothing and migration	Internal (R-R)	Rural	Rainfall means and variances	No

[a] Is climate change or environmental migration a focus of the paper?
[b] Rainfall anomalies = deviations from the country's long-term mean, divided by its long-run standard deviation.
[c] Rainfall shock: largest deviation of rainfall from 25-year average annual rainfall.
[d] Drought: % rain below long-term 50yr average in 1983-1985.
[e] Rainfall shock: changes in local rainfall constructed as rainfall in year t in that season minus rainfall in the same season in year $t-1$.