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INSTITUTT FOR SAMFUNNSØKONOMI

DEPARTMENT OF ECONOMICS

SAM 31 2014
ISSN: 0804-6824
October 2014

Discussion paper

Climate Variability and International Migration: an empirical analysis

BY

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Climate Variability and International Migration: an empirical analysis

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Abstract

Is international migration an adaptation strategy to sudden or gradual climatic shocks? In this paper we investigate the direct and the indirect role of climatic shocks in developing countries as a determinant of out-migration flows toward rich OECD countries in the period 1990-2001. Contrarily to the bulk of existing studies we use a macro approach and explicitly consider the heterogeneity of climatic shocks (type, size, sign of shocks and seasonal effects). Our results show that the occurrence of adverse climatic events in origin countries has significative direct and indirect effects on out-migration from poor to rich countries.

JEL code: Q54, F22

Keywords: climate shocks; international migration;

This research has been conducted within the CIRCE (Climate Change and Impact Research: the Mediterranean Environment) project funded by the European Commission Contract No 036961 GOCE. The usual disclaimers apply.

1. Introduction

There is a growing consensus in the scientific community that substantial changes in climatic conditions – including a growing frequency of extreme weather events – are under way.

The current knowledge on the potential socio-economic impacts of substantial changes in climatic conditions is still limited for two main reasons. Firstly, notwithstanding the large research effort devoted to climate studies there is still a large degree of uncertainty on the exact nature of future climate scenario. Secondly, individuals and communities affected directly and/or indirectly by climatic shocks behave in a rather complex and heterogeneous way. The complexity of adaptation dynamics (or resilience/vulnerability to changes in climatic conditions) is well identified in the IPCC 2007 report: "*Barriers, limits and costs of adaptation are not fully understood, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints*" (IPCC 2007, Ch. 17).

In fact, individuals put in place different adaptation strategies in order to cope with the consequences of climate shocks. One adaptation strategy that raises a lot of concerns in the public opinion around the world is out-migration. Human mobility is one among several possible adaptation strategies to changes in climatic conditions and it is fundamental to understand under which conditions migration is the preferred option. A limited but growing number of studies has tried to empirically investigate the links between climate shocks and international migration.[1] In particular, several case studies and analysis based on household-level surveys have contributed to boost our knowledge on the micro-level behaviour of individuals and communities affected by climatic shocks. Although insightful, these studies give us findings that are highly heterogeneous (and often contradictory) due to their unavoidable case-specific nature. One potentially important limit of micro-level studies is related to their inability to investigate behaviours of individuals and communities that are affected only indirectly by climate shocks (for instance through market dynamics such as changes in prices and factors' rewards). This drawback is likely to underestimate the link between climate shocks and geographical relocation.

In this paper, contrarily to the bulk of the existing literature, we employ a 'macro-approach'[2] in order to investigate the nexus between climate shocks and international migration[3]. We estimate a theoretically-rooted pseudo-gravity model in order to investigate the effect of climate shocks of

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[1] The availability of reliable national and international data on out-migration is one of the major constraint for the development of this important research strand. It should be noted that a growing effort has been devoted more recently to these research issues from a variety of disciplines and with the use of different methodological approaches. See Piguet 2010 for a methodological survey of the existing literature.

[2] According to Piguet (2010) a limitation of studies employing – as in our paper – a macro approach is given by the so called "ecological fallacy", ie the fact that "*correlations measured at the aggregated level might not hold true at the individual level*". We believe that – given the research question – it is irrelevant whether or not migrants are precisely those who have been directly affected by climate shocks; employing a macro approach allow us to specifically investigate aggregate 'net effects' and hence take into account important general equilibrium effects that micro-level studies generally miss-out. Micro and macro-level studies are clearly complementary tools for the analysis of the socio-economic consequences of climate change in general.

[3] A similar approach is adopted by recent papers such as Marchiori et al (2011) – which analyse the role of climatic anomalies in explaining urbanization and international migration in a sample of Sub-Saharan African countries, Reuveny and Moore (2009) – which investigates the role of environmental degradation and natural disasters as push factors in a dyadic model of bilateral migration – and Beine and Parson (2013). In particular the latter study adopts a similar empirical strategy but with the main difference of focussing on long-term changes in the distribution of population across countries (bilateral migration flows over 10 year intervals).

different size and nature on bilateral international migration from a large sample of emerging and developing countries toward OECD countries in the period 1990-2001.

Our results show that past climatic shocks have contributed – both directly and indirectly – to the outflow of migrants from poor to rich OECD countries. We find that the magnitude, the sign and the nature of shocks matters in explaining the link between climate variability and international migration. Not all precipitation and temperature anomalies have the same impact on migration flows. We find evidence that a strong and persistent change in the intra-annual variability of precipitations has a significant effect on out-migration toward rich destinations. In the sample of developing countries considered in the study, precipitation shocks have a positive impact on international migration flows but the effect o excessive rainfall is generally stronger that that of severe rainfall shortages. Climate shocks have indirect effects via relative wages and direct effects which are probably related to changes in both the quality of amenities and in individuals' expectations. In fact, such events can substantially modify the expectation of (potential) migrants over future streams of utilities associated with the home location.

Our findings also point out the importance of the socio-economic characteristics of the origin country (such as the level of development and the vulnerability of the agricultural sector) in shaping the nexus between climate shocks and international migration flows. In general, countries with a lower level of development and with a relatively larger agricultural sector are more sensitive to climate shocks.

Our analysis is closely related to a recent study by Beine and Parsons (2013) which do not find evidence of direct impacts of climate anomalies on international migration but only an indirect effect through international wage differentials. Like in the present analysis, the authors investigate the role of environmental changes as a push factor of bilateral international migration using a global panel dataset on migrants' stocks for the period 1960-2000. Their analysis has the advantage of using a longer time span and a more comprehensive set of origin/destination countries[4] but at the cost of measuring both migration flows and climatic shocks over a rather long time period (10 year intervals). In this respect, our study and Beine and Parsons (2013) are highly complementary to each other. In fact, as stated by the authors, there is a trade-off between the '*geographic coverage and the frequency of observations*'. The use of low frequency observation is likely to lead to the following undesirable consequences: i) miss intra-period temporary migration and return migration; ii) generate a less precise identification of climate anomalies due to use of a 10 year average; iii) miss the precise timing between the occurrence of the environmental shock and the occurrence of migration flows.

Our paper contributes to the thin existing literature employing a macro approach to the study of the role of climate shocks as a determinant of international migration flows using yearly observations. As in Beine and Parsons (2013), we ground our estimated model in microeconomic theory. To our knowledge, our study is the first one which tests in a detailed and systematic way the impact of heterogeneous precipitation and temperature shocks. In fact one of the main critique moved to previous empirical analysis employing a multivariate methodological approach (see Piguet 2010) is the rough and unsophisticated identification of climate variables. Our study takes this criticism seriously and explicitly tests for the heterogeneous impact of climate shocks.

The paper is organized as follows. In *Section 2* we briefly discuss the link between climate shocks and human mobility and we outline a selective literature review. In *Section 3* we firstly derive our

[4] Importantly, Beine and Parsons (2013) analysis includes South-South migration which is likely to be of greater magnitude given the substantially larger costs of South-North migration.

model starting from a random utility model of migration which takes into account the role of future expectations in the individual's migration decision. In the second part of the section we describe the dataset and the methodology employed in our analysis. *Section 4* reports the results of the empirical analysis. Some conclusive remarks are reported in *Section 5*.

2. Climate and migration: what are the links?

Every year millions of individuals originating from poor and rich countries change their place of residence across international boundaries (see OECD 2013 for recent data on international migration flows). Human mobility might assume very different forms: voluntary versus forced, temporary versus permanent, legal or illegal, within or across countries. The common trigger in most cases is a change in individual/ family conditions and / or change in actual or expected economic and social opportunities in the origin (push factors) and the destination (pull factors) locations.

Can we consider actual and/or expected changes in climatic conditions as push (or pull) factors of human migration? While the answer is certainly positive, the link between climate shocks and migration are complex. Whether a change in climatic conditions in a specific location is sufficient enough to induce individuals to geographically relocate depends on several factors such as the nature of the climatic shock, the characteristics of the population affected and the degree of vulnerability of the socio-economic system (including the ability to undertake alternative coping strategies).

Different socio-economic systems – and the individuals within them – have different degrees of vulnerability to the same type of climatic shocks. Besides, climatic shocks are highly heterogeneous in their nature and type and might lead to significantly different effects. For instance, extreme climatic events such as droughts, floods or hurricanes are likely to have severe impacts – at least in the short run – on the economic resources of a given community and, as a consequence, can severely limit the adoption of strategies alternative to migration. On the other hand, changes such as the gradual reduction of precipitations is likely to have a small impact on the well being of a community if individuals adjust their productive strategies over time (for instance through investments in irrigation systems or the use of drought-resistant agricultural varieties).

The economic consequences of climatic events might also be highly non-linear: the increase in temperature or reduced precipitations generally have trivial or even no effects up to certain thresholds and, on the contrary, cause very severe effects if such thresholds are crossed. An interesting work by le Blanc and Perez (2008), using GIS data on rainfall and population densities in Sub-Saharan Africa for year 2000, shows that water scarcity constraints human density only below a certain threshold[5]. This result suggests that the vulnerability of population to water stress (caused by climatic or population pressures) depends upon the level of water resources.

Another aspect that should be highlighted is the asymmetric impact that climate shocks have across the affected population. While some individuals or industries might experience negative effects, others might benefit from climate anomalies (both as a direct consequence of such changes or as an indirect effect taking place through market mechanisms). Recent evidences on adaptation strategies

[5] The authors find that above a mean annual runoff of 900mm rainfall and human densities are not correlated. Note that, as the authors point out, sixty percent of the population in Africa lives in zones with mean annual runoffs of less than 300mm.

in a sample of African countries show that counteracting effects might be also present in highly vulnerable communities. Analysis based on micro-level data on a sample of African farmers point out that higher annual temperatures are associated with positive variations of net revenues for livestock owners and with negative variations of net revenues from crop production (CEEPA 2008). This result suggests that climate shocks affect asymmetrically the productivity or the endowment of different factors of production (labor, capital, land) and, in turn, also the structure of production and of factors' rewards.

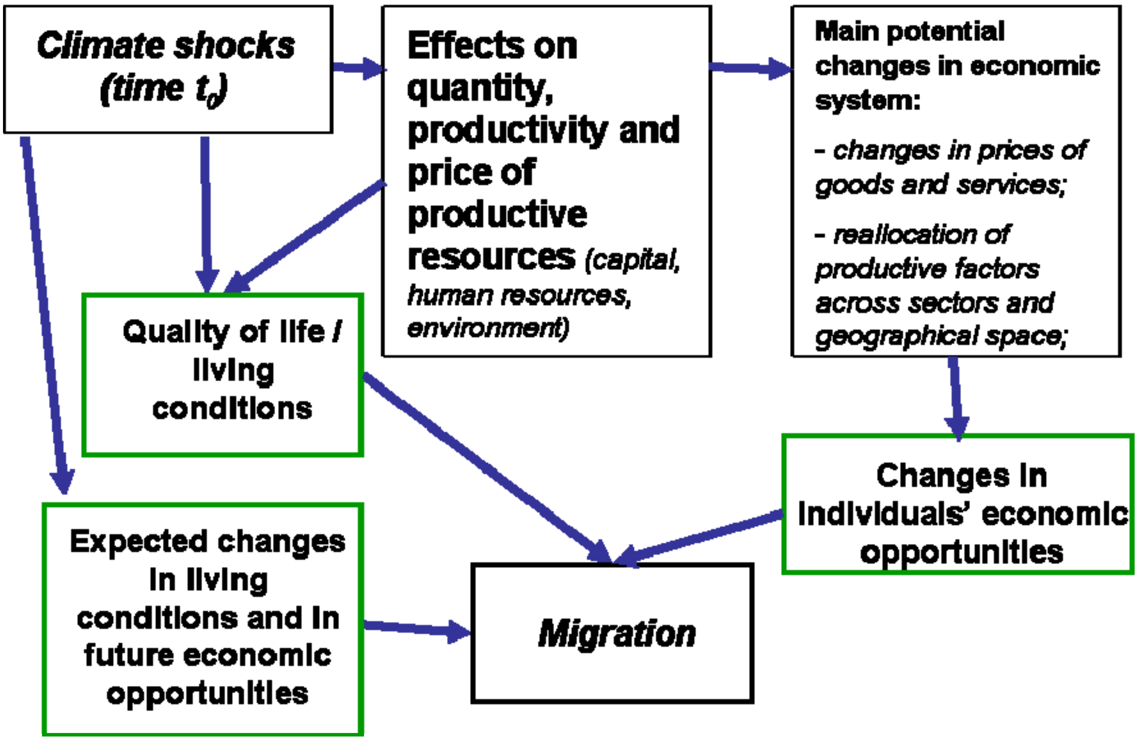
The adoption of coping strategies (including out-migration) will also depend on the perceived duration of direct and indirect effects of climate shocks and on expectations on the occurrence of additional shocks in the future. Given that migration is a costly adaptation strategy – in particular migration across international borders – if individuals perceive changes (and their effects) as transitory they might decide to adopt alternative strategies even if shocks are highly destructive. On the contrary, if climatic shocks are perceived as a permanent or long-lasting variation of the home country climate then individuals are likely be more inclined to opt for costly but resolving adaptation strategies such as geographical relocation. Halliday (2006) provides evidence which support the idea that shocks of a different nature might have different effects on the formation of future expectations. Using data on a panel of rural household from El Salvador the author finds that while adverse agricultural shocks – which lead to harvest and livestock losses – increased migration toward the US, the damage caused by the 2001 earthquake was associated to a reduced probability of out-migration. The transitory nature of the latter shock can be a possible explanation for such heterogeneous reactions.[6]

In order to analyse the effects of climate shocks on migration it is important to distinguish direct from indirect channels. The latter produce their effects on migration flows via other push and pull factors (see *Figure 1*). Changes in climatic conditions could have *direct effects* as push factors of migration flows when the possibility of human survival in the "new" environment is reduced (for instance because of unsustainable water supplies) or the quality of amenities is substantially lowered. Another *direct channel* through which environmental adverse events trigger out-migration is through a change in individuals' future expectations. In fact, the decision on whether or not to migrate depends both on current and expected push and pull factors. Expectations might change both in terms of future expected effects of shocks that have already occurred and in terms of the perceived likelihood of future climatic shocks. An example will help to clarify this point. Suppose that a severe drought occurs in an agrarian community. This shock will reduce agricultural productivity for the current crop season but is also likely to carry out effects for several additional crop seasons – for instance because part of production factors have been damaged (trees, cattle, farming tools). In his choice on whether or not to migrate an individual, suppose a worker whose wage depends upon agricultural production, will consider not only the current effect of the shock but also the stream of future effects. Besides, the occurrence of the drought today might alter the individual's perception over the likelihood that similar shocks might occur again in the future; he might be more inclined to believe that these type of events, and in turns their negative effects, will become more and more frequent.

[6] The author suggests another possible explanation related to the different labor market effect of these two shocks. "*One explanation is that the earthquakes created exigencies in El Salvador that increased the incentives for families to retain labor at home*" (page 895, Halliday 2006). The two explanations need not be substitute but they go in the same direction: in fact if the destructive event is perceived to be highly likely to happen again in the future then the incentive for families to retain labor at home would be weak.

Climate shocks have also substantial *indirect effects* on the migration decision through market forces, for instance by affecting the wage differential between home and (potential) host locations (Marchiori et al 2011; Beine et al 2013).[7] *Figure 1* suggests the complexity of the adjustment of the economic system to a shock; in fact impacts on factors' endowments (or on productivities) will translate into changes in factors' prices and, in turn, in the price of the final goods and services that employ them. If factors of productions are sufficiently mobile a sectoral and a geographical reallocation will likely occur.

Figure 1. *Climate shocks and migration: a map of direct and indirect links*



Migration is also induced by direct and indirect changes in the quality of life[8], in economic opportunities or a combination of both set of factors. Note that such changes need not to happen in the location (and for the individuals) that is initially affected by the climate shock. Although in the empirical exercise which follows we shed some lights on direct[9] versus indirect channels a precise

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[7] Indirect changes can also occur through non market forces. Environmental degradation has often been one important factor behind social conflicts (see the interesting work by Reuveny 2007). Also in these cases, it is often possible to track back the occurrence of social conflicts and wars to the economic and re-distributive consequences of climate shocks.

[8] There is a rich literature on the role of climatic amenities on migration decisions (or demographic variables in general). Cebula (2005) finds that gross state in-migration in the US over the period 1999-2002 is an increasing function of warmer temperatures, sunshine and recreation possibilities. Cheshire and Magrini (2006) show that urban population growth in EU countries is positively related to good climate but the spatial variation in such amenities seems to matter only within national borders: Europeans do not respond to differences in weather conditions by relocating across borders.

[9] Note that our definition of direct effects includes the individual's expectation over *future direct and indirect* effects caused by climatic shocks.

assessment of the specific channel through which the climate-induced migration materialise is beyond the scope of the present paper.

Economic systems might have different degrees of resilience to climate-related shocks, hence the ability to undertake different adaptation strategies is highly heterogeneous across space and even across communities in a given area. Reuveny (2007) argues that "*people can adapt to environmental problem in three ways: stay in place and do nothing, accepting the costs; stay in place and mitigate the changes; or leave affected areas*" (page 657). The costs and benefits of each of the above options will largely depend on the resources available to individuals (which might also be affected by environmental changes), on future expectations and on the (partly-exogenous) institutional framework within which the environmental shock takes place. Individuals and households with a larger endowment of resources (financial assets, land and other capital goods, human capital, social capital) are more likely to undertake adaptation strategies rather than 'do nothing' but out-migration is not necessarily the strategy that will be adopted. For instance, individuals with large endowments of immobile capital (such as land or real estates) are probably less mobile than individuals with limited amounts of capital or who derive income exclusively from their labor. Individuals with high level of human capital might have a relative low-cost access to technologies or productive processes which overcome the negative consequences of climate change/shocks.

One kind of resource which is particularly relevant in shaping the links between climate shocks and out-migration is the possibility for individuals to rely on a network of family and friends who reside in other locations: migration networks or "relationship capital"[10]. The effect of migration networks on individuals' migration propensities might be ambiguous. On one hand, the network might exercise a strong pull effect by reducing migration costs. On the other hand, external support (for instance in the form of remittances) might facilitate the adoption of alternative coping strategies. Yang and Choi (2007) using household level data from the Philippines find that remittance flows increase as a consequence of rainfall shocks and replace up to 60% of the decline in household income. Findley (1994) in a study on migration from rural Mali after the severe 1983-85 drought finds no evidence of increased international migration and Findley and Sow (1998) find that food deficit in rural households in Mali were compensated by remittances from migrants in France. These findings confirm the role of remittances from established networks of migrants as an insurance mechanism against climate-related income shocks. On the opposite side, studies by McLeman on the drought in Oklahoma during the 1930s suggest that networks played a fundamental role of "bridge" and favoured the adoption of migration as a coping strategy (McLeman 2006; McLeman and Smit 2006).

Another important element that might play a significant role in the nexus between climate shocks and migration is the public policy response both before – such as pre-emptive measures and insurance mechanisms that limit the vulnerability to or the consequences of shocks – and after the environmental damages occur (emergency help, financial subsidies and aid, recovery plans etc.). Countries with a higher level of development and a relatively good and effective public governance will generally limit the extent of climate-shocks induced damages and reduce the number of individuals who will adopt migration strategies. An important role is often played by international support. According to a recent paper by Collier and Goderis (2009) the level of international aid mitigates the effect of negative shocks. The authors also find that donors do not re-distribute aid over time toward shock-prone countries. By looking at the consequences of a specific type of

[10] Here we define relationship capital as the potential economic value derived from individuals' (weak and strong) ties with other individuals who reside in the same location or in other locations not affected by climatic shocks.

climatic shock in developing countries, ie hurricanes, Yang (2008)[11] finds that a greater exposure to these events leads to a large increase in foreign aid. In his study, the author considers different types of international financial flows to developing countries in the aftermath of hurricanes: official development assistance (ODA), foreign direct investments, remittances, lending from multilateral institutions, portfolio investment in addition to intra-bank and trade-related lending. For the poorer countries within his sample, total financial inflows in the 3-years following an extreme climatic event represent approximately three-fourths of the estimated damage.

Along the same lines, the quality of Institutions affects the efficiency of shock-absorption mechanisms both before and after the occurrence of climatic shocks. According to Reuveny (2007), the role of the US federal government was fundamental in limiting out-migration from the US Great Plains in the 1930s after a series of very severe droughts. In fact, policymakers gave substantial financial and technological assistance to the farmers who decided to stay in affected areas.

The list of factors outlined above gives an idea on the complexity of the nexus between climate shocks and migration. Another issue that should be considered is the *type of mobility patterns* that is more likely to be triggered by climatic events of significant magnitude. Relocation strategies can be highly different according to which individual is affected and by which kind of climatic shock. For those individuals who lack the resources to finance a costly international move, or for those communities who have a weak or inexistent network of established migrants in foreign locations, migration is likely to be of short distance and within the country borders.

Barrios et al (2006) investigate the role of climate change on rural – urban migration in a panel of 78 countries over the period 1960-90. Their results outline a positive and statistically significant relationship between urbanization and precipitation shocks for Sub-Saharan Africa. No significant results are found for other developing countries suggesting that the strength of the link between climate change and migration is larger for those communities where agriculture is more vulnerable to rainfall shortages. Marchiori et al (2012) conclude that climate anomalies have contributed to rural-urban migration in Sub-Saharan Africa; the authors also show that internal and international migration are linked phenomena.

Cross-border migration will take place if, compared to other adaptation strategies, this option is cost-effective. International migration is likely to materialise when the country affected by adverse climatic shocks is, *ceteris paribus*, geographically, culturally or socially close to potential receiving countries.[12]

The dominance in terms of magnitude of internal over international flows is a stylised fact in the migration literature. Whatever is the determinant of migration, individuals are more sensitive to differentials in socio-economic conditions within countries than to differences between them. The fact that climate shocks are more likely to have a stronger effect on internal migration does not rule out the possibility of significant effects also on international migration flows as documented by Beine et al (2013) and by the present study.

[11] An interesting innovation of Yang (2008) is the use of a time-varying storm index which allows to take into account the magnitude of shocks (proxied by the fraction of the country population affected by these events).

[12] Migration might also differ in terms of duration. The move can be temporary (if, for instance the climatic shock does not produce long-lasting effects) or permanent. Analysing a sample of irregular migrants crossing Italian borders in 2003, Coniglio et al (2009) find that individuals experiencing adverse climatic shocks or natural disaster in the village of origin are more likely to return home that individuals experiencing social conflicts.

Bearing in mind the complex 'web of link' outlined in this section, we present in the following part the data and the empirical strategy adopted in our analysis on the role of climatic shocks on international migration flows.

3. *Empirical strategy and data*

3.1. Climate shocks, expectations and migration: from a simple theoretical framework to the empirical model

Our starting point, like in Beine and Parsons (2013), is a simple neoclassical model where native individuals optimally choose their location at time t over alternative destinations $j \in K$ (including the home destination i).[13] The migration decision of a native will depend not only on current utilities derived in alternative destinations but also on expected ones. Suppose for simplicity that individuals consider only two period, t (current) and $t + 1$ (future).[14] The expected present values of utilities of a native of country i in his current (home) and perspective location j are respectively:

$$\begin{aligned} u_{ii,t} &= w_{i,t} + A_{i,t} + E_{i,t}^{t+1} + \varepsilon_{i,t} \\ u_{ij,t} &= w_{j,t} + A_{j,t} + E_{j,t}^{t+1} - C_{ij,t} + \varepsilon_{j,t} \end{aligned} \qquad (1)$$

Where we assume that individual's utility is linear in wages (w); depends on the current level of amenities ($A_{k,t}$) in each location with $k = i, j$ and $\varepsilon_{k,t}$ is a random term drawn from a iid extreme-value distribution. The term $C_{ij,t}$ captures the cost of moving from i to j at time t. Note that both $A_{k,t}$ and $C_{ij,t}$ encompass several dimensions of respectively amenities and mobility costs which we assume as distinct and separable in the utility function above. For instance, amenities can be environmental, and hence directly affected by climatic shocks, or related to the quality of the social and institutional environment of a specific location. Mobility costs depend on bilateral factors – such as the existence of a bilateral diaspora or cultural and/or geographical distance between i and j – but can also be origin or destination specific.

Differently from other studies based on the utility maximization approach – such as Beine et al (2013), Grogger and Hanson (2011) and Ortega and Peri 2009 – we introduce, $E_{i,t}^{t+1}, E_{j,t}^{t+1}$ which capture expectations on future realizations of wages and amenities in alternative locations as follows:[15]

$$E_{k,t}^{t+1} = EV\left(u_{k,t+1}\right) = EV\left(w_{k,t+1} + A_{k,t+1} + \varepsilon_{k,t+1}\right) \qquad (2)$$

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[13] For the sake of comparability we keep the notation of our model as close as possible to that of Beine and Parsons (2013).

[14] The model can be generalized to N periods. In this case the solution to the decision problem is analytically more complicated and can be characterized by multiple moves across alternative destinations. The solution to the optimal location problem can be obtained by backward induction (see Kennan and Walker 2013).

[15] See Kennan and Walker (2011; 2013) on the role of expected income in shaping individuals' migration decisions.

Following McFadden (1984) we can express the bilateral migration rate as:

$$\frac{N_{ij,t}}{N_{ii,t}} = \frac{\exp\left[w_{j,t} + A_{j,t} + E_{j,t}^{t+1} - C_{ij,t} \right]}{\exp\left[w_{i,t} + A_{i,t} + E_{i,t}^{t+1} \right]}$$

Where $N_{ij,t}$ is the number of migrants from country i to country j and $N_{ii,t}$ is the number of native who decide to stay put in the home location, i.e. the home population at time t ($N_{ii,t} \simeq Pop_{i,t}$). Taking the log of the above expression and substituting eq. (2), we obtain the following expression for the (log of) bilateral migration rate between the home location i and destination j:

$$\ln\left(\frac{N_{ij,t}}{Pop_{i,t}} \right) = \left(w_{j,t} - w_{i,t} \right) + \left(A_{j,t} - A_{i,t} \right) + EV\left[\left(w_{j,t+1} - w_{i,t+1} \right) + \left(A_{j,t+1} - A_{i,t+1} \right) \right] - C_{ij,t} \quad (3)$$

As argued above, climate shocks in the home location i might have effects on: i) the current levels of wages, $w_{i,t}$; ii) the current utility derived from amenities, $A_{i,t}$; iii) individuals' expectations concerning future economic opportunities in the home location. The latter effect is particularly important since expectations can be substantially shaped by climatic shocks in highly vulnerable communities; in our notation $E_{i,t}^{t+1} = f\left(\mathbf{X}_i, \text{ClimeShocks}_{i,t} \right)$ where X_i is a set of country i characteristics which might affect future expected utility.

Our main goal is to identify the overall (direct) impact of climatic shocks on bilateral out-migration.[16] We use the following econometric specification based on equation (3):

$$\ln\left(N_{ij,t} \right) = \beta_1 \left(\text{ClimeShocks}_{i,t} \right) + \beta_2 \left(\frac{w_{i,t}}{w_{j,t}} \right) + \beta_3 \mathbf{A}_{i,t} + \beta_4 \ln\left(Pop_{i,t} \right) + \beta_5 \mathbf{C}_{ij,t} + \alpha_{j,t} + \alpha_i + \varepsilon_{ij,t} \quad (4)$$

where N_{ijt}, our dependent variable, represents migration flows from the origin country i to the destination country j at time t. We use annual data from the OECD – International Migration Database, covering bilateral migration flows toward OECD countries. Due to a lack of data on climatic variables – see below – we limit our analysis to the period 1990-2001 using an unbalanced panel data, which includes 128 origin and 29 destination countries (see Appendix *1*).[17] A description of the dependent variable and of the covariates used in the estimation is reported in Appendix *2*. As a robustness check, we perform the same empirical exercise using an alternative dataset on international bilateral migration flows – our dependent variable – developed by the

[16] The identification of the specific channels – direct contemporaneous effects of shocks on amenities versus effects on future expectations over income and/or amenities – is beyond the scope of the present study. Such an analysis would require individual level longitudinal data that are seldom available to the researcher.

[17] To the best of our knowledge, comprehensive datasets on bilateral migration flows, which consider also South-South migration (i.e. migration between and within less developed and emerging countries), are not available. Beine and Parsons (2013) employ an alternative dataset on international bilateral migration stocks observed over 10 years' intervals in the period 1960-2000. Their more extensive geographical coverage, which includes also South-South migration, implies the drawback of using a substantially wider migration interval, with the potential consequences described in the introduction.

United Nation Population Division (2011).[18] Given our focus on climate shocks affecting the origin country, a set of country-of-destination-by-time fixed effects (α_{jt}) is included in our estimates. This set of dummies will hence absorb any time-varying pull factors specific to the OECD destination countries, such as climate shocks and other economic, social and policy changes (including the ones related with $A_{j,t}, F_{j,t}^{t+1}$ in eq. (3) and changes in migration costs for country *j* in all origin countries). The specification above also includes fixed effects for country of origin and destination in order to control for time-unvarying characteristics affecting migration flows. Note that these time-unvarying effects normally take account also of international differences in registering the immigrant population across OECD countries.

In our empirical exercise we also study the effect of climate anomalies on the wages in migrant destination countries, an important indirect channel through which these shocks might affect migration flows. In particular we estimate the following specification:

$$w_{i,t} = \delta_1 \left(\text{ClimeShocks}_{i,t}\right) + \delta_2 \boldsymbol{A}_{i,t} + \delta_3 \ln\left(Pop_{i,t}\right) + \alpha_i + \varepsilon_{ij,t} \qquad (5)$$

In the following subsections we describe in more detail the covariates that have been included in our empirical model and strategy.

3.2. Climate data and the identification of climate shocks

The covariates[19] used in our econometric specification include a vector of past climatic anomalies in the origin country *i*, $ClimateShocks_{i,t}$. Note that the coefficients β_1 in eq. (4), captures – as discussed in Section 2 – both the direct effects on migration flows related to changes in current amenities/quality of life and the effects occurring via a change in future expectations $F_{i,t}^{t+1}$. By including in eq. (4) the (ln) of wages in the home country and other home-country covariates, we control (at least partly) for other indirect channels through which climatic factors affect migration flows.

The existing evidence outlined above emphasizes the highly heterogeneous effect of climate shocks/anomalies. Simple measures of changes in rainfall – like the one used in Barrios et al. (2006) – represent an unsatisfactory identification of climatic shocks. An important novelty in our approach is the explicit focus on the empirical analysis of the heterogeneous nature of climate anomalies.[20]

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[18] United Nations, Department of Economic and Social Affairs, Population Division (2011). *International Migration Flows to and from Selected Countries: The 2010 Revision* (web-based database). This database has the advantage of reporting a larger number of observations but at the cost of including a more narrow set of destination countries.

[19] Note that for some covariates, such as climatic shocks, we use lagged rather than contemporary values, as in similar analysis on bilateral migration flows.

[20] Some data limitations are unavoidable; in particular we are aware that using yearly data on country-level might mask significant intra-borders variations (a problem that interests any cross-country empirical study, independently of the research question). We have performed our estimation taking explicitly into account two important dimensions which amplify the country-level aggregation problem: (i) the absolute size of the origin country (surface); (ii) the climatic zone homogeneity of the origin country (percentage of the country falling within the main climate zone). Estimates have been obtained by progressively removing the largest and more climate-diverse origin countries. The results (available upon request) confirm the conclusions reported in the paper.

Our climatic variables are based on data from Mitchell et al. (2003), who provide detailed information on monthly precipitation and temperature on country-level for the period 1901-2000[21]. The first step in the definition of our variables is the computation, for each of the 128 origin country, of the long-term monthly mean values of precipitation ($\overline{p}_m$; where $m \in M\left[january,..,december\right]$) and temperature ($\bar{t}_m$), as well as, their respective standard deviations ($\overline{p}_{SD,m}$ and $\bar{t}_{SD,m}$) in the period 1901-1990[22].

On the basis of the first two month-specific moments, referring to climatic variable distributions, we compute a rich set of variables, which measure distinct climate anomalies – in temperature and precipitation – occurred in three different time horizons before the begin of bilateral migration between country *i* and *j* [23]: (i) 1 year lag; (ii) 3 years lag; (iii) 5 years lag.

More specifically, we test for the relevance of the following climatic variables as push factors of international migration flows:

absolute levels of precipitation and temperature (yearly average) computed respectively as:

$p_{abs} = \left(\sum_{y=t-1}^{t-n} \sum_{m=1}^{M} p_{y,m} \right) / n$ and $t_{abs} = \left(\sum_{y=t-1}^{t-n} \sum_{m=1}^{M} t_{y,m} \right) / n$, where y is the year index that can assume values t - n for n equal to 1, 3 or 5 on the basis of the time lag considered;

(ii) *surplus* (or *deficit*) of precipitation and temperature (yearly average) with respect to countries' long-term values (both in level – respectively millimeters and Celsius degree - and percentage value). The formulas applied (here restricted to precipitation, for illustrative purposes) are:

$$p_{surplus} = \frac{\sum_{y=t-1}^{t-n} \sum_{m=1}^{M} \left(p_{y,m} - \overline{p}_m \right)}{n} \text{ and } p_{\%surplus} = \frac{\sum_{y=t-1}^{t-n} \sum_{m=1}^{M} \left(\frac{p_{y,m} - \overline{p}_m}{\overline{p}_m} 100 \right)}{n};$$

(iii) *anomalies* above or below 1 standard deviation with respect to long-term values. We consider separately anomalies above 1 standard deviation from the mean, henceforth defined as '*positive*', and those below 1 standard deviation from the mean, defined as '*negative*'. For precipitation, the following formulas have been applied:

[21] TYN CY 1.1 database, Mitchell et al. (2003). Available at: www.cru.uea.ac.uk/~timm/cty/obs/TYN_CY_1_1.html

[22] The analysis is robust to the use of alternative periods for the computation of the long-term means. In particular we have used the full period 1901-2000 or sub sets like 1901-1970. The correlation of alternative measurements is close to 0.99. For this reason, we prefer to use the full period preceding the time-span covered in the analysis (i.e. 1901-1990).

[23] Since we have no information on the monthly distribution of migration flows and since several existing studies emphasize the reaction to climatic shocks is likely to occur with a time lag we do not consider in the present study contemporaneous anomalies.

$$p_{(+)anomalies} = \frac{\sum_{y=t-1}^{t-n}\sum_{m=1}^{M}\max\left[0, p_{y,m} - \left(\overline{p}_m + \overline{p}_{SDm}\right)\right]}{n}$$

$$p_{(-)anomalies} = \frac{\left|\sum_{y=t-1}^{t-n}\sum_{m=1}^{M}\min\left[0, \left(\overline{p}_m - \overline{p}_{SDm}\right) - p_{y,m}\right]\right|}{n}$$

We have also considered an overall measurement of climatic anomalies – positive and negative – given by the sum of the above formulas:

$$p_{anomalies} = p_{(+)anomalies} + p_{(-)anomalies} \,.$$

Besides, anomalies have been computed as percentage deviations from the mean:

$$p_{\%anomalies}, p_{\%(+)anomalies}, p_{\%(-)anomalies} \,.$$

(iv) *index of intra-annual rainfall variability*, which is calculated as the mean absolute deviation (MAD) over the long-term MAD for each of the three lags considered in the analysis. The formula applied is the following:

$$p_{MAD,n} = \frac{90\sum_{y=t-1}^{t-n}\sum_{m=1}^{M}\left|p_{y,m} - \overline{p}_m\right|}{n\sum_{y=1901}^{1990}\sum_{m=1}^{M}\left|p_{y,m} - \overline{p}_m\right|}$$

The standardization of the index allows a convenient interpretation of the values as deviation from the country-specific natural level of variability. For example, an index equal to 1.2 at lag 3 for a specific year in country i implies that during the 3 years preceding the observed migration flow, precipitations have been 20% more volatile than usual.

(v) *seasonal effects of climatic shocks*. We have computed distinct measurements of temperature and precipitation *anomalies* for *rainy and dry seasons*. These measurements allow us to test the heterogeneous impacts of shocks – for instance through current and future damages to the agricultural systems – according to the timing of climatic events. The definition of rainy season is conventional for most of the countries in our sample[24]; where this information was missing we have

[24] We follow the conventional definition of rainy season which can be retrieved in the CIA "The World Factbook" database (https://www.cia.gov/library/publications/the-world-factbook/fields/2059.html).

defined as rainy months those with an average rainfall above the monthly mean for the full period available (1901-2000).

Figure 2 – HERE

Figure 2 shows a compelling illustration of the importance of our refined identification of climatic shocks. It reports monthly precipitations occurred in Bangladesh during two years – 1993 (*panel A)* and 1998 (*panel B*) – together with the long-term average monthly rainfall (1901-1990) and its standard deviations. During the flood occurred in the summer of 1998, over 68% of the country was inundated with major economic consequences and a death toll of approximately 2.4 thousands people. This major precipitation shock would not be sufficiently identified when using the year average, as it has been usually done in previous econometric analysis, due to a rather large rain shortfall in the two months preceding the shock. Namely, the year rainfall average was only 6.6% higher, compared to the long-term mean thus not substantially different from other minor events that occurred in Bangladesh (and other countries). On the contrary, our computed index of intra-annual rainfall variability ($P_{MAD1,y=1998}$) was 21.5% over its long term value.

Even more problematic is the aggregation of climatic variables over longer time span. For instance, between 2000 and 1991 the yearly rainfall average in Bangladesh was 2642 mm, i.e. below the long-term average of 2736mm. As a consequence, the aggregation would have completely excluded the two major floods occurring in 1998 and 1993 reported in *Figure 2*. This "aggregation bias" has characterized previous studies, like Barrios et al. (2006), Reuveny (2007), but also recent analysis, such as Marchiori et al (2012) and Beine and Parsons (2013).

3.3. Description of other covariates

We introduce in our econometric specification a set of additional covariates (see *Appendix 2* for a detailed description of the sources). As a proxy for wage at the origin country in eq. (4) we employ the (ln) *GDP per capita* lagged 1 year. Furthermore, we include the (ln) origin country *employment rate*. In both cases, we expect negative estimated coefficients.

The inclusion of a control for the origin country population, $Pop_{i,t}$, originates from the theoretical model above. Even in the relative short time-span used in our analysis, some countries have experienced a significant increase in their population; hence, the time invariant origin-country fixed effects might overlook the importance of demographic pressures on migration.[25]

Our specification includes a set of variables which control for different dimensions of amenities in the origin country, $\boldsymbol{A}_{i,t}$. The first one is a proxy for social (in)stability, *armed conflicts*, a dummy variable equal to 1 when episodes of armed conflict occurs in the origin country in year *t*. Note that this variable is likely to capture some of the indirect effects of climatic shocks on migration flows (see Reuveny 2007). Short-term environmental shocks are captured through a *natural disasters* variable, which embraces events such as earthquakes, floods, extreme temperatures, epidemics, mass movements, storms, floods and wildfires. The variable is calculated as the sum of the number of episodes in the origin country in a year. In addition, we control for the

[25] We are thankful to two anonymous referees for pointing out this potential omitted variable bias.

quality of institutions in the home location by employing the Political Institutional Quality Index developed by Kuncic (2014), which ranges between 0 and 1.

In addition, we consider a set of bilateral variables $\boldsymbol{C}_{ij,t-1}$ affecting the costs of bilateral migration flows, such as *geographical distance, contiguity, common language, and colonial ties* between country *i* and *j*. We also include the log of the (past) *bilateral stock of migrants* from the origin country *i* in to the destination country *j* in year 1960 as a proxy for the important role played by the diaspora in shaping subsequent waves of migration flows. We also expect, as in the existing studies, that *geographical distance* is negatively related with bilateral flows between origin and destination countries. On the contrary, we expect that a common language, shared borders, colonial ties and a dense network of already established migrants, by reducing the cost of migration and increasing the number (and value) of opportunities in the destination country, are positively associated with bilateral flows.

Finally we employ the *share of agriculture over total GDP* at time *t-1* as a conditioning factor of the effects of climatic shocks upon our dependent variable. The agricultural sector in developing countries is often highly sensitive (and hence vulnerable) to climate shocks; we expect that the larger the weight of agriculture in the origin country economy, the wider will be the effect of climate shocks on individuals' socio-economic opportunities and the smaller the capacity of other sectors to absorb adverse consequences.

3.4. Econometric issues

Two main issues need to be addressed in the estimation of equation (4). The first one is the presence of "zeros" in bilateral migration flows, a problem leading to bias when using OLS estimations. Although in our sample the relative size of zeros is less pronounced, compared to other empirical works on migration determinants, like Beine et al. (2011) or Pedersen et al (2008), we address the issue by using a Poisson pseudo-maximum likelihood estimator (PPML), which has a superior performance compared to other estimators commonly employed in the literature even when the dependent variable has a large proportion of zeros (Santos Silva and Tenreyro 2006; 2011)[26],[27]. The second issue is related to the endogeneity of bilateral migration stocks (diaspora) – one of the regressors – and to our dependent variable, i.e. bilateral migration flows. Namely, unobservable bilateral characteristics might affect both the size of diasporas and the subsequent migration flows. Beine et al. (2011) follow Munshi (2003) and employ an instrumental variable estimation approach instead of using the current size of diasporas (i.e. the bilateral stock between country *i* and *j*). In particular, they use as instruments – supposedly correlated with the size of bilateral diasporas, but not with current flows – a dummy variable, which captures the existence of guest workers' scheme between the country of destination and origin in the '60s and '70s, and a variable which proxies the bilateral diaspora in the '60s (see Beine et al. 2011 for details). In this paper, we use as a proxy for

[26] Estimation results using Poisson and scaled-OLS estimation are available from the authors upon request.

[27] Note that when using a PPML our dependent variable - the size of bilateral migration flow will also depend on the attractiveness of alternative destinations, even under iid Extreme Value Theory-1 disturbances. In contrast to OLS estimations the inclusion of 'population at origin' (as a proxy for the number of stayers) does not represent a way to fully control for the effect of variations in the attractiveness of an alternative destination. Our estimated coefficients on climatic shocks at origin might, in principle, capture also the indirect effect of changes in the attractiveness of alternative (neighbouring) destinations which are similarly affected by the same shocks. In this respect – given our lack of information on South-South migration flows - our estimates, using PPML, departs from what would be strictly derived from the underlying theory. This shortcoming should be considered when interpreting the results. We acknowledge an anonymous referee for highlighting this issue and refer the interested reader to Beine et al. (2014).

the intensity of network effects in the bilateral diaspora of year 1960, which has been recently made available by Ozden et al. (2001) - World Bank Global Bilateral Migration Database. Using past diaspora is, in our opinion, a good measure of bilateral migration costs given the more effective role exercised by established migrants compared to more recent waves of migrants. Besides, this 'vintage' diaspora measure is unlikely to be affected by the same estimation issue, given the large time lag between the stocks and the 1990-2001 flows.[28]

4. *Empirical results*

The starting point of our analysis is the baseline model of bilateral migration flows, reported in the first column of *Table 1*. Estimation results for the non-climatic covariates are generally in line with our expectations. The size of bilateral migration flows is decreasing in the GDP per capita in the origin country; hence, a relative increase in wages (or level of development) translates into smaller bilateral migration flows. The employment rate in the origin country presents a negative but not statistically significant coefficient. Distance, as expected, is negatively associated with the size of the flows, while a common language and a common border have positive effects on out-migration flows. We do not find a statistically significant effect on the dummy variable for colonial ties. As highlighted in previous studies (see Beine et al 2011 and Pedersen et al 2008), migration networks play a crucial role in directing immigration flows; in our baseline model, the bilateral stock of already established migrants in 1960 is a strong determinant of subsequent bilateral flows. Note also that the estimated coefficient on the index of (political) quality of institutions is always negative and significant suggesting a higher migration from origin countries with relatively weak institutional environments.

In columns (1) to (3) of *Table 1* we report model specifications which include simple measurements of average rainfall respectively in 1, 3 and 5 year lags. The estimated coefficients of these rather un-sophisticated measurements of climate shocks – see our discussion in section 3.2 – are always not statistically significant. Things change when we consider the excessive variability of precipitations instead of the amount of rainfall. In columns (4) to (6) we include in the baseline regression the *index of (excess) rainfall variability,* $P_{MAD,y}$, computed at different time spans (averages of 1, 3 and 5 years lags). The estimated coefficients of the index are positive and significant; an increase in intra-annual precipitation variability, with respect to the long-term mean variability, is strongly associated with an increase in out-migration. It is interesting to notice that the magnitude of the coefficients is increasing in the time span considered. This result implies that a persistent excess variability amplifies the out-migration push. This is in line with our hypothesis that climate shocks affect individuals' expectations on future consequences of climate shocks and on the occurrence of further shocks in the future; a persistent high intra-annual variability of rainfall might indeed induce individuals to believe that these shocks are a persistent feature of the origin country climate rather than transitory, one-off events. For instance if we consider column (5), a back-of-the-envelope calculation reveals that, *ceteris paribus*, an increase in the index of rainfall variability at 3 years from mean value to 1 standard deviation above the mean is associated with a 13.7% increase in average bilateral migration.

[28] Robustness tests conducted by the authors using more recent bilateral diaspora measurements (70, 80s and 90s) do not alter the main results referring to the variables of our interests. An alternative strategy would be that of using a IV-PPML estimation. This would be the preferred option in case one believes that the inclusion of a more recent network variable is a more effective measuring tool for the intensity of bilateral diaspora.

Table 1 – HERE

Precipitation anomalies, i.e. monthly rainfall deviations from a long-term mean exceeding one standard deviation, are associated with an increase in bilateral migration flows toward OECD countries (see column 7). On the contrary, we do not find significative direct effects of temperature shocks, considering both surplus and anomalies (column 8-9).

As argued in *Section 2*, the nexus between climate shocks and migration is mediated by some conditioning factors; in particular, the adoption of migration as a coping strategy might depend on the vulnerability of the individuals directly and/or indirectly affected by the shocks. Beine and Parsons (2013) find a heterogeneous impact of climate anomalies when estimating separate models for developed (North) and developing (South) countries. In particular, they find evidence of significative effects of climate anomalies upon the latter group when conditioning these shocks to 'vulnerability' factors, such as the importance of the agricultural sector and water stress. In *Table 2*, we interact the *index of (the excess of) rainfall variability* with the GDP per capita (columns 1 and 2) – our proxy for the relative level of development – and with the agriculture share of GDP in the origin country (columns 3 and 4). The estimated coefficient on the interactions of the employed climatic variables with the GDP per capita are negative. In *Figure 3,* we report the marginal effects of $P_{MAD,3y}$ (*Panel A*) and $P_{MAD,5y}$ (*Panel B*) upon bilateral migration conditional on the GDP per capita in the origin country. Confidence intervals around the marginal effect lines and the histogram of the distribution of the conditioning variable are also in the figure. The findings suggest that an excess of rainfall variability is significantly associated with out-migration flows only in relatively poor countries. This result confirms the hypothesis that less developed areas are more likely to cope with climatic shocks by adopting cross-boundaries relocation strategies.

Table 2 – HERE

Figure 3 – HERE

Countries where the agriculture sector is large[29] experience a sizable climate-induced out-migration (column 3 and 4 of *Table 2*). As for the previous conditioning variable, we report the marginal effects associated to a change in $P_{MAD,3y}$ (*Panel C*) and $P_{MAD,5y}$ (*Panel D*), conditional upon the size of the agricultural sector. The results confirm that rainfall variability generates a positive effect on migration flows in countries with a large agricultural sector; on the contrary, the marginal effect is negative for countries where this sector is rather small. A higher agriculture share of GDP implies that eventual shocks to this sector might produce very strong effects and that, at the same time, they are less likely to be absorbed by other sectors of the economy.

Table 3 – HERE

[29] Similar results emerge when we use a measure of agriculture employment over total employment, although the availability of such data considerably reduces the number of usable observations.

In *Table 3,* we report our analysis on the heterogeneous effect of precipitation anomalies with different signs; respectively above or below one standard deviation with respect to the long-term mean. Our findings suggest that the magnitude of the effect is generally larger for excessive rainfall, compared to severe droughts. Note that the aggregated measures using a 3 years lag are not statistically significant (columns 1 and 3 in *Table 3*), while these are marginally significant at 5 years lag.

Climate shocks generally have different impacts on economic systems (and on individuals' current and future livelihoods), depending also on the timing of events. Namely, excessive precipitation or temperature anomalies during the main crop season might have devastating effects on the affected economy; on the contrary, a similar event might not produce significant effects in another period of the year. Given the impossibility to conduct a highly disaggregated analysis, which considers differences in agricultural systems across all countries in the sample, we study the effects of climatic shocks occurring in rainy and dry seasons separately.

The estimation results reported in *Table 4* confirm the relevance of the timing of precipitation and temperature anomalies. In *column (1)* we include in the baseline model a variable which measures the magnitude of temperature anomalies occurred during the rainy season in the past 3 years. The sign of the coefficient is negative, hinting that a severe decrease (increase) in temperature during the rainy season is associated with more (less) out-migration. In *column (2)*, we interact the climatic variable with the per capita GDP in the origin country; the interaction effect has a negative but not statistically significant coefficient for those countries in our sample with a large GDP per capita. When considering the temperature anomalies in the previous 5 years – i.e. a relative more persistent anomaly – the effects have a higher magnitude and the role of GDP per capita as a mediating factor is statistically significant (columns 3 and 4).

The effects of temperature anomalies during the dry season have the same pattern but are substantially different in magnitude and, generally, the effects are weakly statistically significant (columns 5-8). In the last three columns of *Table 4*, we report the different seasonal effects of precipitation anomalies. We find evidence of positive and statistically significant effects only for anomalies occurring during the dry season at all the time lags considered.

In *Appendix 3*, we report the same estimates shown in *Tables 1* to *4* where we use as dependent variable the international bilateral migration flows of the UN Population Division (2011). The results related to the climatic variables are robust although the magnitude of the average effects slightly diverge due to the different pool of origin/destination countries covered. Hence, the findings are robust to a different composition of origin/destination countries.[30]

The climate-shocks-induced effects highlighted so far represent average effects across the large sample of origin and destination countries included in the sample. There are good reasons to suspect that effects might be highly heterogeneous across country pairs – i.e. across migration corridors – due to specific dyadic factors that affect bilateral migration costs (for instance visa policies). In *Table 5*, we estimate the heterogeneous impact of rainfall variability, measured respectively at lag 1 and 3. In the first part, *Table 5a*, the index of intra-annual rainfall variability is interacted with origin areas dummies (columns 2 and 5) and with destination areas dummies (columns 3 and 6). The estimates highlight significantly different effects. In particular, the

[30] The following destination countries are covered by the UN Population Division database on bilateral yearly migration flows: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Hungary, Iceland, Israel, Italy, Netherlands, New Zealand, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, United States.

magnitude of the effects are larger for origin countries belonging to Europe and Central Asia and to East Asia and Pacific.   A positive and significant effect on outmigration is found also for countries belonging to Sub-Saharan Africa and Latin America when we consider excess volatility of rainfall at lag 1. Interestingly, countries belonging to South Asia where rainfall volatility is structurally quite high do not seems to be significantly affected by anomalies. Probably this result is related to a higher ability to adjust to climatic shocks of population that are structurally exposed to highly unstable climatic conditions. In terms of destination area, we find that outmigration associated to climatic shocks is more likely to happen toward European destinations, and to a lesser extent, to Australia and Asia, rather than toward the American continent. *Table 5b* shows the coefficients obtained by interacting the index of intra-annual rainfall variability (in the past 3 years) and origin-by-destination area dummies; besides it reports summary statistics of rainfall variability for the origin areas.

Interesting differences across (macro-area) migration corridors emerge.[31] Rainfall volatility seems to increase substantially out migration in most of migration corridors that involve a European county as a final destination with the exception of South-Asia / Europe, and to a lower extent, Sub-Saharan Africa / Europe, migration corridors. For some corridors such as South-Asia / Australia and Asia and Sub-Saharan Africa / America there is evidence of a decrease in international migration flows when rainfall volatility is particularly high in the origin country. Climate shocks occurring in the Middle-East and North Africa and in Europe and Central Asia have a significant effect on outmigration only toward European macro corridors; i.e. toward more accessible and less costly destinations. On the contrary, rainfall shocks in Latin America seems to have direct effects on outmigration toward Europe and Australasia but not toward the USA, Canada and Chile. One possible explanation might be related to quick adjustments in border enforcement – mainly in the USA – as a consequence of increasing migration pressure. These findings suggest that structural factors characterizing specific migration corridors are crucial in determining the direction and size of migration flows.[32]

Finally, we propose an exercise on the indirect role of climatic shocks through the GDP per capita in the origin country (our proxy for wage). *Table 6* reports our estimates, where we regress the GDP per capita in country i on a set of covariates including climatic shocks at 1 and 3 years lags.[33] We find evidence of a negative effect of excessive rainfall variability in the previous 3 years on GDP per capita. Besides, we find evidence on the negative effect on GDP associated with abundant rainfall (floods). This latter analysis confirms that climate shocks might be fundamental drivers – in a direct or indirect way – of out-migration from developing toward rich countries.

Table 4-5-6 – HERE

[31] We are grateful to an anonymous referee for suggesting to explore differences of climate shocks induced migration across migration corridors.

[32] A precise interpretation of dyadic specificity is beyond the scope of the present work but surely represents an interesting avenue for further research on climate shocks and other push factors as determinant of bilateral migration flows.

[33] Similar results, available upon request, are obtained when we consider 5 years averages.

4. *Conclusive remarks*

In the past few years, the public opinion has often been exposed to apocalyptic figures of migration flows that in the near future will be induced by changes in climatic conditions. Some of these prognostics were taken, often uncritically, from important reports, such as the Stern review or other studies such as Christian Aid (2007). These estimates are often based on simplistic assumptions and what they actually measure is ‘population at risk’ (for instance the number of people living in coastal floodplains below one meter of elevation), rather than actual migrants. These estimates do not consider other forms of adaptation strategies that might take place.

The complexity of the nexus between climate shocks and international migration demands the use of different methodological tools and investigation approaches (i.e. from different methodological approaches). In this paper, we develop a theoretically-grounded “macro” approach that takes into account and empirically tests the importance of climate shocks as push factors using a panel dataset of international bilateral migration flows. To our knowledge, this is the first paper which, rather than using highly aggregated and simple measurements of climate shocks, explicitly tests the importance of past climate shocks differing for type, magnitude and sign. Contrarily to the existing studies, we also consider the importance of shock’s timing by computing measurements of climate anomalies occurring in rainy and dry seasons.

We find evidence of both direct and indirect effects of climatic shocks on international migration flows. As emphasized in our simple theoretical model the direct effect of climatic shocks is likely to be related also to the impact that past events might have upon expectations on prospective streams of climate-induced changes in income and in non-monetary benefits and/or on expectations of the likelihood of additional adverse climate shocks.

Our findings show that climate shocks have heterogeneous effects depending not only on the specific kind of shock but also depending on co-factors, such as the level of development or the relative importance of agriculture within the local economy. In particular, we find that precipitation variability with respect to the long-term mean contributes to migration outflows toward rich OECD destinations. We find a different effect of floods compared to draught – respectively measured as rainfall average above or below 1 standard deviation from the long-term mean. Namely, the magnitude of the out-migration effect is on average larger for excessively abundant rainfall. With respect to temperature shocks, we find evidence that temperature anomalies have a significant effect on migration flows. We find evidence that a large fall in average temperature during the rainy season increases out-migration, in particular in less developed economies. The magnitude of these effects are substantially smaller if these shocks occur during the dry season. Finally, we highlight differences in the effects of rainfall variability across (macro-area) migration corridors. We detect a positive association between rainfall shocks in particular in migration corridors which include Europeans destinations; probably as a consequence of more ‘porous’ borders and a higher heterogeneity of immigration policies.

A corollary of our analysis is the difficulty – and probably the impossibility at least with the current methodological tools – of producing plausible predictions on future climate-induced migration flows. In order to provide reliable forecasts, researchers would need more accurate information on the exact nature and timing of future climatic shocks and on future evolutions of alternative coping strategies in societies and economies hit by these shocks.

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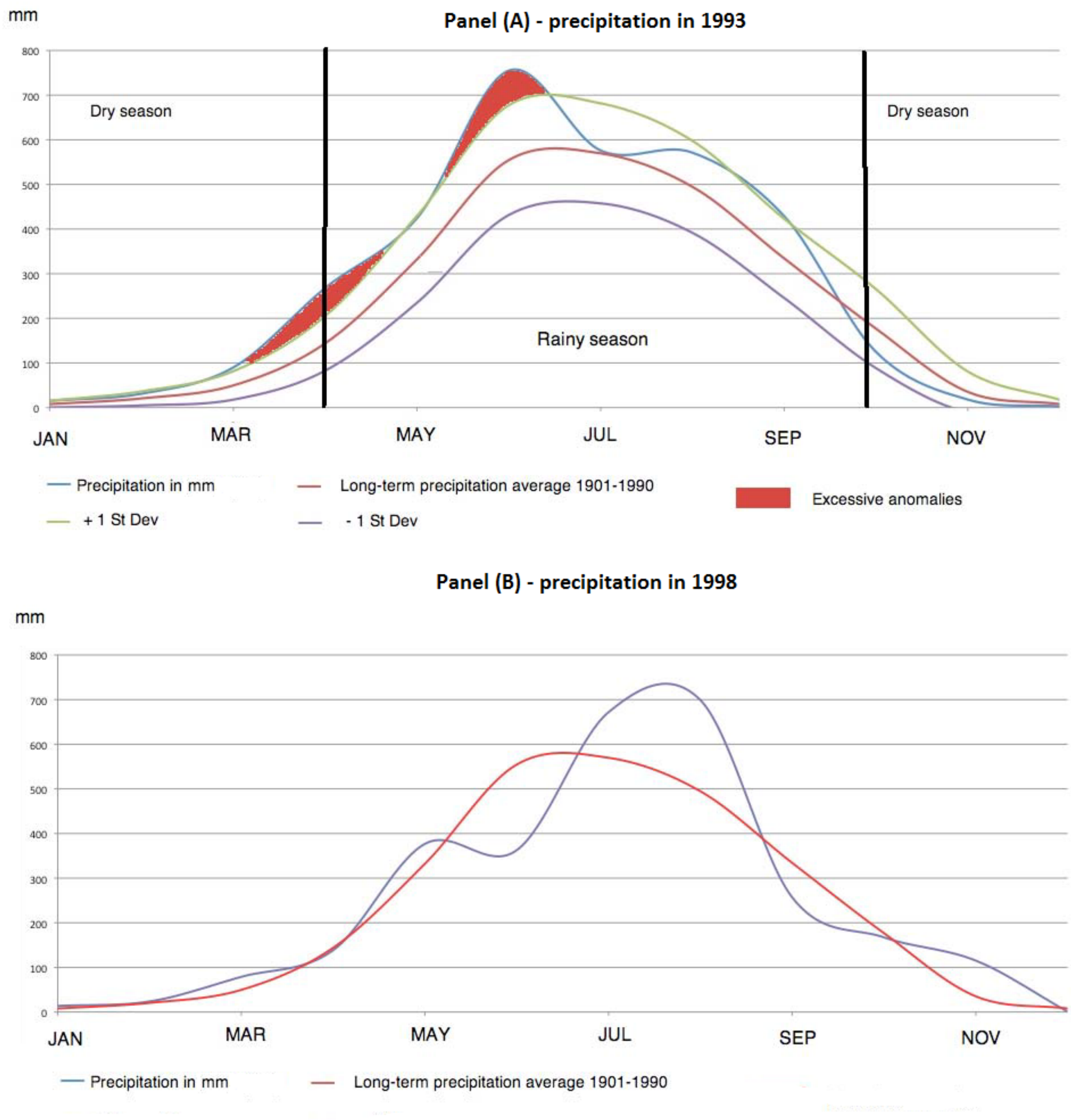
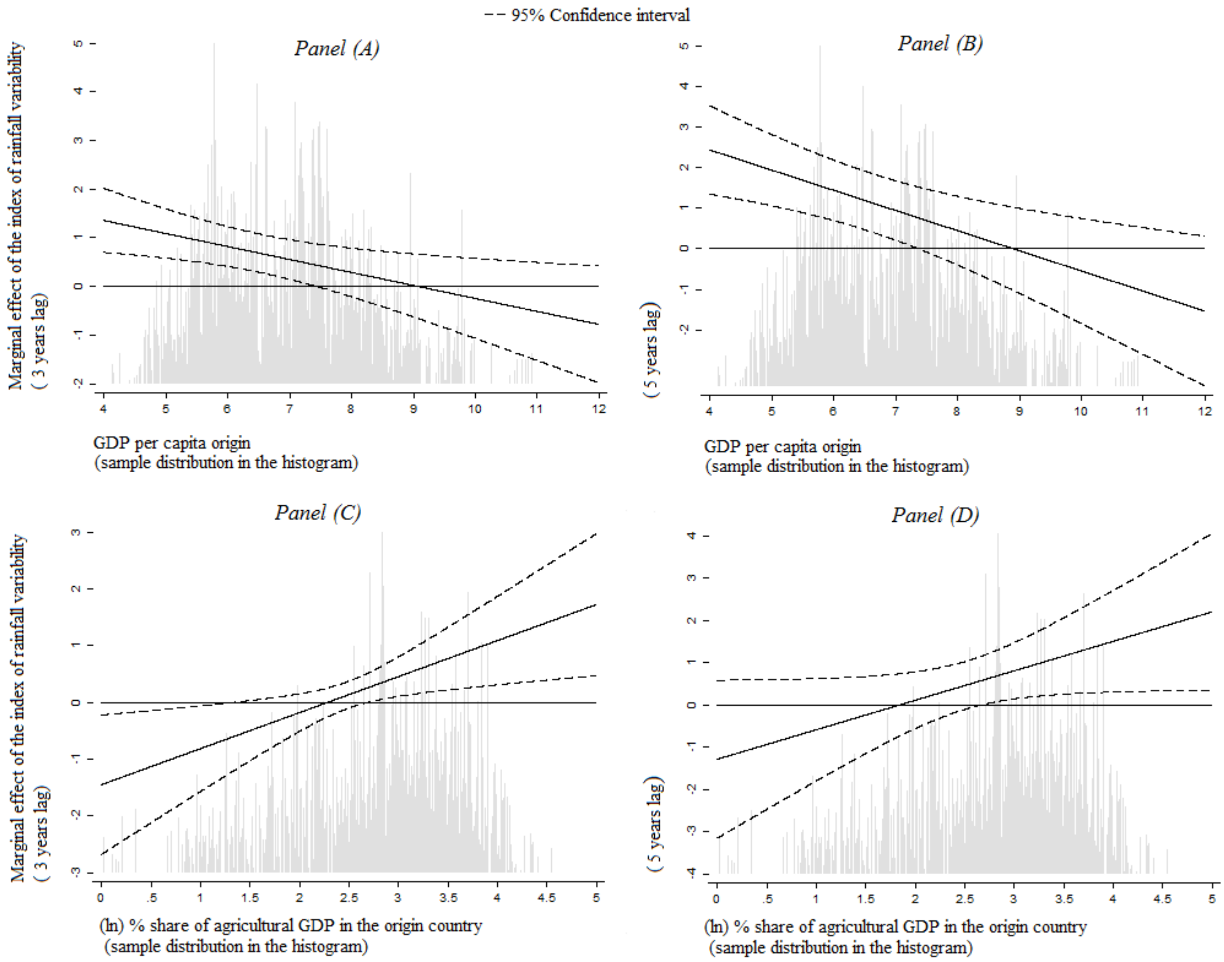
Figure 2. *Monthly precipitation in Bangladesh: 1901-1990 averages and rainfall in 1993 and 1998*



Source: authors' elaboration

Figure 3 - The marginal effect of rainfall variability on bilateral out-migration: the role of the relative level of development and the size of the agricultural sector.



Note: marginal effects computed using estimates reported in *Table 2*.

Appendix 1 *– List of countries included in the empirical analysis*

Origin countries (128)

East Asia and Pacific: Brunei Darussalam, Cambodia, China, Fiji, Indonesia, Laos, Malaysia, Mongolia, North Korea, Papua New Guinea, Philippines, Solomon Islands, Thailand, Vietnam.

South Asia: Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka.

Sub-Saharan Africa: Angola, Benin, Botswana, Burkina Faso, Burundi, Cape Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Democratic Republic of Congo, Cote d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mal, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Togo, Uganda, Zambia, Zimbabwe

Middle East and North Africa: Algeria, Bahrain, Egypt, Libya, Iran, Iraq, Jordan, Kuwait, Lebanon, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, Yemen.

Latin America and Caribbean: Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, Venezuela.

Europe and Central Asia: Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Moldova, Romania, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.

OECD destination countries (number of countries: **29**; in parenthesis we report the starting year of series only for countries with incomplete observations)

Europe and Middle East: Austria (1996), Belgium, Czech Republic (1995), Denmark, Finland, France (1995), Germany, Hungary (1995), Iceland (1999), Israel (1998), Italy (1998), Luxembourg (1996), Netherlands, , Norway, Poland (1998), Portugal, Slovenia (1998), Spain (1997), Sweden, Switzerland (1997), Turkey (1995), United Kingdom.
American continent: Canada, Chile (2000), United States.
Australian and asian continent: Australia, Japan, Korea, New Zealand (1994).

Appendix 2 *– Covariates included in the empirical analysis*: description and data sources*

Variable	**Description and source**
Bilateral migration flows	***Main source.*** Bilateral migration flows per year are taken from the OECD International Migration Database (freely available on http://stats.oecd.org/Index.aspx?DataSetCode=MIG). Since the purpose of the OECD database is to describe the "immigrant" population (generally the foreign born population), bilateral flows data covers the total immigrant population and immigrant labor force (together with data on acquisition of nationality). It is important to stress that data are taken from individual countries, which implies that they have not been fully standardized and are consequently not fully comparable across countries. For example, the criteria for registering population and the conditions for granting residence permits vary across countries. As an ***alternative source***, we use bilateral migration flows by year are taken from the UN Population Division - International Migration Database (freely available at http://esa.un.org/unmigration/MigrationFlows.html).
$P_{MAD,t-n}$ *Intra-annual rainfall variability i*	Mean Absolute Deviation (MAD) of monthly precipitation over the period considered / long-term MAD (period 1901-1990). An index > 1 implies higher variability in rainfall compared to the usual level of variability.
$P_{surplus,t-n}$ *Precipitation (or temperature) surplus*	Sum of monthly differences between precipitation (or temperature) over the period considered (year lag 1, 3 or 5) and monthly long-term averages. Positive values implies higher precipitation (or temperature) than the long-term mean. The variable is calculate both in absolute values – respectively in mm or Celsius degrees – and in % of the long-term mean.
$P_{anomaly,t-n}$ *Precipitation (or temperature) anomalies*	Sum of monthly precipitation (or temperature) shocks over the period considered considered (year lag 1, 3 or 5)that **are at least one standard deviation above or below the long-term averages**. Positive values implies excess precipitation (or temperature). The variable is calculate both in absolute values – respectively in mm or Celsius degrees – and in percentage with respect to the long-term mean.
$P_{(+)anomaly,t-n}$ *Positive precipitation anomalies (% values; lag1)*	Sum of monthly precipitation (or temperature) shocks over the period considered considered (year lag 1, 3 or 5)that are **equal or larger than one standard deviation above the long-term averages**. The variable is calculate both in absolute values – respectively in mm or Celsius degrees – and in percentage with respect to the long-term mean.
$P_{(-)anomaly,t-n}$ *Negative precipitation anomalies (% values; lag1)*	Sum of monthly precipitation (or temperature) shocks over the period considered considered (year lag 1, 3 or 5)that are equal or larger than **1 standard deviation below the long-term averages**. The variable is calculate both in absolute values – respectively in mm or Celsius degrees – and in percentage with respect to the long-term mean.
GDP per capita in the origin country (ln; lag 1)	As proxy of the wage rate, we used the (log) per capita GDP in the origin country. These data are taken from the United Nations Statistics Division Database.
Employment rate in the origin country (ln; lag 1)	Percentage of the active workforce which is employed. Source: World Bank – World Development Indicators database.
Common language	A common language in origin and destination countries is captured by a dummy variable (which equals to 1 if a significant proportion of the population in the two countries share the same language; 0 otherwise). Data are taken from the CEPII database (www.cepii.fr); we refer the reader to the source for the exact definition of the variable.
Colonial ties	Colonial ties factors are captured by a dummy variable (which equals to 1 if two countries have ever had a colonial link; 0 otherwise). Data are taken from the CEPII database (www.cepii.fr).
Contiguity	Measure of contiguity are taken from the CEPII database (www.cepii.fr). The variable is a dummy variable, which equals to 1 if two countries share a common border.
Distance	Geographical distances between capitals. Data are taken from the CEPII database (www.cepii.fr).
Network migrants ij	Stock of migrants from origin country *i* in destination country *j* in 1960. Source: Ozden et al. (2011), Global Bilateral Migration Database – World Bank
Armed conflicts at origin country	Short-term social instability factors are captured through a variable connected to armed conflict Including: international violence, international war, international independence war, civil violence, civil war, ethnic violence, and ethnic war. The variable is calculated as the sum of the annual number of episodes of armed conflict in the origin country. These data are obtained from the Major Episodes of Political Violence database of the Center for Systemic Peace.

Natural Disasters at origin country	Short-term environmental factors are captured through a variable referring to natural disasters, which comprises: droughts, earthquakes, epidemics, extreme temperatures, floods, mass movements, storms, volcanic eruptions and wildfires. These data are obtained from The International Disaster Database, which is compiled by the Centre for Research on the Epidemiology of Disasters. The variable is calculated as the sum of the number of episodes in the origin country in a year.
Quality of institutions at origin country	Quality of political institutions of origin countries is captured through the Political Institutional Quality Index (see Kuncic 2012) ranging between 0 and 1. The author clusters more than thirty established institutional indicators into three homogenous groups of formal institutions (legal, political and economic). A latent quality of legal, political and economic institutions is developed by using factor analysis for every country in the world and for every year, relative to the values of others countries. For more details see: *Kuncic, A. (2014).*
Agricultural GDP share	Percentage of Agriculture share of GDP. Source: World Bank – World Development Indicators database.
Population at origin country	Demographic conditions in origin countries are captured by the total population. Data are collected by the United Nations World Urbanization Prospects Database.

* Climate covariates are computed by using monthly precipitation and temperature data over the period 1901-2000, based on Mitchell et al. (2003) see *Section 3.2* for the formula applied for the computation of each variable above.

Summary statistics

Variable	**Obs**	**Mean**	**Std. Dev.**
Bilateral migration flows ij (OECD database)	14.066	1,25	5,54
Bilateral migration flows ij (UN Population Division database)	23.265	0,76	4,54
GDP per capita i (lag 1; ln)	13.652	7,01	1,23
Employment rate i (lag 1; ln)	12.094	58,65	11,67
Population i (ln)	13.741	8,62	2,30
Armed Conflicts i (dummy)	14.066	0,21	0,41
Natural Disasters i	14.066	2,31	3,85
Quality of institutions i	12.595	0,42	0,16
Distance ij (ln)	13.943	8,74	0,69
Common language (dummy)	13.943	0,14	0,35
Colony (dummy)	13.943	0,06	0,23
Contiguity (dummy)	13.943	0,01	0,09
Network migrants ij (1960s; ln)	9.776	4,82	2,97
Agricultural GDP share (% GDP; ln)	12.155	2,74	0,90
Precipitation i (absolute value; lag1)	13.575	1.239,76	880,07
Precipitation i (absolute value; lag3)	13.575	1.236,91	856,15
Precipitation i (absolute value; lag5)	13.575	1.233,05	853,09
Intra-annual rainfall variability i (lag 1)	13.575	1,03	0,34
Intra-annual rainfall variability i (lag 3)	13.575	1,04	0,24
Intra-annual rainfall variability i (lag 5)	13.575	1,03	0,20
Precipitation anomalies (sum of absolute values; lag3)	13.575	191,78	169,37
Temperature surplus (wrt long-term mean, lag 3)	13.575	0,47	0,34
Temperature anomalies (wrt longterm mean, lag 3)	13.575	0,75	0,41

Precipitation anomalies (% values; lag 3)	13.575	2,13	10,68
Positive precipitation anomalies (% values; lag 3)	13.575	9,67	9,79
Negative precipitation anomalies (% values; lag 3)	13.575	7,54	4,98
Precipitation anomalies (% values; lag 5)	13.575	2,07	9,65
Positive precipitation anomalies (% values; lag 5)	13.575	9,57	9,17
Negative precipitation anomalies (% values; lag 5)	13.575	7,50	4,19
Temperature anomalies - Rainy season (% of mean value; lag 3)	13.575	1,66	2,79
Temperature anomalies - Rainy season (% of mean value; lag 5)	13.575	1,38	2,07
Temperature anomalies - Dry season (% of mean value; lag 3)	13.575	-10,15	98,21
Temperature anomalies - Dry season (% of mean value; lag 5)	13.575	-8,68	76,61
Precipitation anomaly - Rainy season (% of mean value; lag 1)	13.575	16,28	17,66
Precipitation anomaly - Dry season (% of mean value; lag 1)	13.575	20,22	18,89
Precipitation anomaly - Rainy season (% of mean value; lag 3)	13.575	16,34	13,32
Precipitation anomaly - Dry season (% of mean value; lag 3)	13.575	20,44	12,81
Precipitation anomaly - Rainy season (% of mean value; lag 5)	13.575	16,19	12,27
Precipitation anomaly - Dry season (% of mean value; lag 5)	13.575	20,24	10,74

Table 1. Climate shocks and international migration: baseline estimation (OECD data)
Dependent variable: bilateral migration flows ij (absolute values)

	Baseline	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		PREC	PREC	PREC	PREC	PREC	PREC	PREC	TEMP	TEMP
GDP pc i (lag 1; ln)	-0.32*** (0.107)	-0.299*** (0.102)	-0.294*** (0.0982)	-0.296*** (0.102)	-0.29*** (0.0992)	-0.215** (0.0935)	-0.209** (0.0964)	-0.227** (0.106)	-0.31*** (0.103)	-0.31*** (0.0976)
Employment rate i (lag 1; ln)	0.00237 (0.0170)	0.000231 (0.0145)	-0.00340 (0.0112)	-0.00392 (0.0116)	-0.00209 (0.0155)	-0.00845 (0.0131)	-0.0107 (0.0140)	-0.00393 (0.0133)	0.00215 (0.0179)	0.00254 (0.0163)
Population i (ln)	1.440 (1.084)	1.403 (1.099)	1.546 (1.114)	1.619 (1.122)	1.476 (1.071)	1.365 (1.000)	1.470 (0.956)	1.202 (1.055)	1.464 (1.054)	1.443 (1.068)
Armed Conflicts i (dummy)	0.0127 (0.0934)	0.00666 (0.0950)	0.0162 (0.0958)	0.0148 (0.0988)	0.0181 (0.0907)	0.0436 (0.0964)	0.0654 (0.105)	0.00727 (0.0939)	0.0103 (0.0941)	0.0104 (0.0990)
Natural Disasters i	0.012** (0.0051)	0.0142** (0.00580)	0.0151** (0.00606)	0.0148** (0.00600)	0.00950* (0.0051)	0.0103** (0.0050)	0.00883* (0.0050)	0.014*** (0.0054)	0.0125** (0.0053)	0.013*** (0.0048)
Quality of institutions i	-1.78** (0.847)	-1.764** (0.831)	-1.730** (0.824)	-1.762** (0.849)	-1.712** (0.797)	-1.721** (0.777)	-1.731** (0.773)	-1.732** (0.799)	-1.784** (0.843)	-1.784** (0.840)
Distance ij (ln)	-.60*** (0.193)	-.602*** (0.194)	-.605*** (0.194)	-.602*** (0.193)	-.60*** (0.194)	-.61*** (0.193)	-.601*** (0.189)	-.608*** (0.194)	-.599*** (0.193)	-.599*** (0.193)
Common language (dummy)	.867*** (0.219)	.862*** (0.217)	.859*** (0.217)	.860*** (0.218)	.862*** (0.217)	.856*** (0.215)	.859*** (0.217)	.860*** (0.216)	.866*** (0.220)	.866*** (0.219)
Colony (dummy)	0.272 (0.287)	0.274 (0.286)	0.270 (0.284)	0.271 (0.284)	0.276 (0.286)	0.277 (0.285)	0.279 (0.286)	0.283 (0.287)	0.272 (0.286)	0.272 (0.287)
Contiguity (dummy)	1.083*** (0.336)	1.084*** (0.336)	1.082*** (0.337)	1.081*** (0.335)	1.081*** (0.338)	1.081*** (0.337)	1.092*** (0.335)	1.083*** (0.337)	1.083*** (0.336)	1.083*** (0.336)
Network migrants ij (1960s; ln)	.203*** (0.0321)	.203*** (0.0322)	.203*** (0.0322)	.203*** (0.0322)	.203*** (0.0321)	.202*** (0.0321)	.201*** (0.0325)	.201*** (0.0323)	.203*** (0.0322)	.203*** (0.0326)
Precipitation i (absolute value; lag1)		0.000205 (0.00018)								
Precipitation i (absolute value; mean of past 3 years)			0.000583 (0.00051)							
Precipitation i (absolute value; mean of past 5 years)				0.000936 (0.00078)						
Intra-annual rainfall variability i (lag 1)					0.169*** (0.0470)					
Intra-annual rainfall variability i (lag 3)						0.570*** (0.194)				
Intra-annual rainfall variability i (lag 5)							0.986*** (0.346)			
Precipitation anomalies (sum of absolute values; lag3)								0.00098* (0.0005)		
Temperature surplus (wrt long-term mean, lag 3)									-0.015 (0.109)	
Temperature anomalies (wrt longterm mean, lag 3)										-0.0288 (0.346)
Constant	-8.180 (9.356)	-7.785 (9.427)	-9.139 (9.666)	-9.936 (9.832)	-8.560 (9.191)	-7.881 (8.536)	-9.337 (8.338)	-5.907 (8.832)	-8.399 (8.959)	-8.204 (9.210)
Observations	8,771	8,771	8,771	8,771	8,771	8,771	8,771	8,771	8,771	8,771
R-squared	0.715	0.717	0.718	0.717	0.718	0.722	0.722	0.720	0.715	0.715

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects. Robust standard errors (in parentheses) clustered by country of destination.

Table 2. Rainfall variability: the role of the level of development and of the agricultural sector (OECD data)
Dependent variable: bilateral migration flows ij (absolute values)

	(1) PREC	(2) PREC	(3) PREC	(4) PREC
GDP pc i (lag 1; ln)	0.0715	0.316*	-0.292***	-0.262***
	(0.137)	(0.190)	(0.0788)	(0.0834)
Employment rate i (lag 1; ln)	-0.00789	-0.0107	-0.00890	-0.0118
	(0.0133)	(0.0139)	(0.0147)	(0.0156)
Population i (ln)	1.306	1.530*	0.895	1.119
	(1.007)	(0.912)	(1.043)	(1.010)
Armed Conflicts i (dummy)	0.0476	0.0760	-0.0913	-0.0646
	(0.0950)	(0.100)	(0.0718)	(0.0707)
Natural Disasters i	0.0103**	0.00870*	0.0104***	0.00776**
	(0.00493)	(0.00474)	(0.00391)	(0.00378)
Quality of institutions i	-1.750**	-1.758**	-1.229***	-1.242***
	(0.781)	(0.770)	(0.443)	(0.436)
Distance ij (ln)	-0.604***	-0.597***	-0.643***	-0.639***
	(0.193)	(0.190)	(0.213)	(0.211)
Common language (dummy)	0.860***	0.863***	0.774***	0.775***
	(0.214)	(0.215)	(0.222)	(0.222)
Colony (dummy)	0.278	0.280	0.270	0.269
	(0.285)	(0.285)	(0.291)	(0.291)
Contiguity (dummy)	1.080***	1.093***	1.246***	1.252***
	(0.336)	(0.335)	(0.373)	(0.372)
Network migrants ij (1960s; ln)	0.202***	0.201***	0.192***	0.192***
	(0.0319)	(0.0322)	(0.0308)	(0.0309)
Intra-annual rainfall variability i (lag 3)	2.422***		-1.448**	
	(0.707)		(0.616)	
Index of rainfall variability i (lag 3) * GDP pc i	-0.267**			
	(0.104)			
Intra-annual rainfall variability i (lag 5)		4.414***		-1.282
		(1.100)		(0.940)
Index of rainfall variability i (lag 5) * GDP pc i		-0.496***		
		(0.158)		
Agricultural GDP i (lag 1; ln)			-0.765**	-0.801
			(0.385)	(0.501)
Index of rainfall variability i (lag 3) * Agric GDP i			0.634***	
			(0.244)	
Index of rainfall variability i (lag 5) * Agric GDP i				0.698*
				(0.357)
Constant	-9.353	-13.59*	-0.947	-3.322
	(8.197)	(7.464)	(7.361)	(7.323)
Observations	8,771	8,771	8,087	8,087
R-squared	0.722	0.723	0.743	0.743

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects. Robust standard errors (in parentheses) clustered by country of destination.

Table 3. Precipitation anomalies and international migration: draught versus floods (OECD data)
Dependent variable: bilateral migration flows ij (absolute values)

	(1) PREC	(2) PREC	(3) PREC	(4) PREC
GDP pc i (lag 1; ln)	-0.315*** (0.101)	-0.244** (0.106)	-0.324*** (0.102)	-0.241** (0.106)
Employment rate i (lag 1; ln)	-0.00152 (0.0134)	-0.00544 (0.0127)	-0.00189 (0.0145)	-0.00716 (0.0136)
Population i (ln)	1.670 (1.151)	1.411 (0.987)	1.725 (1.217)	1.439 (0.989)
Armed Conflicts i (dummy)	0.0164 (0.0908)	0.00880 (0.0883)	0.0179 (0.0937)	0.0176 (0.0946)
Natural Disasters i	0.0131** (0.00520)	0.0120** (0.00504)	0.0129** (0.00533)	0.0114** (0.00506)
Quality of institutions i	-1.752** (0.821)	-1.701** (0.780)	-1.705** (0.811)	-1.592** (0.718)
Distance ij (ln)	-0.604*** (0.195)	-0.607*** (0.194)	-0.595*** (0.192)	-0.596*** (0.190)
Common language (dummy)	0.858*** (0.217)	0.854*** (0.215)	0.863*** (0.219)	0.861*** (0.218)
Colony (dummy)	0.268 (0.285)	0.274 (0.286)	0.269 (0.285)	0.278 (0.287)
Contiguity (dummy)	1.073*** (0.337)	1.084*** (0.336)	1.068*** (0.333)	1.097*** (0.333)
Network migrants ij (1960s; ln)	0.203*** (0.0322)	0.203*** (0.0325)	0.204*** (0.0321)	0.202*** (0.0328)
Precipitation anomalies (% values; lag 3)	0.00747 (0.00507)			
Positive precipitation anomalies (% values; lag 3)		0.0175** (0.00773)		
Negative precipitation anomalies (% values; lag 3)		0.00965* (0.00583)		
Precipitation anomalies (% values; lag 5)			0.0142* (0.00859)	
Positive precipitation anomalies (% values; lag 5)				0.0336** (0.0166)
Negative precipitation anomalies (% values; lag 5)				0.0137* (0.00776)
Constant	-10.22 (10.04)	-8.114 (8.425)	-10.83 (10.69)	-8.722 (8.567)
Observations	8,771	8,771	8,771	8,771
R-squared	0.717	0.722	0.716	0.721

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects. Robust standard errors (in parentheses) clustered by country of destination.

Table 4. Climate shocks and international migration: dry and rainy seasons (OECD data)
Dependent variable: bilateral migration flows ij (absolute values)

	(1) TEMP	(2) TEMP	(3) TEMP	(4) TEMP	(5) TEMP	(6) TEMP	(7) TEMP	(8) TEMP	(9) PREC	(10) PREC	(11) PREC
GDP pc i (lag 1; ln)	-.321***	-.323***	-.306***	-.295***	-.368***	-0.406***	-0.377***	-0.410***	-0.291***	-0.224**	-0.230**
	(0.108)	(0.108)	(0.111)	(0.112)	(0.0913)	(0.0934)	(0.0912)	(0.0924)	(0.0969)	(0.0990)	(0.106)
Employment rate i (lag 1; ln)	0.00279	0.00268	0.00231	0.00407	0.000155	-7.99e-05	0.000299	9.97e-05	-0.00111	-0.00519	-0.00591
	(0.0166)	(0.0165)	(0.0164)	(0.0164)	(0.0171)	(0.0171)	(0.0171)	(0.0170)	(0.0149)	(0.0142)	(0.0156)
Population i (ln)	1.404	1.418	1.352	1.241	1.672	1.814	1.725	1.842*	1.482	1.317	1.280
	(1.106)	(1.111)	(1.102)	(1.095)	(1.127)	(1.115)	(1.121)	(1.113)	(1.071)	(0.981)	(0.902)
Armed Conflicts i (dummy)	0.00377	0.00377	-0.00280	-0.00420	0.127	0.156	0.144	0.163	-0.00684	-0.00402	-0.00438
	(0.0914)	(0.0915)	(0.0905)	(0.0899)	(0.119)	(0.123)	(0.116)	(0.119)	(0.0889)	(0.0918)	(0.0925)
Natural Disasters i	0.0127**	0.0127**	0.0119**	0.0115**	0.00532	0.00296	0.00548	0.00328	0.00921*	0.0102**	0.00901*
	(0.0051)	(0.0050)	(0.00529)	(0.0051)	(0.0048)	(0.00513)	(0.00467)	(0.00477)	(0.00494)	(0.00501)	(0.00477)
Quality of institutions i	-1.772**	-1.776**	-1.750**	-1.715**	-1.549**	-1.356*	-1.506**	-1.333*	-1.799**	-1.727**	-1.551**
	(0.847)	(0.847)	(0.836)	(0.833)	(0.733)	(0.724)	(0.725)	(0.706)	(0.805)	(0.825)	(0.791)
Distance ij (ln)	-.602***	-.602***	-.605***	-.606***	-.597***	-.597***	-.597***	-.597***	-.600***	-.601***	-0.597***
	(0.194)	(0.194)	(0.195)	(0.195)	(0.193)	(0.193)	(0.193)	(0.193)	(0.194)	(0.193)	(0.189)
Common language (dummy)	0.864***	0.864***	0.861***	0.860***	0.86***	0.864***	0.865***	0.864***	0.864***	0.863***	0.868***
	(0.218)	(0.218)	(0.217)	(0.217)	(0.218)	(0.217)	(0.218)	(0.217)	(0.217)	(0.215)	(0.217)
Colony (dummy)	0.273	0.274	0.273	0.272	0.279	0.281	0.279	0.280	0.278	0.278	0.274
	(0.286)	(0.286)	(0.286)	(0.286)	(0.289)	(0.289)	(0.289)	(0.289)	(0.288)	(0.288)	(0.291)
Contiguity (dummy)	1.082***	1.082***	1.073***	1.068***	1.08***	1.083***	1.083***	1.082***	1.086***	1.098***	1.106***
	(0.338)	(0.339)	(0.336)	(0.335)	(0.336)	(0.336)	(0.336)	(0.336)	(0.338)	(0.336)	(0.334)
Network migrants ij (1960s; ln)	0.203***	0.203***	0.203***	0.203***	0.20***	0.202***	0.202***	0.203***	0.202***	0.202***	0.202***
	(0.0319)	(0.0319)	(0.0319)	(0.0320)	(0.0324)	(0.0325)	(0.0324)	(0.0324)	(0.0318)	(0.0317)	(0.0327)
Temperature anomalies - Rainy season (% of mean value; lag 3)	-0.0122*	-0.0202									
	(0.0068)	(0.0435)									
Temperature anomalies - Rainy season (% of mean value; lag 3) * GDP pc i		0.00118									
		(0.00578)									
Temperature anomalies - Rainy season (% of mean value; lag 5)			-0.0293**	0.0672							
			(0.0136)	(0.0629)							
Temperature anomalies - Rainy season (% of mean value; lag 5) * GDP pc i				-0.0141*							
				(0.00799)							
Temperature anomalies - Dry season (% of mean value; lag 3)					-.00055*	0.00656*					
					(0.0003)	(0.00370)					
Temperature anomalies - Dry season (% of mean value; lag 3) * GDP pc i						-0.00102*					
						(0.000556)					
Temperature anomalies - Dry season (% of mean value; lag 5)							-0.00120*	0.00606			
							(0.000647)	(0.00406)			
Temperature anomalies - Dry season (% of mean value; lag 5) * GDP pc i								-0.00101*			
								(0.000615)			
Precipitation anomaly - Rainy season (% of mean value; lag 1)									0.00240		
									(0.00171)		
Precipitation anomaly - Dry season (% of mean value; lag 1)									0.0042***		
									(0.0011)		
Precipitation anomaly - Rainy season (% of mean value; lag 3)										0.00742	
										(0.00594)	
Precipitation anomaly - Dry season (% of mean value; lag 3)										0.0085***	
										(0.0015)	
Precipitation anomaly - Rainy season (% of mean value; lag 5)											0.0110
											(0.00830)
Precipitation anomaly - Dry season (% of mean value; lag 5)											0.0141***
											(0.00455)
Constant	-7.734	-7.842	-7.157	-6.347	-10.21	-11.42	-10.71	-11.69	-8.625	-7.423	-7.288
	(9.592)	(9.643)	(9.585)	(9.459)	(9.705)	(9.551)	(9.659)	(9.561)	(9.136)	(8.265)	(7.635)
Observations	8,771	8,771	8,771	8,771	8,771	8,771	8,771	8,771	8,771	8,771	8,771
R-squared	0.716	0.716	0.717	0.717	0.716	0.715	0.716	0.715	0.722	0.722	0.722

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects. Robust standard errors (in parentheses) clustered by country of destination.

Table 5a. Rainfall variability at lag 1 and lag 3: different impacts by origin and destination area (OECD data) Dependent variable: bilateral migration flows ij (absolute values)

	Rainfall variability : **1-year lag**			Rainfall variability : **3-years lag**		
	(1) Baseline	(2) Origin	(3) Destination	(4) Baseline	(5) Origin	(6) Destination
GDP pc i (lag 1; ln)	-0.290***	-0.288***	-0.297***	-0.215**	-0.193**	-0.210**
	(0.0992)	(0.0965)	(0.0984)	(0.0935)	(0.0950)	(0.0923)
Employment rate i (lag 1; ln)	-0.0021	-0.0025	-0.00059	-0.00845	-0.0105	-0.0101
	(0.0155)	(0.0155)	(0.0158)	(0.0131)	(0.0127)	(0.0122)
Population i (ln)	1.476	1.582	1.421	1.365	1.427	1.299
	(1.071)	(1.088)	(1.098)	(1.000)	(1.046)	(1.026)
Armed Conflicts i (dummy)	0.0181	0.0120	0.00807	0.0436	0.0553	0.0407
	(0.0907)	(0.0959)	(0.0907)	(0.0964)	(0.0961)	(0.0971)
Natural Disasters i	0.00950*	0.00870	0.0117**	0.0103**	0.0105**	0.00979*
	(0.00507)	(0.00563)	(0.00559)	(0.00503)	(0.00509)	(0.00517)
Quality of institutions i	-1.712**	-1.672**	-1.650**	-1.721**	-1.704**	-1.694**
	(0.797)	(0.801)	(0.798)	(0.777)	(0.792)	(0.774)
Distance ij (ln)	-0.601***	-0.602***	-0.613***	-0.607***	-0.608***	-0.627***
	(0.194)	(0.194)	(0.195)	(0.193)	(0.193)	(0.195)
Common language (dummy)	0.862***	0.862***	0.845***	0.856***	0.855***	0.822***
	(0.217)	(0.217)	(0.216)	(0.215)	(0.215)	(0.213)
Colony (dummy)	0.276	0.280	0.281	0.277	0.279	0.295
	(0.286)	(0.286)	(0.284)	(0.285)	(0.283)	(0.277)
Contiguity (dummy)	1.081***	1.074***	1.069***	1.081***	1.082***	1.066***
	(0.338)	(0.334)	(0.338)	(0.337)	(0.337)	(0.339)
Network migrants ij (1960s; ln)	0.203***	0.202***	0.204***	0.202***	0.202***	0.202***
	(0.0321)	(0.0320)	(0.0320)	(0.0321)	(0.0323)	(0.0319)
(Intra-annual) rainfall variability i **(RV)**	0.169***			0.570***		
	(0.0470)			(0.194)		
ORIGIN MACRO-AREAS						
RV * East Asia Pacific i		0.225**			0.668***	
		(0.104)			(0.18)	
RV * South Asia i		-0.0560			-0.367	
		(0.159)			(0.235)	
RV * Sub-Saharan Africa i		0.182***			0.355	
		(0.06)			(0.292)	
RV * MENA i		0.0160			0.425*	
		(0.0847)			(0.237)	
RV * Latin America Caribbean i		0.158**			0.656	
		(0.079)			(0.411)	
RV * Europe and Central Asia		0.397**			0.786***	
		(0.171)			(0.259)	
DESTINATION MACRO-AREAS						
RV * Europe			0.318***			0.866***
			(0.0782)			(0.234)
RV * America			0.0629			0.287*
			(0.0661)			(0.171)
RV * Australia-Asia			-0.132			0.535**
			(0.144)			(0.235)
Constant	-8.560	-7.498	-6.930	-7.881	-9.327	-7.678
	(9.191)	(8.771)	(8.857)	(8.536)	(9.236)	(9.524)
Observations	8,771	8,771	8,771	8,771	8,771	8,771
R-squared	0.718	0.722	0.728	0.722	0.719	0.723

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects. Robust standard errors (in parentheses) clustered by country of destination.; RV is used as abbreviation of the intra-annual index of rainfall variability.

Table 5b. Rainfall variability and migration: evidence of heterogeneous effects upon different international migration corridors (OECD data)

Legend: In the table we report the **coefficients obtained by interacting the measure of intra-annual rainfall variability at 3-year lag with origin-by-destination area dummies**. (only coefficients for climatic coefficients reported)

	Continent of destination			**Intra-annual rainfall variability at 3-year lag:**	
	Europe	*America*	*Australia and Asia*	*Mean value (standard deviation)*	*Min / Max values*
Macro-area of origin					
East Asia and Pacific	1.383***	0.631***	0.0813	1.039	0.15 /
	(0.205)	(0.171)	(0.302)	(0.211)	1.59
South Asia	-0.0662	-0.335	-1.197**	0.984	0.67 /
	(0.359)	(0.409)	(0.483)	(0.123)	1.35
Sub-Saharan Africa	0.783*	-0.903**	-0.308	1.010	0.346 /
	(0.434)	(0.407)	(0.621)	(0.244)	1.986
MENA	0.571**	-0.00445	0.294	1.101	0.383 /
	(0.272)	(0.265)	(0.382)	(0.219)	1.944
Latin America	1.019***	0.160	1.448***	1.101	0.616 /
Caribbean	(0.272)	(0.285)	(0.540)	(0.241)	2.21
Europe and Central	1.070***	-0.209	0.645	1.002	0.778 /
Asia	(0.304)	(0.366)	(0.647)	(0.099)	1.276

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects. Robust standard errors (in parentheses) clustered by country of destination.

Table 6. The effects of climate shocks on GDP per capita in origin countries (OECD data)
Dependent variable: GDP per capita i (ln)

	(1) PREC	(2) PREC	(3) PREC	(4) PREC	(6) PREC
Employment rate i (lag 1; ln)	0.00234***	0.00238***	0.00245***	0.00236***	0.00238***
	(0.000492)	(0.000495)	(0.000497)	(0.000494)	(0.000495)
Population i (ln)	-0.0703***	-0.0704***	-0.0687**	-0.0703***	-0.0667**
	(0.0269)	(0.0269)	(0.0268)	(0.0269)	(0.0271)
Armed Conflicts i (dummy)	-0.00679*	-0.00678*	-0.00695**	-0.00660*	-0.00661*
	(0.00352)	(0.00352)	(0.00351)	(0.00352)	(0.00351)
Natural Disasters i	-0.000927*	-0.000910*	-0.000902	-0.000920*	-0.000934*
	(0.000549)	(0.000549)	(0.000549)	(0.000549)	(0.000549)
Quality of institutions i	0.0618***	0.0620***	0.0635***	0.0613***	0.0614***
	(0.0168)	(0.0168)	(0.0168)	(0.0168)	(0.0168)
Intra-annual rainfall variability i (lag 1)		-0.00333			
		(0.00261)			
Intra-annual rainfall variability i (lag 3)			-0.0103**		
			(0.00477)		
Positive precipitation anomalies (% values; lag 1)				-0.000107**	
				(0.000054)	
Negative precipitation anomalies (% values; lag 1)				0.00003	
				(0.000107)	
Positive precipitation anomalies (% values; lag 3)					-0.000252**
					(0.000099)
Negative precipitation anomalies (% values; lag 3)					-0.000052
					(0.000215)
Constant	2.192***	2.195***	2.181***	2.192***	2.160***
	(0.266)	(0.266)	(0.265)	(0.266)	(0.267)
Observations					
	1,267	1,267	1,267	1,267	1,267
R-squared	0.978	0.978	0.978	0.978	0.978

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively;
robust standard errors in parenthesis;; estimates include origin country fixed effects.

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