The Scandinavian
Journal of Economics

Scand. J. of Economics 117(2), 723–767, 2015
DOI: 10.1111/sjoe.12098

Climatic Factors as Determinants of International Migration*

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Abstract

We examine natural disasters and long-run climatic factors as potential determinants of international migration, implementing a panel dataset of bilateral migration flows from 1960 to 2000. We find no direct effect of long-run climatic factors on international migration across our entire sample. These results are robust when conditioning on origin-country characteristics, when considering migrants returning home, and when accounting for the potential endogeneity of migrant networks. Rather, we find evidence of indirect effects of environmental factors operating through wages. We find that epidemics and miscellaneous incidents spur international migration, and there is strong evidence that natural disasters beget greater flows of migrants to urban environs.

Keywords: Environmental change; natural disasters; utility maximization

JEL classification: *F*22; *O*15

I. Introduction

Climate change remains at the vanguard of the international development policy debate. In *The Stern Review*, while analyzing the economic impact

*This paper was commissioned under the auspices of the Foresight Global Environmental Migration project and the authors gratefully acknowledge funding from the UK Government Department for Business, Innovation and Skills. The authors are indebted to Tim Osborn for providing the environmental data and to Simon Gosling who went beyond the call of duty to facilitate their use at short notice. Gratitude also needs to be extended to the members of the Determinants of International Migration (DEMIG) project, based at the International Migration Institute at the University of Oxford, which received funding from the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013)/ERC Grant Agreement 240940 (see http://www.imi.ox.ac.uk/research-projects/demig), for allowing privileged access to their bilateral visa data. The authors also wish to thank the editor, the Lead Expert Group of the Foresight Global Environmental Migration project, especially Stefan Dercon, in addition to Cécile Couharde, Richard Disney, Frédéric Docquier, Markus Eberhardt, Giovanni Facchini, Katrin Millock, Richard Upward, and L. Alan Winters for useful and timely comments.

of climate change, Stern (2007) emphasized the global consequences of inaction, the need for a coordinated international response, and the fact that developing countries will likely suffer disproportionately. This final point was also stressed in the first United Nations (UN) intergovernmental report on climate change, which further stated that "the gravest effects of climate change may be those on human migration as millions will be displaced" (International Panel on Climate Change, 1990). Myers (1996) counted some 25 million environmental refugees in 1995, and forecast some 200 million by 2050 (Myers, 2002). Although the term "environmental migrant" is perhaps not a useful distinction to make (Castles, 2002), these estimates nevertheless highlight the magnitude of possible future movements that might, at least in part, be driven by environmental change. Despite these dire predictions, surprisingly few papers examine either the direct or indirect effects of environmental factors on international migration.

This paper contributes to the literature by examining, for the first time, the overall (macroeconomic) impact of the effects of climate change on international migration using a panel of global bilateral migration flows. Our key finding, once we have controlled for other leading drivers of international migration (i.e., economic, cultural, political, social, and demographic factors) is that we uncover no evidence of long-run climatic factors directly affecting international migration. Conversely, our results suggest that long-run climatic factors might affect international migration indirectly, and we argue that at least one plausible mechanism is via wage differentials. Although for some counterintuitive, this conclusion is in line with much of the recent literature on the subject, as shown, for example, by the following.

> Environmental Change will affect migration now and in the future, specifically through its influence on a range of economic, social and political drivers which themselves affect migration. However, the range and complexity of the interactions between these drivers mean that it will rarely be possible to distinguish individuals for whom environmental factors are the sole driver. (UK Government Office for Science, 2011)

Conversely, we find that epidemics and miscellaneous incidents spur international migration, and we uncover evidence that natural disasters beget greater flows of migrants to urban environs.

Climatic factors manifest in many guises and might impinge upon migration in myriad ways. These include extreme weather phenomena and variability in temperature and precipitation (Boko *et al.*, 2007). Marchiori *et al.* (2011) advocate two channels (one direct and the other indirect), via which these types of climatic factors beget international migration. Most obviously, climatic factors have the greatest impact upon countries that rely more heavily upon agricultural activities (Mendelsohn and Dinar, 1999), which in turn might encourage international migration directly. Most likely, in such contexts, climatic factors will result in greater urbanization, the increased pressures from which might foster greater incentives to migrate abroad. However, rural–urban migration might also indirectly lead to international migration, because increased rural–urban migration results in downward pressure on urban wages, thus creating greater incentives for emigration. Less obviously, climatic factors might also directly result in international migration because of a change of amenities or because of changes in non-market costs, such as a higher incidence of disease (Patz *et al.*, 1996). In either case, the effects of climatic factors likely most affect the rural poor in developing countries, exactly those who are least able to self-insure or to adopt alternative coping strategies.

Piguet *et al.* (2011) emphasize two main, interconnected, arguments concerning the climate change–migration nexus. Their first argument pertains to the fact that the identification of environmental factors as the sole cause of migration might never prove possible, because complex interactions exist between climatic change and other categories of deterministic factors: economic, social (and/or cultural), political, and demographic. Therefore, societies already vulnerable in some sense will likely be disproportionately challenged, with the rural poor arguably affected the most. Dell *et al.* (2012), for example, show that a rise in temperature of one degree in a given year translates into a reduction of annual economic growth of 1.1 percent points in poor countries (but has negligible effects in rich countries). They also show that the effects of higher temperatures have widespread effects, including reductions in agricultural productivity, industrial output, and investment. Furthermore, Dell *et al.* (2009) show that similar rises in temperature result in reductions in per capita GDP both across and within countries and within states. Their theoretical model predicts that approximately half of these reductions in income might be mitigated by adapting to the environment, through migration, changes in fertility rates, and mortality. Barrios *et al.* (2010) provide evidence that sub-Saharan Africa would have reduced the gap in per capita GDP (by between 15 and 40 percent) compared with the rest of the developing world, were no decline in rainfall to have occurred in this region after 1960. Because climatic variations affect individuals' incentives to migrate and also their ability to do so, it proves impossible to disentangle migrants' primary motivations to migrate, whether it be forced or voluntary (i.e., separating economic incentives from environmental push factors). At the macroeconomic level, the best we can do is to assess the relative direct impact of climatic factors on international migration, having accounted for other classes of determinants. Macroeconomic studies that examine climatic factors often suffer from selection biases, because unobservable country characteristics are difficult to control for (Lilleør and Van de Broeck, 2011), so the inclusion of all main classes of determinants, together with the implementation of a far more rigorous empirical specification, are undoubtedly the strengths of the current paper.

The second argument of Piguet *et al.* (2011) relates to the political framework in which any environmentally motivated migration flows might occur, and how destination countries should receive environmental migrants. While their detailed discussion of how such migrants might be received is not directly relevant for the current work, their argument nevertheless serves to highlight the key role of the migration policies of the destination country as a determinant of bilateral migration flows.

This paper is most closely related to the wider discourse on environmental change and the macroeconomic body of literature on the determinants of international migration, both areas that have been remarkably understudied. Climatic factors no doubt have heterogeneous impacts across countries (Black *et al.*, 2011) that are a function of the socioeconomic idiosyncrasies at origin, and, in turn, determine the vulnerability of individuals. As a result, many existing studies have reached alternative conclusions in a variety of differing contextual settings. Munshi (2003), for example, finds a statistically significant and positive correlation between emigration from rural Mexico to the US and low rainfall at origin. Similarly, Barrios *et al.* (2006) find that rain shortages increase the ratio of the urban over rural populations across sub-Saharan Africa, but not in other parts of the developing world. Marchiori *et al.* (2011) find that climate anomolies spur both internal and international migration in sub-Saharan Africa and, furthermore, that urbanization might mitigate the effects of climatic factors on international migration. More broadly, Afifi and Warner (2008) find that a number of variables that capture environmental degradation are positively correlated with increased numbers of international migrants. Conversely, Findley (1994), in the case of Mali, finds that episodes of drought lead to lower numbers of migrants because of the tightening of credit constraints, the result of rising food prices, especially to other African countries and to France. Finally, in the context of international migration from two Mexican regions, Kniveton *et al.* (2008) find (in the case of Durango) that greater amounts of rainfall lead to increased numbers of emigrants to the US.

The evidence concerning the effects on migration of natural disasters is also mixed. Piguet *et al.* (2011) highlight a range of microlevel studies, which conclude that such phenomena result in short-term internal migrations, as opposed to long-distance or international movements. Indeed, Paul (2005) finds evidence that the 2004 tornado in north-central Bangladesh resulted in no migration whatsoever. However, a growing body of macrolevel literature instead finds a positive relationship between natural disasters and international migration (e.g., Reuveny and Moore, 2009; Drabo and Mbaye, 2011). Naudé (2008) finds only very weak evidence of any link between natural disasters and migration, arguing instead that conflicts at origin exert a far greater influence. Halliday (2006) instead finds that earthquakes significantly reduce migration from El Salvador to the US. Doubts persist, however, as to the validity of the econometric approaches adopted in many of these macrolevel studies, most notably in their failure to account for unobserved heterogeneity that might be driving their results.

Environmental determinants have remained wholly absent from the macroeconomic literature on the determinants of migration. In two of the earliest contributions (of the latest wave of migration research), Hatton and Williamson (2001, 2002) focus, respectively, on the demographic and economic determinants of international emigration rates from Africa and, more broadly, from various countries across differing historical periods. The use of emigration rates at origin (and/or at the destination level) tends to mask the fact that the migration process is extremely heterogeneous across both sending and receiving regions. Rather, the implementation of data at the bilateral level allows us to account for the peculiarities between the two countries, such as distance, diasporas, and cultural proximity, which also play important roles.

Pedersen *et al.* (2008) investigate the extent to which selection and network effects foster bilateral migration flows for 27 countries of the OECD.[1] Network effects (i.e., the positive role played by social capital in driving observed migration flows) are found to be strong, but to vary significantly across country-pairs. To examine the role of selection effects, they test the "welfare magnet" hypothesis (e.g., Borjas, 1987); that is, migrants from poorer countries will be disproportionately attracted to countries with higher levels of social welfare provision. Because data are lacking, their approach is to interact the share of tax revenue collected at destination with the income levels of the origin country. They fail to find any conclusive evidence, which they argue might be a result of the restrictive migration policies of the destination country that they fail to account for explicitly.

This matter is taken up in more detail by Mayda (1996), who again investigates the OECD as the destination region. A variable is constructed that captures changes in the migration policy of the destination country. The results show that when the migration policies at the destination become less restrictive, positive pull factors are found to exert a larger influence on bilateral emigration rates (as when compared to the sample average). Unfortunately, the important role of migrant networks is largely omitted from the analysis,[2] which might explain some of the low coefficients of determination obtained.

[1] The focus on the countries of the OECD as destinations in the majority of studies is a consequence of the general paucity of global migration data.

[2] Migrant networks are examined in a single regression by including the lag of migration flows, when arguably a more superior specification would instead consist of immigrant stocks.

More recently, some authors have better emphasized the underlying theory. Based on the utility maximization approach (Roy, 1951; Borjas, 1987), Grogger and Hanson (2011) and Beine *et al.* (2011) investigate the determinants of the size and composition of migration patterns at the world level, again using OECD countries as destination countries. Grogger and Hanson (2011) analyze migrant stocks and focus, in particular, on the role of the wage differential between the origin and destination of migrants. They omit the role of migrant networks, although some historical diasporic component will likely be captured by their measures of colonial links. Beine *et al.* (2011) instead analyze migration flows in the 1990s and the extent to which diasporas have contributed to shaping these flows, while abstracting from explicitly modeling the role of wage differentials. Both of these studies use cross-sectional data, however, which necessarily restricts the scope of their analysis. Ortega and Peri (2009) again draw upon the utility maximization approach to investigate the causes (and consequences) of international migration to the OECD in a panel that includes explicit measures of migration policy. They utilize the panel dimensions to their fullest, because they employ both destination (time-invariant) and origin time-varying fixed effects to account for a multitude of unobserved factors, which might otherwise be driving any observed relationship. Unfortunately, environmental determinants are omitted from their study. Arguably the closest work to the current paper is that of Dallman and Millock (2013) who draw on the utility maximization approach to examine the impact of climate variability on inter-state migration in India.

The aim of this paper is to reconcile the various innovations from across the literature, and to test the overall impact of climate anomalies and natural disasters on international migration using a previously unexploited panel dataset of international migration. We augment a traditional neoclassical utility maximization model of migration to incorporate environmental factors in the context of amenities at origin. We consider the onset of sudden climatic phenomena, which are largely unexpected, in addition to long-term changes in both temperature and rainfall. Recognizing the multi-dimensionality of individuals' decisions to migrate, we incorporate variables to account for economic, demographic, social (and/or cultural), and political factors that existing studies have shown to be important determinants of international migration. We also account (in part) for the role of immigration policies and welfare systems in receiving countries. To the best of our knowledge, our paper is the first to investigate the impact of long-term climate anomalies and natural disasters on international migration using bilateral data, and the first to estimate the impact of natural disasters and changes in temperature and precipitation simultaneously. More generally, our paper is the first macroeconomic study that implements bilateral data to examine the determinants of international migration using a model grounded in microeconomic theory, whilst also accounting for economic, demographic, social, political, and environmental factors.

Importantly, our panel includes countries of the global "South" as both origins and destinations. The omission of nations of the relatively poorer global South would result in the most significant proportion of international migration being completed omitted from analysis. From a sending perspective, this is particularly important in the context of environmental factors, because agriculture remains more prevalent in poorer societies. It is also crucial to account for Southern countries from a receiving perspective, because migrants from developing countries often cannot afford to pay the migration costs involved in long-distance emigration to countries of the relatively more affluent global "North". Therefore, the expansive dataset of 166 destinations and 137 origins allows us to better capture the heterogeneous impacts of climatic factors across countries and over time. We exploit the longitudinal dimension of the migration data to control for unobserved heterogeneity of different types in order to provide long-run estimates of the effects of climatic factors around the globe. Having controlled for differences between countries, we then examine global patterns by conditioning our regressions on particular country characteristics, such as the availability of natural water sources or the relative importance of the agricultural sector at origin.

Using our primary specification, we find no direct evidence of long-run climatic factors on international migration in the medium to long run across our entire sample. These results are robust when further considering migrants returning home and the potential endogeneity of migrant networks. Further conditioning our regressions upon the characteristics of the origin country, we find evidence that shortfalls in precipitation constrain migration to developing countries from countries that rely more heavily upon agriculture, and spur movements to developing countries from countries with fewer groundwater reserves. However, we do provide some support that environmental factors indirectly affect international migration through wages. Conversely, we find that epidemics and miscellaneous incidents spur international migration. Furthermore, using the rate of urbanization as a proxy for internal migration, we find strong evidence that natural disasters beget greater flows of migrants to urban environs.

II. Theoretical Background: Utility Maximization Approach

Our theoretical foundation is derived from the utility maximization framework, which is used to identify the main determinants of international migration and to pin down our empirical specification. The utility maximization approach was first introduced by Roy (1951) and Borjas (1987), and further developed by Grogger and Hanson (2011) and Beine *et al.* (2011). The recent advances further consider migrants' choices of moving to potentially all destinations, and yield pseudo-gravity models that can be readily estimated. One of the main strengths of the utility maximization approach is the ability to generate predictions in line with the recent (macroeconomic) literature on international migration. By grounding our empirical specification in a theory with a well-proven track record, we also address one of the main shortcomings of the macrolevel literature that deals with climatic factors, which generally adopts looser, ad hoc, specifications. This model has been successfully applied to analyze the specific role of wage differentials (Grogger and Hanson, 2011), the significance of social networks (Beine *et al.*, 2011) and the brain drain phenomenon (Gibson and McKenzie, 2011).

Our model comprises homogeneous agents, who decide whether or not to migrate, and then their optimal destination should they decide to move. Agents therefore maximize their utility across the full set of destinations, which includes the home country as well as all possible foreign countries globally. Let $N_{i,t}$ be the size of the native population in country i at time t. At each period of time, the natives choose their optimal location among a set of n alternative destinations. These alternative destinations include their home country i. The number of natives choosing the optimal destination j is denoted by $N_{ij,t}$.[3] The choice of the optimal location by each native is based on the comparison of the utility associated with each possible destination. An individual's utility is log-linear in income and depends upon the characteristics of their country of residence as well as any migration costs. The utility of an individual born in country i and staying in country i at time t is given by

$$u_{ii,t} = \ln(w_{i,t}) + A_{i,t} + \varepsilon_{i,t}, \tag{1}$$

where $w_{i,t}$ refers to the instantaneous wage in country i at time t, $A_{i,t}$ denotes the characteristics of country i (i.e., amenities, public expenditures, employment opportunities) including climate at time t, and $\varepsilon_{i,t}$ is an independent and identically distributed (i.i.d.) extreme-value distributed random term. The utility related to migration from country i to country j at time t is given by

$$u_{ij,t} = \ln(w_{j,t}) + A_{j,t} - C_{ij,t}(\cdot) + \varepsilon_{j,t}, \tag{2}$$

where $C_{ij,t}(\cdot)$ denotes the migration costs of moving from i to j at time t.

[3] It should be clear that while $N_{i,t}$ is a stock, $N_{ij,t}$ is a flow. Furthermore $\sum_j N_{ij,t} = N_{i,t}$. In the Anderson (2011) set-up, $N_{ij,t}$ is the analogue to the export flow from i to j at time t, $N_{ii,t}$ is akin to the value of goods sold by domestic firms in their own country, and $N_{i,t}$ is comparable to the total stock of goods available at time t for export and domestic consumption.

When the random term follows an i.i.d. extreme-value distribution, we can apply the results in McFadden (1984) to write the probability that an agent born in country i will move to country j as

$$\Pr\left[u_{ij,t} = \max_k u_{ik,t}\right] = \frac{N_{ij,t}}{N_{i,t}} = \frac{\exp\left[\ln(w_{j,t}) + A_{j,t} - C_{ij,t}(\cdot)\right]}{\sum_k \exp\left[\ln(w_{k,t}) + A_{k,t} - C_{ik,t}\right]}.$$

The bilateral migration rate between i and j $(N_{ij,t}/N_{ii,t})$ can therefore be written as

$$\frac{N_{ij,t}}{N_{ii,t}} = \frac{\exp\left[\ln(w_{j,t}) + A_{j,t} - C_{ij,t}(\cdot)\right]}{\exp\left[\ln(w_{i,t}) + A_{i,t}\right]}, \tag{3}$$

where $N_{ij,t}$ is the number of migrants in the i–j migration corridor at time t. Taking logs, we obtain an expression giving the log of the bilateral migration rate between i and j at time t:

$$\ln\left(\frac{N_{ij,t}}{N_{ii,t}}\right) = \ln\left(\frac{w_{j,t}}{w_{i,t}}\right) + A_{j,t} - A_{i,t} - C_{ij,t}(\cdot). \tag{4}$$

Expression (4) therefore identifies the main components of the aggregate bilateral migration rate: the wage differential in the form of the wage ratio $(w_{j,t}/w_{i,t})$, the factors at destination $A_{j,t}$, the factors at origin $A_{i,t}$, and the migration costs between i and j, $C_{ij,t}$.[4]

Migration costs, $C_{ij,t}$, are in turn themselves a function of components of various dimensions, and we assume separability in these costs. They depend upon factors that are dyadic and change over time, such as networks, which are captured by the stock of migrants from i living in country j before the migration process takes place (denoted by $M_{ij,t}$). Migration costs are also contingent upon factors that are dyadic but time-invariant, such as distance d_{ij}, contiguity b_{ij} (i.e., if countries share a common border), and linguistic proximity l_{ij}. Migration costs also depend upon factors specific to the origin country but which are constant over time, x_i (e.g., geographic location). Finally, migration costs include factors that are destination-specific, either constant over time x_j, time-specific x_t, or time-varying $x_{j,t}$. Leading candidates for these latter factors include the migration policies of destination countries and the benevolence of the welfare state at destination.[5]

[4] Note that the categorization of deterministic factors by Black *et al.* (2011), which include push, pull, and intervening factors, is appropriately captured in expression (4).

[5] Anderson (2011) derives a structural gravity model of migration analogous to his (second) influential contribution on the use of gravity models in the context of international trade (see Anderson and van Wincoop, 2003). The key additional insight, in the context of goods, is that trade between pairs of countries depends not only upon the barriers between themselves, but also upon the various barriers (termed multilateral resistances) of both countries with the rest of the world. Should the multilateral resistance of both countries increase with the rest of the world therefore, both countries would have greater incentives to trade relatively more with

Putting everything together, our cost function can be expressed as

$$C_{ij,t} = c(M_{ij,t}, d_{ij}, b_{ij}, l_{ij}, x_i, x_j, x_t, x_{j,t}). \tag{5}$$

Non-pecuniary costs (and benefits) at origin are collected in $A_{i,t}$,[6] and these comprise political variables $Pol_{i,t}$, demographic differences across origin countries $Dep_{i,t}$, and environmental factors $E_{i,t}$. The expected theoretical sign of the political regime at origin is unknown, *a priori*. This is because, while repressive political regimes might increase residents' desire to leave, they typically also increase the costs of migration. It might be extremely difficult for residents living in a dictatorship to obtain authorization to leave the country, for example. Foreign diplomatic representation also tends to be less important in such countries, which, in turn, significantly raises the costs for emigration candidates of obtaining a visa. The total dependency ratio is used to capture demographic push factors at origin. This is calculated as the total population aged less than 15 or over 64, divided by those of working age. A higher total dependency ratio therefore indicates the presence of fewer workers to support both the young and the elderly, either directly or through the tax system. Conversely, a lower dependency ratio suggests, instead, that greater numbers of working age people exist at origin, who are in some sense more free to emigrate abroad. Other variables typically used to capture demographic push factors at origin include the lag (by 20 years) of the birth rate, which is purported to capture a cohort effect at origin, or the share of young people at origin, typically those aged 15–29, who typically exhibit the greatest propensity to migrate abroad (see Hatton and Williamson, 2001, 2002). Typically, we would expect a rise in either of these variables to ultimately beget further migration. Both of these mechanisms are captured through the total dependency ratio however, because either an increase in the lagged birth rate or

one another. The key insight of these arguments likely holds in the context of international migration (as detailed by Bertoli and Fernández-Huertas Moraga (2013). We opt to use the utility maximization approach because it has proven itself in numerous applications. However, it is important to note that our inclusion of destination time-varying fixed effects will completely account for any multilateral resistances in receiving countries (see Feenstra, 2004), which is arguably the most important aspect in the context of international migration given the migration policies of the destination country. Moreover, in the context of trade (Parsons, 2012), it has been shown in large panels that separate origin and time fixed effects provide similar results to the inclusion of origin–time fixed effects, which should allay fears of multilateral resistance from origin.

[6] Note that given the focus of our paper, we do not devote specific attention to factors at destination ($A_{j,t}$). The panel dimension of the data allows us to capture the role of these factors through the inclusion of dummies combining the j and t dimensions. See the following section for details. By construction, their imposition also captures macroeconomic trend effects over time, which are typically captured with separate time dummies.

greater numbers of those aged between 15–29 in the current period lead to reductions in the total dependency ratio.

As far as our environmental factors are concerned, we draw upon a similar taxonomy as Piguet *et al.* (2011), who distinguish between two main types of factors. First, we consider short-run factors (i.e., completely unexpected natural disasters, such as floods, earthquakes, and volcanic eruptions). Such events tend to drive people out of their regions within a short period of time and with a sense of urgency. Secondly, we capture what we can consider to be long-run climatic factors, which comprise long-run deviations or anomalies in both temperature and precipitation around their long-run averages.[7] In contrast to natural disasters, these environmental factors are (partly at least) expected by agents. The expression for non-pecuniary costs and benefits at origin can thus be written as

$$A_{i,t} = A(Pol_{i,t}, Dep_{i,t}, E_{i,t}). \tag{6}$$

III. Estimation

From Theory to Estimation

Combining equations (4), (5), and (6), whilst assuming separability in migration costs and including an error term, leads to the following econometric specification:

$$\ln\left(\frac{N_{ij,t}}{N_{ii,t}}\right) = \ln\left(\frac{w_{j,t}}{w_{i,t}}\right) + A_{j,t} - A(Pol_{i,t}) - A(Dep_{i,t}) - A(E_{i,t}) - C(M_{ij,t}) - C(d_{ij}) - C(b_{ij}) - C(l_{ij}) - c(x_{j,t}) - c(x_j) - c(x_i) + \epsilon_{ij,t}. \tag{7}$$

This specification models bilateral migration rates (i.e., the number of migrants from country i in country j as a ratio of natives from i who have chosen to stay at home).[8] Because our primary focus is upon environmental factors at origin, we use appropriate fixed effects and dummies to capture the impact of destination-specific factors and time-invariant origin factors. First, we use fixed effects $\alpha_{j,t}$ that are specific to each destination and each period. These capture the role of amenities at destination $A_{j,t}$ as well

[7] This taxonomy is akin to that favored by Lilleør and Van de Broeck (2011) when distinguishing “climate change” from “climate variation”. Note that we do not consider the effects of rising sea levels, which are predicted to result in large numbers of environmental migrants (see Black *et al.*, 2008).

[8] Note that this specification differs from that of Beine *et al.* (2011), who analyze migration flows N_{ij} using country fixed effects allowing them to control for N_{ii}. The ability to recover N_{ii} from our data allows us to work with a specification that is more closely related to the theoretical equilibrium bilateral migration rate.

as the role of destination-specific cost variables $c(x_{j,t})$ and $c(x_j)$, as well as time-specific $c(x_t)$ (such as the general decrease in transportation costs). Crucially, these variables also (in part) capture migration policies, which remain largely absent from much of the existing body of literature. The unavailability of data capturing migration policies has been a recurrent issue in the empirical macroeconomic literature devoted to international migration. The panel dimension of our data allows us to alleviate this problem and significantly lowers the risk of misspecification. Time-invariant origin-specific push factors A_i as well as time-invariant origin-related cost variables $c(x_i)$ are captured by origin-country dummies α_i.

Substituting in equation (7) leads to the following estimable equation:

$$\ln\left(\frac{N_{ij,t}}{N_{ii,t}}\right) = \beta_1 \ln\left(\frac{w_{j,t}}{w_{i,t}}\right) + \beta_2 \ln(1 + M_{ij,t}) + \beta_3 \ln(Pol_{i,t}) + \beta_4 \ln(Dep_{i,t}) + \beta_5 \ln(E_{i,t}) + \beta_6 d_{ij} + \beta_7 b_{ij} + \beta_8 l_{ij} + \alpha_{j,t} + \alpha_i + \epsilon_{ij,t}. \quad (8)$$

Given the focus on the impact of environmental factors, we adopt a parsimonious specification in terms of observable controls. With the exception of environmental factors therefore, for which we allow a detailed inspection, we choose a limited number of key indicators, which we believe capture the main fundamentals that drive the observed patterns of international migration. Importantly, those factors have a robust impact on bilateral migration with expected signs across the full sample and the many subsamples we consider throughout this paper. In particular, we include variables that capture the wage differential $w_{j,t}/w_{i,t}$, network $M_{ij,t}$, political determinants at origin $Pol_{i,t}$, demographic factors at origin $Dep_{i,t}$, physical distance d_{ij}, shared borders b_{ij}, and linguistic proximity l_{ij}.

Econometric Issues

The estimation of equation (8) is at first glance straightforward. Indeed, ordinary least-squares (OLS) estimation is feasible but is likely to yield inconsistent estimates of the coefficients. One of the main reasons for the inconsistency is the presence of a high proportion of zero values in the dependent variable $N_{ij,t}$ (i.e., the bilateral flows). The presence of these zeros generates two important biases in OLS estimation. First, because equation (8) is a pseudo-gravity model in a double log form, the presence of zeros leads to the exclusion of many observations. If the country pairs with zero flows have a different population distribution compared to pairs with positive flows, this exclusion generates the usual selection bias. The use of a non-linear estimator, such as the Poisson pseudo-maximum likelihood (PPML) estimator, allows us to include the zero values for the dependent variable, and rules out any selection bias of this kind. The second bias is more subtle and has been clearly identified by Santos-Silva and Tenreyro (2006). They show, in particular, that if the variance of $\epsilon_{ij,t}$ depends on the covariates of $N_{ij,t}/N_{ii,t}$, then its expected value will also depend on some of the regressors in the presence of zeros. This, in turn, invalidates one important assumption of consistency of OLS estimates. Furthermore, they show that the inconsistency of parameter estimates is also found using alternative techniques such as the (threshold) Tobit model. In contrast, in the case of heteroskedasticity and a significant proportion of zero values, the PPML estimator generates unbiased estimators of the parameters of equation (8). As a result, we use the PPML estimator to estimate model (8). This model generates consistent estimates even when the underlying distribution is not strictly Poisson, (i.e., in cases of overdispersion).[9] We calculate robust standard errors to ensure appropriate t-statistics results.

IV. Data

Migration Data

The resurgence in migration research has arisen, in large part, as a result of the proliferation of available datasets on bilateral migration. This paper draws upon Özden *et al.* (2011), which details bilateral migration stocks between 226 origin and destination countries, territories, and dependences, corresponding to the last five completed census rounds, 1960–2000. Drawing upon the largest depository of censuses and population registers ever collated, Özden *et al.* pay particularly close attention to the underlying problems encountered when making migration statistics comparable. These include the alternative definitions of migration, how countries variously code their census data (together with how aggregated origin regions recorded in censuses might be disaggregated), the varying years in which censuses are conducted, the changing of borders of nation states over time, and cases where census data are missing altogether.

The resulting database therefore addresses the prior lack of migration data for developing countries as destinations, whilst also greatly expanding the number of time periods to which the data pertain. This proves important, not only because South–South migration dominates global migration

[9] Furthermore, in an extended analysis of their first paper, using Monte Carlo simulations, Santos-Silva and Tenreyro (2011) show that the PPML estimator performs well even in the presence of a large number of zero observations.

in levels, but also because climatic factors disproportionately affect those in developing nations. Moreover, because liquidity constraints are more likely binding in relatively poorer nations, any international migratory response to climatic factors is more likely to be regional – most likely to neighboring countries – as opposed to the countries of the OECD, the only countries for which, until very recently, longitudinal data were available (e.g., Docquier and Marfouk, 2006). The panel dimensions of the data prove particularly important in the context of an empirical examination at the global level, because they allow us to control for a plethora of time-varying and time-invariant factors, across a broad spectrum of countries for which data are unavailable. In other words, we can meaningfully control for myriad unobserved factors that might otherwise confound results. To ensure consistency across countries over time, we implement the version of the data that is merged to the aggregates of the UN (see Özden *et al.*, 2011).

However, several issues remain with regards to the way the data are implemented in our empirical model. First, although the underlying data relate to migrant stocks, we proxy migration flows by differencing these data for contiguous census rounds. Inevitably, negative migration flows result when bilateral migrant stocks decline over time. This might be a result of migrants returning home, moving on to a third-party country, or death. Therefore, in constructing this proxy, we assume that both deaths and return migration are small relative to net flows. The relevance of this assumption is difficult, if not impossible, to test for in the absence of appropriate data. For the sake of robustness however, we recalculate our migration flows, assuming that all negative flows constitute return migration. In other words, we sum our initial positive flows between countries i and j and the absolute value of the negative flow from j to i.

Panel A of Table 1 reports some descriptive statistics of the variables capturing international migration. We provide statistics that shed light on the distribution of the diaspora variable and the two definitions of migration flows. We also provide statistics of the distribution involving only positive values because migration stocks and flows comprise many zero values at the dyadic level. To further highlight the significance of this issue, Table 2 shows the proportions of zero values for bilateral stocks for each decade from the underlying migration database. Although the proportion of zeroes declines over time, around half of the observations in the proposed dependent variable are still zero in each decade. In the absence of an appropriate estimator, the presence of these zero observations would clearly result in a selection bias.

A final issue is to recover $N_{ii,t}$ from the data in order to compute bilateral migration rates. $N_{ii,t}$ comprises the number of natives from i having chosen to stay at home. This is recovered from the population data by subtracting

Table 1. *Descriptive statistics: migration and environmental variables*

	All values						Positive values only			
	Obs	Mean	Std	Med	Min	Max	Obs	Mean	Std	Med
Panel A: Migration										
Diaspora	236,530	2,394	55,093	0	0	922,9417	106,665	5,307	81,947	15
Migration flows	189,224	793	25,924	0	0	4,655,050	55,967	2,680	47,615	11
Adjusted flows	189,224	1,119	30,567	0	0	5,077,778	67,326	3,145	51,183	15
Panel B: Environmental variables										
Natural disasters										
Disasters	181,412	7.74	18.05	3	0	250	131,502	10.68	20.45	5
Temperature										
Anomalies	182,280	0.561	0.450	0.427	0.004	2.061				
Deficit temp.	70,525	0.149	0.111	0.132	0.002	0.548				
Excess temp.	111,755	0.306	0.253	0.241	0.004	1.237				
Rainfall										
Anomalies	181,412	0.348	0.262	0.294	0.0002	1.419				
Excess rain	81,592	4.484	5.063	2.952	0.022	39.31				
Shortage rain	99,820	5.800	6.581	3.402	0.0027	37.79				

Notes: All countries are included as origins and destinations. Sample: 1960–2000. Deficit temperatures and rainfall shortages are expressed in absolute terms. Migration flows refer to the original data, with negative values set to 0. Adjusted flows refer to the original migration flows augmented by the opposite of negative flows in the reverse direction. See the main text for more details about variables.

Table 2. *Proportion of zero values in the underlying migration data*

Decade	Percent
1960	62
1970	59
1980	56
1990	51
2000	47

Source: Özden *et al.* (2011).

the total number of immigrants in country i, which in turn is calculated from the migration data as $\sum_{j=1}^{J} N_{ji,t}$.[10]

Climatic Factors

Our model examines the impacts of both short- and long-run climatic factors on medium- to long-run changes in international migration. According to Piguet *et al.* (2011), the weight of existing evidence suggests that rapid onset phenomena result in short-term internal displacements as opposed to migrations further afield for longer durations. Whereas there is a tendency to associate international migration with migration over long distances, this might not necessarily be the case. In regions with porous borders, such as Africa, the costs of crossing an international border might well be lower than an internal migration over longer distances. On average, however, because of the increased costs of obtaining passports and visas, we can assume that this conjecture generally holds. Moreover, Piguet *et al.* (2011) argue that many of those affected by such events return home quickly to begin rebuilding their lives. They conjecture that slower onset phenomena (i.e., gradual and sustained changes in the environment over time) will likely result in longer-term migration, from which we might also infer migration over greater distances. As previously argued however, the macrolevel literature paints a very different picture. For example, Naudé (2008) argues that the correlation between natural disasters and migration will be even stronger than the links between migration and long-term environmental change because such unforseen events give little time for people to adapt.

Our short-term environmental factors are captured through a natural disasters variable, which comprises droughts, earthquakes, extreme temperatures, floods, storms, volcanic eruptions, epidemics, insect infestations, and

[10] Importantly, only a complete bilateral migration matrix facilitates our being able to do this. This explains why Beine *et al.* (2011), who rely on the database of Docquier and Marfouk (2006), are not able to compute $N_{ii,t}$.

miscellaneous occurrences (i.e., technological accidents of a non-industrial or transport nature).[11] These data are obtained from the International Disaster Database, which is compiled by the Centre for Research on the Epidemiology of Disasters.[12] This variable is simply calculated as the total number of natural disasters in a given decade. The mean number of natural disasters in a given decade in our sample is about eight and the standard deviation is 18. The minimum value of this variable is 0 while the maximum is 250. Panel B of Table 1 provides the descriptive statistics of our natural disasters variable. We also provide some statistics for the truncated distribution involving only positive values.

To capture long-run environmental factors, we use precipitation and temperature data obtained from the TS3.0 dataset, created under the auspices of the QUEST-GSI project and obtained from the Climatic Research Unit of the University of East Anglia. The original observations correspond to high-resolution $0.5^\circ \times 0.5^\circ$ grids, and are collected on a monthly basis. Area weights are used to aggregate the data to the country level. Annual observations are then calculated as the average of monthly observations, and decennial observations as the means across years.

While the impact of these variables has been found to vary across localities, uncertainty also remains with regards to the most appropriate way of formulating these variables for use in our empirical model. Measuring precipitation and temperature in absolute levels might not be appropriate because this formulation fails to adequately capture migratory responses to changes from standard climatic conditions. Rather, these would capture whether migration is more prevalent from rainier or warmer countries. This is unlikely to prove useful because tropical countries, for example, are more likely to be poorer on average. Any significant results would instead likely capture part of the effect of GDP per capita at origin, which in turn would be highly correlated with our measure of wage differentials.

Instead, we calculate two separate measures, termed deviations and – drawing upon the wide body of climate literature (e.g., Nicholson, 1986) and following Marchiori *et al.* (2011) – anomalies. Deviations (in both temperature and precipitation) are calculated as the differences of countries' decadal averages from their long-run averages. Across our sample, the average deviation in rainfall from the corresponding decadal average is -1.43 mm, its standard deviation is 6.65 mm and its minimum and maximum values are -33.3 and 39.3 mm, respectively. The average deviation

[11] The pairwise correlations between any of our measures of precipitation and temperature and natural disasters used throughout the paper are extremely low, at a maximum of 0.1579, which should allay any fears of multicollinearity in our measures of climatic factors. As such, our results are robust to our excluding droughts, extreme temperatures, and floods from our natural disaster variable.

[12] See http://www.emdat.be.

in temperature from its corresponding decadal average is $+0.15^\circ$ Celsius, its standard deviation is 0.29°C and its minimum and maximum values are -0.54°C and $+1.24^\circ$C, respectively. Collectively, these figures demonstrate the impact of climatic factors in terms of the planet becoming warmer and receiving less precipitation, on average, across our sample. Following Marchiori *et al.* (2011), we take the long run to refer to the period 1901–2000, and anomalies are calculated as the deviations of countries' decadal averages (in temperature and precipitation) from their long-run average, divided by the corresponding long-run standard deviation, formally defined as

$$Clim_{i,t} = \frac{Clim_{\text{level},it} - \mu_i^{\text{LR}}(Clim_{\text{level}})}{\sigma_i^{\text{LR}}(Clim_{\text{level}})}. \tag{9}$$

Here, $Clim_{\text{level},it}$ denotes the level of rainfall or temperature of country i in decade t, $\mu_i^{\text{LR}}(Clim_{\text{level}})$ denotes the long-run mean average rainfall or temperature of country i, and similarly $\sigma_i^{\text{LR}}(Clim_{\text{level}})$ denotes the long-run standard deviation of rainfall or temperature of country i. Marchiori *et al.* (2011) argue that the use of anomalies eliminates scale effects as well as correcting for the fact that climatic variations in more arid regions are typically greater when compared to the mean. Moreover, because the long-term mean can be assumed to capture typical weather conditions in a particular country, "anomalies thus describe how far the weather conditions depart from this normal in a given year [...] capturing deviations in the weather from the norm" (Marchiori *et al.*, 2011, p. 18).

Panel B of Table 1 provides the descriptive statistics of anomalies and deviations for the temperature and rainfall.Furthermore, we take the absolute value of the numerator of equation (9), and use positive and negative anomalies separately, in order to further test whether positive or negative deviations and anomalies influence international migration in differing ways.

Remaining Covariates

The remaining covariates derive from a variety of sources. The wage differential is proxied as the log of the ratio of per capita GDP in destination and origin countries. These data are taken from an updated version of (what is described in detail in) Gleditsch (2002), which represents an extension of the Penn World tables (Summers and Heston, 1991). Our migrant network, or diaspora variable, is again taken from Özden *et al.* (2011), and is defined as the bilateral migrant stock in the beginning year to which a flow corresponds. Measures of geodesic distance, contiguity, and linguistic proximity are taken from Head *et al.* (2010).[13] The language dummy takes the value one if at least 9 percent of both populations in a country-pair speak the same language.

Demographic conditions in sending countries are captured using the total dependency ratio at origin; these data are taken from the World Population Prospects database (United Nations, 2010). Because migration policies are included in the model through destination country time-varying fixed effects, our last variable captures political push factors from origin. This is calculated as the sum of the number of episodes of international violence at origin over the ten-year period to which a particular flow corresponds, with the exception of the last year. For example, the number of episodes for 1990–1999 are summed and then equated with the flow from 1990–2000. These data are obtained from the Major Episodes of Political Violence database of the Center for Systemic Peace.[14] Once all of the data are merged, 137 origin and 166 destination countries remain, a full list of which can be found in the Appendix.[15]

V. Results

What the Model Does (and Doesn't Do)

High-frequency migration data are only published by a limited number of countries globally. Therefore, adopting a truly international perspective necessarily involves a trade-off between geographic coverage and the frequency of observations, which in our case are observed decennially. It is important to understand the consequences of this sacrifice. It is not likely that we will capture seasonal or temporary migrations. Instead, our results will yield the average effects of climate change, both over time and across countries. These will also be the overall impact; so, if a particular variable has a heterogeneous impact across different countries, only the average impact will be detected. Nor does our model say anything as to the composition of migration flows (i.e., migrants' status), because we assume agents are homogeneous. The underlying migration database captures migrants of all ages and education levels as well as both genders, but focuses upon an economic concept of migration.[16] Finally, estimations based on equation (8) only capture the direct effect of environmental factors on

[13] These can be downloaded from http://www.cepii.fr/anglaisgraph/bdd/gravity.htm.

[14] See http://www.systemicpeace.org/inscrdata.html.

[15] The resulting number of countries is due to a combination of missing data for our GDP per capita, dependency ratio, and international violence variables.

[16] It is important to mention that our migration data exclude refugees and, in general, illegal migrants (undocumented migrants are nevertheless captured to varying degrees in national censuses, such as the US census). The implication of this in terms of the assessed impact

international emigration. To the extent that climatic factors decrease the income in origin countries, climatic factors might lead to a higher wage differential over time, which in turn is found to lead to more emigration. Therefore, the absence of a direct effect does not rule out the existence of some significant indirect effect going through economic incentives. This conjecture is explored later in this section, in the subsection *Indirect Effects of Environmental Factors*.

Baseline Results

Table 3 shows the results of estimating equation (8). We consider two measures of long-run climatic factors: deviations and anomalies. We further separate positive deviations and anomalies from negative deviations and anomalies, because if they are not separated and are instead combined into a single variable, then the positive and negative deviations and anomalies might cancel one another out.

In all regressions, both types of fixed effects are included (i.e., origin-country fixed effects α_i and time-destination fixed effects $\alpha_{j,t}$). In each regression, short-run climatic factors are captured by the number of natural disasters during the decade in the origin country. Columns 1 and 2 report the results with anomalies, and Columns 3 and 4 report the results with deviations. Columns 1 and 3 present results relating to positive temperatures and negative rainfall, and Columns 2 and 4 present the results for negative temperatures and positive rainfall.[17]

The coefficients are elasticities or semi-elasticities such that a 10 percent change corresponds to an equivalent percentage change of the dependent variable equal to the size of the coefficient. For example, a 10 percent rise in the wage ratio between origin and destination is associated with a positive increase in decennial bilateral migration rates of slightly more than 3 percent. For the dummy variable such as common language, the corresponding coefficient can again be interpreted as a percentage change, only this time for switching the dummy from zero to one.

of climatic events on international emigration is nevertheless unclear. On the one hand, refugees and undocumented migrants are likely to respond quickly to these shocks in terms of their mobility. On the other hand, because they are likely to be both poor and uneducated, they are also more subject to high implicit migration costs. This would favor the option of internal migration. The response of refugees and undocumented migrants to climatic shocks is beyond the scope of this paper but deserves future investigation.

[17] It is important to note that our results do not change when we estimate our measures of natural disasters and temperature and precipitation separately. It is worth emphasizing once again that the lower number of observations (i.e., 62,234, instead of the 113,710 theoretical data points ($137 \times 166 \times 5$)) is induced exclusively by missing data for the covariates and not by the zero values for the bilateral migration flows. These zero values are included in the PPML estimation.

Table 3. *Impact of climate on migration: unconditional results*

Variables	(1)	(2)	(3)	(4)
Constant	−4.130***	−4.102***	−4.167***	−4.151***
	(1.234)	(1.223)	(1.226)	(1.288)
Wage ratio	0.319**	0.326**	0.325**	0.338**
	(0.150)	(0.153)	(0.152)	(0.148)
Distance	−0.766***	−0.764***	−0.767***	−0.765***
	(0.090)	(0.089)	(0.091)	(0.091)
Network	0.398***	0.399***	0.398***	0.399***
	(0.044)	(0.043)	(0.045)	(0.046)
Common language	0.460***	0.459***	0.461***	0.458***
	(0.136)	(0.136)	(0.136)	(0.138)
Contiguity	0.409**	0.409**	0.409**	0.409**
	(0.166)	(0.168)	(0.168)	(0.171)
Dependency	−0.013**	−0.013**	−0.013**	−0.013**
	(0.005)	(0.005)	(0.005)	(0.005)
International violence	0.379***	0.374***	0.381***	0.372***
	(0.092)	(0.092)	(0.091)	(0.091)
Natural disasters	0.062	0.072	0.059	0.057
	(0.084)	(0.089)	(0.089)	(0.085)
Rain deviation/anomaly	−0.003	0.025	0.007	0.037
	(0.058)	(0.039)	(0.042)	(0.055)
Temperature deviation/anomaly	0.040	0.018	0.049	−0.004
	(0.0453)	(0.055)	(0.037)	(0.040)
Origin-country dummies (α_i)	Yes	Yes	Yes	Yes
Destination–year dummies (α_{jt})	Yes	Yes	Yes	Yes
No. of observations	62,234	62,234	62,234	62,234
R^2	0.626	0.628	0.626	0.625

Notes: The dependent variable is the decadal bilateral migration rates. The estimation period is 1960–2000. Columns 1 and 2 give the anomalies, and Columns 3 and 4 give the absolute deviations. Columns 1 and 3 show excess temperatures and rainfall shortages, and Columns 2 and 4 show temperature shortages and excess rainfall. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively. Robust standard errors are provided in parentheses.

Overall, the regressions explain more than 60 percent of the variation in the observed migration flows, which is deemed reasonable given that the migration rates are extremely heterogeneous across corridors. Given the breadth of our sample and the fact that our independent variable is proxied by the difference in migrant stocks, the R^2 values are deemed reasonable. The coefficients of all of the explanatory variables – with the exception of those that capture long-run environmental change – are highly significant and in the expected direction. The coefficients are also very stable across the various models. Higher wage differentials, a larger diaspora, a lower dependency ratio at origin, shared linguistic roots, contiguity, and more frequent episodes of international violence all beget higher migration flows. Conversely, the larger the distance between origin and destination (i.e., the greater the migration costs), the lower, on average, are the associated migration flows.

To give a flavor of what the estimated elasticities of the other covariates imply, starting with the wage ratio, the value of the third quartile of the distribution of the wage ratio is about 3. This means that between countries characterized by such a difference, an increase by 0.3 in the wage ratio will lead to an increase of 3 percent in the migration rates between the two countries. Similarly, an increase of 10 percent in the diaspora abroad will lead to an increase of about 4 percent in the rate of new migrants over the next ten years. The obtained elasticity of the network effect is slightly lower than the one estimated by Beine *et al.* (2011), which is about 0.65. Nevertheless, Beine *et al.* (2011) only include OECD countries as destinations, giving important weight to South–North migration. It is expected that migrants involved in this type of migration rely heavily upon networks. Interestingly, our subsequent subsample analysis focusing on migration to the global South (see Table 8) yields elasticities that are much closer to those obtained by Beine *et al.* (2011). Common language is also found to be an important determinant. Compared to pairs of countries with similar conditions, countries sharing a common language experience migration rates that are 50 percent higher. The presence of international violence at origin is a strong push factor, as reflected by the estimated elasticity. Nevertheless, it should be emphasized that this concerns only a small set of countries, because more than 90 percent did not have any episode of this kind over the last 40 years under investigation.[18] Finally, the negative effect of the dependency ratio is in line with the fact that a younger population has a higher propensity to migrate, all else being equal.

Turning now to the environmental variables, the unconditional results yield no statistically significant results whatsoever, concerning either long-run or short-run factors. These regressions capture the average impact of the explanatory factors on migration rates over time and across countries. On the face of it, in line with some previous microeconomic findings such as Munshi (2003), we might expect that both rain shortfalls (and high temperatures) provide an additional motivation for residents to become migrants. The insignificance of the response to environmental factors gives rise to various alternative explanations.

First, as previously stated, the environmental variables only capture the direct impact of climatic factors on international migration. To the extent that climatic factors decrease the income in origin countries, climatic factors might lead to a higher wage differential over time, which in turn engenders additional emigration. The fact that we find a significant and

[18] Given our use of a non-linear estimator, we deem it important to estimate a parsimonious model. A measure of civil war at origin constitutes one omission in this regard. Our results (which can be obtained from the authors on request) are robust to the inclusion of a measure of civil war at origin, but this variable was omitted because it is more collinear with our measure of the wage differential in comparison with our measure of international violence.

stable elasticity of emigration with respect to wage differential opens up the possibility of some indirect effect of climatic factors going through the wage differential. This conjecture is explored later in this section, in the subsection *Indirect Effects of Environmental Factors*.

Secondly, the results here only concern international migration. As argued by Black *et al.* (2011), these are exactly the same factors that might in turn result in lower incomes from which people have to pay to migrate. This is especially the case in poor countries. In other words, although residents might choose to become international migrants, they might not have the resources to actually move. If liquidity constraints are binding, then internal migration to less affected areas within the same country is a valuable option. This case is not captured by our data, although we investigate this possibility in an extension. However, this interpretation in turn calls for some additional inspection to allow for some heterogeneous response across origin countries to climatic events. Generally speaking, one possible interpretation of the results is that our estimation mixes up cases that are very different from one another. If there is some impact of climatic factors, this will depend on one or several factor(s) shaping the sensitivity of people to the climatic events. Regressions that are not conditioned upon various country characteristics would therefore be unable to uncover the heterogeneity in the response.

A third line of reasoning concerns the frequency of our observations, which are decennial. The literature suggests that unexpected climatic shocks likely result in more temporary migrations as opposed to long-term climate change or variability, which instead result in more permanent migrations. It is quite possible therefore that migrants are directly affected by climatic change and variability as captured by our variables, but are not picked up in estimation because they return home. Without more detailed microeconomic or bilateral migration flow data, this hypothesis is impossible to test.

Heterogeneous Effects

The heterogeneity in the responses of individuals can be related to several dimensions. First, the impact of climatic factors might depend upon initial climatic conditions. Some rise in average temperature might be particularly detrimental in already hot areas. Likewise, shortages in average rainfall will particularly affect those countries with poorer access to natural water sources. Therefore, we use two conditioning climate variables. The first relates to temperature. We consider hot countries as those over the median of the world temperatures (about 22.7°C). The second instead relates to the presence of groundwater. Again, we use the same classification. Countries are classified as having fewer groundwater reserves if they fall below the median of the world groundwater distribution.

Another way to view heterogeneity is to distinguish the geographical locations of countries. Climatic factors likely do not affect countries equally, and countries closer to the equator are often reported to be disproportionately affected. They also tend to be poorer compared to countries from the northern hemisphere. Distance to the equator has been used as an instrument for factors such as institutions in empirical studies of growth. Accordingly, we interact the long-run climatic factors with a dummy that takes the value of 1 if a country lies below (or above) the median latitude, in order to test whether the impact of temperature and rain anomalies depends upon being located close to the equator. A final conditioning scheme is the economic structure of the origin country. One might expect that the share of the agricultural sector in the economy will affect the sensitivity of the country to climatic events. Farmers and others living in rural areas are often mentioned as those mostly affected by climate change. As such, we use interaction terms between climatic factors and a dummy variable that takes the value of 1 if the share of agriculture in total GDP is greater than the median.

The results are reported in Tables 4 and 5. Table 4 gives the results using anomalies involving excess temperature and rainfall shortage. Table 4 reports the findings using anomalies involving rain excess and colder temperatures. In each table, Column 1 gives the results conditioned by temperature, Column 2 reports findings conditional on a country's agriculture share, Column 3 reports the results conditioned on the presence of groundwater, and Column 4 reports the results with latitude as the conditioning variable.

The results in Tables 4 and 5 do not support any significant direct impact of either short-run or long-run climatic factors on out-migration. Whatever the conditioning scheme, positive or negative rain or temperature anomalies do not seem to lead to more migration. Beyond the comments provided above, one possible interpretation of these results is that climatic impacts are far more complex than can be captured by a single dimension. In fact, it might be possible that excess temperatures or rain shortfalls will lead to more emigration but only in a particular context, for example, in middle income countries (so that migration candidates can overcome migration costs) in circumstances in which the agriculture share is significant. Such circumstances are difficult to capture using observed variables corresponding to all these dimensions. As an alternative, a further conditioning strategy is introduced in the following section.

So, too, might we consider heterogeneity in the type of natural disaster because our aggregate measure of natural disasters might, in fact, mask the individual effects of one of more natural disasters. The results from estimating the effects of each class of natural disaster separately are provided in Table 6. Interestingly, we find that epidemics and miscellaneous

Table 4. *Conditional impact of climate on migration: excess temperature and rain shortage*

Variables Conditioning	(1) Temp.	(2) Agricult.	(3) Water	(4) Latitude
Constant	−4.175***	−4.080***	−4.137***	−4.121***
	(1.213)	(1.255)	(1.233)	(1.229)
Wage ratio	0.320**	0.340**	0.298**	0.314**
	(0.150)	(0.154)	(0.152)	(0.150)
Distance	−0.766***	−0.765***	−0.768***	−0.766***
	(0.088)	(0.089)	(0.089)	(0.089)
Network	0.400***	0.399***	0.398***	0.398***
	(0.043)	(0.043)	(0.044)	(0.044)
Common language	0.456***	0.456***	0.460***	0.459***
	(0.132)	(0.133)	(0.135)	(0.135)
Contiguity	0.400**	0.409**	0.406**	0.408**
	(0.163)	(0.164)	(0.165)	(0.165)
Dependency	−0.013**	−0.014**	−0.013**	−0.013**
	(0.005)	(0.005)	(0.005)	(0.005)
International violence	0.405***	0.394***	0.387***	0.382***
	(0.092)	(0.092)	(0.092)	(0.092)
Natural disasters	0.061	0.047	0.062	0.068
	(0.084)	(0.087)	(0.084)	(0.084)
Rain anomaly	−0.069	−0.026	−0.027	−0.014
	(0.082)	(0.087)	(0.069)	(0.061)
Temperature anomaly	0.089	−0.005	0.053	0.041
	(0.061)	(0.058)	(0.057)	(0.047)
Rain∗condition	0.145	0.061	−0.026	0.172
	(0.098)	(0.106)	(0.090)	(0.112)
Temperature∗condition	−0.106	0.114	−0.026	−0.005
	(0.094)	(0.093)	(0.090)	(0.125)
Origin-country dummies (α_i)	Yes	Yes	Yes	Yes
Destination–year dummies (α_{jt})	Yes	Yes	Yes	Yes
No. of observations	62,234	62,234	62,234	62,234
R^2	0.630	0.629	0.625	0.626

Notes: The dependent variable is the decadal bilateral migration rates. The estimation period is 1960–2000. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.Robust standard errors are provided in parentheses.

events spur international migration, although we uncover no evidence that any other type of natural disaster results in additional migration internationally. Importantly, both epidemics and miscellaneous incidents are quite frequent in the data.[19] However, many of the other types of natural disasters are geographically specific (e.g., volcanic eruptions and earthquakes), meaning that many countries never experience such events. For the sake of parsimony, we choose to maintain our aggregate measure of natural disasters throughout the rest of the paper. In the final section of the paper, we

[19] Over the period, 61 destination countries never experienced an epidemic, while the equivalent number for miscellaneous incidents is 71.

Table 5. *Conditional impact of climate on migration: temperature shortage and rain excess*

Variables Conditioning	(1) Temp.	(2) Agricult.	(3) Water	(4) Latitude
Constant	−4.117***	−4.239***	−3.940***	−4.073***
	(1.201)	(1.192)	(1.214)	(1.227)
Wage ratio	0.352**	0.324**	0.357**	0.328**
	(0.156)	(0.155)	(0.155)	(0.154)
Distance	−0.764***	−0.765***	−0.763***	−0.764***
	(0.087)	(0.088)	(0.085)	(0.088)
Network	0.400***	0.399***	0.400***	0.399***
	(0.042)	(0.043)	(0.041)	(0.043)
Common language	0.453***	0.461***	0.456***	0.458***
	(0.133)	(0.135)	(0.132)	(0.136)
Contiguity	0.410**	0.405**	0.414**	0.409**
	(0.166)	(0.167)	(0.165)	(0.167)
Dependency	−0.013**	−0.012**	−0.015***	−0.013**
	(0.005)	(0.006)	(0.005)	(0.005)
International violence	0.382***	0.395***	0.328***	0.374***
	(0.092)	(0.094)	(0.098)	(0.092)
Natural disasters	0.054	0.065	0.078	0.072
	(0.096)	(0.091)	(0.088)	(0.089)
Rain anomaly	0.064	−0.006	0.010	0.029
	(0.052)	(0.048)	(0.039)	(0.040)
Temperature anomaly	0.034	0.057	0.056	0.019
	(0.076)	(0.079)	(0.067)	(0.057)
Rain∗condition	−0.099	0.064	0.085	−0.093
	(0.080)	(0.072)	(0.110)	(0.125)
Temperature∗condition	−0.048	−0.084	−0.200∗	−0.025
	(0.086)	(0.088)	(0.112)	(0.088)
Origin-country dummies (α_i)	Yes	Yes	Yes	Yes
Destination–year dummies (α_{jt})	Yes	Yes	Yes	Yes
No. of observations	62,234	62,234	62,234	62,234
R^2	0.630	0.629	0.636	0.628

Notes: The dependent variable is the decadal bilateral migration rates. The estimation period is 1960–2000. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively. Robust standard errors are provided in parentheses.

provide evidence of an additional channel through which individuals might react to the occurrence of natural disasters, through increased movements to urban environs.

Subsamples, Migrations to the Global North and South

In this section, we continue with our conditioning scheme from the preceding section, and continue by further splitting our sample, that is, restricting the regressions to include destinations from the countries of the global

Table 6. *Heterogeneous impact of natural disasters*

Variables	(1)	(2)	(3)	(4)
Constant	−3.989***	−3.937***	−4.031***	−4.010
	(1.226)	(1.223)	(1.230)	(1.273)
Wage ratio	0.376**	0.378**	0.378**	0.388**
	(0.150)	(0.152)	(0.153)	(0.149)
Distance	−0.722***	−0.768***	−0.772***	−0.769***
	(0.089)	(0.087)	(0.089)	(0.089)
Network	0.398***	0.399***	0.398***	0.399***
	(0.043)	(0.042)	(0.043)	(0.043)
Common language	0.448***	0.447***	0.449***	0.446***
	(0.133)	(0.131)	(0.133)	(0.134)
Contiguity	0.412**	0.411**	0.411**	0.411**
	(0.165)	(0.164)	(0.166)	(0.168)
Dependency	−0.013**	−0.014***	−0.013**	−0.014***
	(0.005)	(0.005)	(0.005)	(0.005)
International violence	0.373***	0.371***	0.375***	0.368***
	(0.090)	(0.089)	(0.090)	(0.089)
Drought	−0.003	−0.006	−0.008	0.007
	(0.080)	(0.079)	(0.078)	(0.079)
Earthquake	−0.023	−0.026	−0.025	−0.027
	(0.122)	(0.121)	(0.121)	(0.122)
Flood	−0.004	−0.001	−0.002	−0.001
	(0.088)	(0.090)	(0.090)	(0.087)
Storm	−0.119	−0.098	−0.118	−0.118
	(0.135)	(0.142)	(0.145)	(0.139)
Volcanic eruption	0.036	0.046	0.046	0.018
	(0.143)	(0.142)	(0.141)	(0.142)
Epidemic	0.176**	0.199**	0.179**	0.182**
	(0.087)	(0.088)	(0.085)	(0.086)
Insect infection	−0.253	−0.260	−0.251	−0.261
	(0.203)	(0.196)	(0.201)	(0.197)
Misc. incident	0.174*	0.181*	0.176*	0.165*
	(0.101)	(0.100)	(0.099)	(0.099)
Extreme temp.	−0.087	−0.125	−0.093	−0.103
	(0.179)	(0.182)	(0.185)	(0.179)
Rain deviation/anomaly	0.005	0.026	0.013	0.043
	(0.057)	(0.037)	(0.043)	(0.050)
Temperature deviation/anomaly	0.043	0.033	0.053	0.005
	(0.045)	(0.056)	(0.037)	(0.041)
Origin-country dummies (α_i)	Yes	Yes	Yes	Yes
Destination–year dummies (α_{jt})	Yes	Yes	Yes	Yes
No. of observations	62,234	62,234	62,234	62,234
R^2	0.633	0.637	0.634	0.634

Notes: The dependent variable is the decadal bilateral migration rates. The estimation period is 1960–2000. Robust standard errors are provided in parentheses. Columns 1 and 2 show the anomalies, and Columns 3 and 4 show the absolute deviations. Columns 1 and 3 are for excess temperatures and rainfall shortages, and Columns 2 and 4 are for temperature shortages and excess rainfall. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively.

Table 7. *Conditional impact of climate on migration, to the countries of the global North: excess temperatures and rainfall shortages*

Variables Conditioning	(1) Temp.	(2) Agricult.	(3) Water	(4) Latitude
Constant	1.245	1.504	1.447	1.318
	(1.405)	(1.412)	(1.415)	(1.411)
Wage ratio	0.500***	0.556***	0.554***	0.523***
	(0.194)	(0.196)	(0.192)	(0.193)
Distance	−1.098***	−1.100***	−1.103***	−1.102***
	(0.099)	(0.098)	(0.099)	(0.099)
Network	0.173***	0.173***	0.170***	0.172***
	(0.037)	(0.037)	(0.038)	(0.037)
Common language	0.941***	0.930***	0.943***	0.938***
	(0.180)	(0.178)	(0.182)	(0.180)
Contiguity	0.460	0.465	0.483	0.470
	(0.317)	(0.315)	(0.323)	(0.319)
Dependency	−0.013*	−0.015**	−0.014*	−0.012*
	(0.007)	(0.007)	(0.007)	(0.007)
International violence	0.467***	0.474***	0.442***	0.465***
	(0.101)	(0.104)	(0.101)	(0.103)
Natural disasters	0.084	0.029	0.045	0.058
	(0.108)	(0.114)	(0.105)	(0.109)
Rain anomaly	−0.071	−0.075	0.028	−0.049
	(0.072)	(0.074)	(0.060)	(0.084)
Temperature anomaly	0.119	0.015	0.068	0.039
	(0.075)	(0.080)	(0.067)	(0.081)
Rain*condition	0.136	0.180	−0.148	0.084
	(0.097)	(0.113)	(0.097)	(0.102)
Temperature*condition	−0.180	0.096	−0.059	0.044
	(0.125)	(0.128)	(0.141)	(0.123)
Origin-country dummies (α_i)	Yes	Yes	Yes	Yes
Destination–year dummies (α_{jt})	Yes	Yes	Yes	Yes
No. of observations	11,393	11,393	11,393	11,393
R^2	0.685	0.687	0.679	0.684

Notes: The dependent variable is the decadal bilateral migration rates. The estimation period is 1960–2000. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively. Robust standard errors are provided in parentheses.

North or South.[20] The results for the countries of the North are presented in Table 7, while Table 8 presents the results restricting migrations to the countries of the global South.[21] The results demonstrate marked differences between the forces that shape migration to the North and South. All

[20] The countries of the global North are taken to be those that remained affluent over the period 1960–2000. These include Australia, New Zealand, Japan, Canada, the US, the EU-15, and the countries of the European Free Trade Association.

[21] These tables only present the results analogous to those presented in Table 3. In other words, we abstract from deviations that involve excess rainfall and colder temperatures. Also, for the sake of brevity, we do not provide unconditioned results across both restricted samples. The coefficients obtained from these latter regressions can be obtained from the

Table 8. *Conditional impact of climate on migration, to the countries of the global South: excess temperatures and rain shortages*

Variables Conditioning	(1) Temp.	(2) Agricult.	(3) Water	(4) Latitude
Constant	−7.997***	−7.622***	−7.515***	−7.852***
	(1.392)	(1.376)	(1.375)	(1.382)
Wage ratio	0.150	0.109	0.068	0.124
	(0.175)	(0.178)	(0.181)	(0.175)
Distance	−0.467***	−0.468***	−0.479***	−0.468***
	(0.087)	(0.087)	(0.086)	(0.088)
Network	0.573***	0.572***	0.571***	0.573***
	(0.039)	(0.039)	(0.039)	(0.039)
Common language	0.140	0.142	0.143	0.145
	(0.119)	(0.117)	(0.117)	(0.119)
Contiguity	0.272**	0.277**	0.265**	0.275**
	(0.116)	(0.116)	(0.117)	(0.117)
Dependency	−0.010	−0.013*	−0.013*	−0.011
	(0.007)	(0.007)	(0.007)	(0.007)
International violence	0.126	0.096	0.110	0.097
	(0.241)	(0.244)	(0.238)	(0.241)
Natural disasters	0.001	−0.020	−0.032	−0.008
	(0.097)	(0.094)	(0.093)	(0.096)
Rain anomaly	−0.028	0.114*	−0.137*	0.071
	(0.067)	(0.061)	(0.070)	(0.066)
Temperature anomaly	0.009	0.007	0.008	0.035
	(0.078)	(0.060)	(0.064)	(0.059)
Rain*condition	0.061	−0.241**	0.382**	−0.166*
	(0.093)	(0.105)	(0.129)	(0.099)
Temperature*condition	0.007	0.012	0.035	−0.044
	(0.105)	(0.094)	(0.095)	(0.096)
Origin-country dummies (α_i)	Yes	Yes	Yes	Yes
Destination–year dummies (α_{jt})	Yes	Yes	Yes	Yes
No. of observations	50,841	50,841	50,841	50,841
R^2	0.833	0.835	0.834	0.834

Notes: The dependent variable is the decadal bilateral migration rates. The estimation period is 1960–2000. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively. Robust standard errors are provided in parentheses.

of the determinants previously tested are important for migrations to the North, with the exception of contiguity and the environmental variables. In comparison with the sample average however, network effects are less important. This reflects the fact that compared to the global sample, migration to the North features greater numbers of skilled agents (Docquier and Rapoport, 2012). Skilled migrants have been found to be less sensitive to networks than unskilled migrants (McKenzie and Rapoport, 2010; Beine *et al.*, 2011). In contrast, wage differentials are found to play a greater

authors, although the results are not significantly different from those presented in Tables 7 and 8.

role, which is consistent with the main incentives of migrants coming to OECD countries. The elasticity of the wage ratio is approximately 25 percent higher than the one obtained with the whole sample. The coefficient on distance is around 1, while the coefficient of contiguity is insignificant. This reflects the fact that migration to the North involves moves over longer distances. The point estimates on the shared common ethnic language are around twice as large when compared to the sample average. Once again, this reflects the importance of skilled migration for which knowledge of languages proves important.

These results are in stark contrast to those for migrations to the global South. In this case, we find no statistically significant effect of wage differentials, shared linguistic roots, or international violence. However, we do find a strong and positive effect on international migration of sharing a common border, reflecting that South–South migration involves moves over shorter distances. In the case of migrations to the global South, however, we also find some statistically significant impacts of long-run environmental factors. Across the sample of countries that rely more heavily upon agriculture and that experienced negative anomalies in rainfall, the century average precipitation was 125 mm, while the average rainfall in 2000 was 118 mm. A 10 percent rise in this negative anomaly, which is equivalent to a decrease in average rainfall across the decade 1990–2000 of approximately 1 mm, is associated with a decrease in international migration to the countries of the global South of $(2.41 - 1.14 =)$ 1.27 percent. This result provides supportive evidence for the conclusions of Findley (1994), and is similar to the results that are conditioned upon the initial level of groundwater, only this time the signs are reversed. Across the sample of countries that have fewer water resources, the century average precipitation was 89 mm, while the average decadal rainfall across the decade 1990–2000 was just 80 mm. A 10 percent rise in this negative anomaly, which is again equivalent to a decrease in average rainfall across the decade 1990–2000 of approximately 1 mm, is associated with an increase in international migration of $(3.82 - 1.37 =)$ 2.45 percent to the countries of the global South. In both tables, across all the various specifications, we again fail to find any affect of natural disasters on international migration.

Robustness Check: Adjustment for Return Migration

In our benchmark estimations, we made a particular choice regarding our dependent variable (i.e., bilateral migration rates). Indeed, we excluded from the sample all negative flows, and estimated our models on a sample including only zero or positive flows. Negative flows are a result of a reduction in migrant stocks. Decreases in bilateral migration stocks might reflect particular processes regarding demographic developments. One is the combination of significant death rates of some old diasporas, which are not fully counterbalanced by new migration flows. A similar case might emerge if significant emigration to countries other than migrants' country of origin occurs. A final possibility is that return migration outweighs the arrival of new migrants. Ideally, one should account for those flows because return migration actually reflects the impact of push factors at destination or the reduced attractiveness of destination countries over time.

While there is no direct way to account for return migration, migration to third-party countries, and deaths, we provide a robustness check based on one particular extreme hypothesis. We recompute the bilateral migration flows assuming that decreases in migration stocks totally reflect the return of migrants to their origin country. We add the opposite value of the negative flows between country i and country j to the observed migration flow between country j and country i. Using the new bilateral migration flows, we re-estimate model (8). We follow the strategy considered in the earlier subsections *Baseline Results* and *Heterogeneous Effects*, again considering any unconditional response in addition to interactions conditional on various country characteristics (equivalent to Table 4). The results are reported in Tables 9 and 10. Regarding the role of the other covariates, such as wages, networks, distance, and the factors at origin, the results are extremely similar to those of the benchmark regressions.

The robustness checks yield interesting results. We find that the results peculiar to the impact of natural disasters are quite robust with respect to our benchmark results. With regards to the role of long-run factors, the coefficients are of a similar magnitude and in the same direction as those presented in Table 3, but in some cases are now statistically significant, thereby assigning a modest role to excess temperatures as push factors. Further conditioning our results on origin characteristics, we found no conclusive evidence that climatic change, climatic variation, or natural disasters spur international migration.

Robustness Check: Potential Endogeneity of the Network

An important econometric issue in our regressions is the potential endogeneity of the diaspora. Endogeneity of network variables in migration models mainly arises because of the potential omission of unobserved factors that might be correlated both with the error term (and thus migration flows) and with the diaspora. Note that this omitted factor must lie in the ijt dimension to qualify.[22] Potential unobserved factors include measures of cultural or political proximity between two countries that are often dif-

[22] Another orthodox source of endogeneity, namely reverse causality, does not apply here at first glance, because network measures are predetermined with respect to migration flows.

Table 9. *Accounting for return migration: unconditional results*

Variables	(1)	(2)	(3)	(4)
Constant	−5.438***	−5.379***	−5.405***	−5.562***
	(1.186)	(1.181)	(1.152)	(1.212)
Wage ratio	0.344**	0.363**	0.355**	0.372**
	(0.161)	(0.163)	(0.160)	(0.162)
Distance	−0.792***	−0.789***	−0.792***	−0.791***
	(0.080)	(0.079)	(0.080)	(0.080)
Network	0.413***	0.414***	0.413***	0.415***
	(0.036)	(0.036)	(0.036)	(0.037)
Common language	0.551***	0.546***	0.552***	0.545***
	(0.134)	(0.134)	(0.133)	(0.134)
Contiguity	0.0120	0.011	0.012	0.011
	(0.156)	(0.156)	(0.155)	(0.158)
Dependency	−0.016***	−0.017***	−0.016***	−0.016***
	(0.005)	(0.005)	(0.005)	(0.005)
International violence	0.376***	0.361***	0.373***	0.361***
	(0.086)	(0.085)	(0.084)	(0.085)
Natural disasters	0.021	0.034	0.022	0.018
	(0.078)	(0.079)	(0.078)	(0.078)
Rain anomaly	0.003	0.039	−0.015	0.088*
	(0.059)	(0.038)	(0.042)	(0.052)
Temperature anomaly	0.082*	−0.031	0.079**	−0.041
	(0.042)	(0.052)	(0.035)	(0.039)
Origin-country dummies (α_i)	Yes	Yes	Yes	Yes
Destination–year dummies (α_{jt})	Yes	Yes	Yes	Yes
No. of observations	71,696	71,696	71,696	71,696
R^2	0.579	0.576	0.579	0.578

Notes: The dependent variable is the decadal bilateral migration rates. The estimation period is 1960–2000. Columns 1 and 2 show anomalies, and Columns 3 and 4 show absolute deviations. Columns 1 and 3 are for excess temperatures and rainfall shortages, and Columns 2 and 4 are for temperature shortages and excess rainfall. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively. Robust standard errors are provided in parentheses.

ficult, if not impossible, to measure with quantitative data. One concern in the current context is that the presence of endogeneity might lead to a significant bias in the estimation of the network effect as well as of the other key parameters of the model.

There are basically two procedures to deal with such an issue. The most traditional approach uses instrumental variable estimates. In a similar setting, while restricting their analysis to a cross-section comprising migratory movements to the countries of the OECD in the 1990s, Beine *et al.* (2011) implement a set of instruments including guest-worker programs and a variable capturing the unobserved diaspora in the 1960s. Importantly for the purposes of the current paper, they find that the estimated coefficient on their diaspora variable is robust to reverse causality. Given the panel data dimensions of our dataset, such instruments are not valid here. Furthermore, the search for an instrument that has an ijt dimension, which is

Table 10. *Accounting for return migration: conditional impact*

Variables Conditioning	(1) Temp.	(2) Agricult.	(3) Water	(4) Latitude
Constant	−5.542***	−5.420***	−5.549***	−5.455***
	(1.162)	(1.217)	(1.176)	(1.183)
Wage ratio	0.299*	0.352**	0.263*	0.350**
	(0.155)	(0.165)	(0.155)	(0.162)
Distance	−0.791***	−0.791***	−0.794***	−0.791***
	(0.079)	(0.080)	(0.080)	(0.080)
Network	0.415***	0.413***	0.413***	0.413***
	(0.035)	(0.036)	(0.036)	(0.036)
Common language	0.544***	0.548***	0.552***	0.551***
	(0.130)	(0.134)	(0.132)	(0.134)
Contiguity	0.007	0.013	0.009	0.012
	(0.153)	(0.156)	(0.154)	(0.155)
Dependency	−0.015***	−0.016***	−0.015***	−0.016***
	(0.005)	(0.005)	(0.005)	(0.005)
International violence	0.404***	0.383***	0.378***	0.392***
	(0.085)	(0.086)	(0.085)	(0.086)
Natural disasters	0.031	0.012	0.035	0.031
	(0.076)	(0.079)	(0.075)	(0.078)
Rain anomaly	−0.084	0.003	−0.033	−0.014
	(0.078)	(0.088)	(0.064)	(0.062)
Temperature anomaly	0.113**	0.057	0.059	0.086**
	(0.055)	(0.053)	(0.048)	(0.044)
Rain$*$condition	0.174*	0.003	0.103	0.212*
	((0.094)	(0.103)	(0.097)	(0.110)
Temperature$*$condition	−0.070	0.072	0.068	−0.065
	(0.084)	(0.084)	(0.086)	(0.122)
Origin-country dummies (α_i)	Yes	Yes	Yes	Yes
Destination–year dummies (α_{jt})	Yes	Yes	Yes	Yes
No. of observations	71,696	71,696	71,696	71,696
R^2	0.585	0.579	0.581	0.577

Notes: The dependent variable is the decadal bilateral migration rates. The estimation period is 1960–2000. Anomalies refer here to excess temperatures and rainfall shortages. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively. Robust standard errors are provided in parentheses.

correlated to the size of the initial bilateral network and uncorrelated with the corresponding subsequent bilateral migration flow, proves to be very difficult, if not impossible.

As an alternative, we augment equation (8) with the inclusion of an observable variable of dimension ijt that might capture (part) of these unobserved time-varying dyadic factors. In turn, we can check whether our results regarding climatic factors are robust to such an inclusion. One conceivably credible variable, which can be used to capture such omissions, is a bilateral time-varying dummy variable that equals 1 if nationals of one origin country require a visa in a specific destination. Presently, these data – originally recorded by the International Air Transport Association in their Travel Information Manuals, and collated under the auspices of the DEMIG project at the International Migration Institute based at the University of Oxford – are only available for some 47 destination countries (see the Appendix) and only for three years; 1979, 1989, and 1999. These data capture whether individuals require visas for the purposes of tourism and social visits in other nations. Nevertheless, given the fact that the issuance of such visas for foreign nationals is doubtless highly correlated with current political realities and historical cultural occurrences, their implementation should be effective in terms of testing for an omitted variable in the ijt dimension.[23]

The visa data for each of the three available years are equated in estimation to the same decade over which the decennial migrant flow occurred.[24] The first column in Table 11 reports the results when including the bilateral visa variable in estimation, while the second column presents the comparable results with the same number of observations when the visa variable is excluded. Given the reduced coverage of this variable in terms of both countries and time periods, the number of observations falls to 16,135. Broadly, the results are comparable to the unconditional regression results presented in Table 3 and the differences that do exist can be attributed to sample selection given the significantly reduced number of observations. These differences include an insignificant impact upon migration flows of countries being contiguously located, a stronger influence of distance, and, perhaps most starkly, the insignificance of the wage differential. Importantly, the wage differential is insignificant in the results in both Columns 1 and 2 (i.e., with and without the visa variable). This demonstrates the fact that sample selection leads to this result and, conversely, it also shows the importance – in terms of the significance of our wage differential proxy – of maintaining a global sample of countries in our foremost estimations. This insignificance is almost certainly because the reduced sample includes many countries at a more similar level of development. That is, the wealthier nations of the world and the few relatively poor countries included in this sample often favor sending migrants to countries omitted from the

[23] This approach should only be regarded as a robustness check of our results for at least for four reasons. First, the inclusion of the visa data in estimation leads to quite a large decrease in the sample size in terms of i, j, and t. In turn, this might generate a sample selection issue. Secondly, and relatedly, many developing countries are dropped from the sample, while previously we have stressed the importance of South–South migration in the current context. Thirdly, only three years of data are available, which makes the correspondence with the migration flows less optimal (see below). Finally, the bilateral visa variable itself might also be endogenous.

[24] These visa data are therefore not ideal because they refer to the last years in each decade over which the decennial flow occurred. Ideally, data would be available for the middle year of each decade because this would be more representative of the availability of visas over the decade, but currently the data obtained from the DEMIG project are the only data available.

Table 11. *Bilateral visa requirements and endogeneity of the network*

Variables	(1)	(2)
Constant	−3.914***	−4.280***
	(1.492)	(1.509)
Wage ratio	0.179	0.092
	(0.182)	(0.185)
Distance	−0.896***	−0.919***
	(0.102)	(0.106)
Network	0.349***	0.351***
	(0.040)	(0.040)
Common language	0.526**	0.525**
	(0.151)	(0.152)
Contiguity	0.257	0.336*
	(0.201)	(0.193)
Dependency	−0.015**	−0.014**
	(0.006)	(0.006)
International violence	0.512***	0.498***
	(0.102)	(0.101)
Natural disasters	0.176	0.198*
	(0.110)	(0.113)
Rain deviation/anomaly	0.021	0.013
	(0.043)	(0.043)
Temperature deviation/anomaly	0.060	0.059
	(0.052)	(0.054)
Bilateral visa requirement	−0.554***	–
	(0.128)	
Origin-country dummies (α_i)	Yes	Yes
Destination–year dummies (α_{jt})	Yes	Yes
No. of observations	16,135	16,135
R^2	0.809	0.807

Notes: The dependent variable is the decadal bilateral migration rates. Anomalies refer here to excess temperatures and rainfall shortages. The estimation period is 1970–2000. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively. Robust standard errors are provided in parentheses.

sample, which conspires to reduce the variability in this variable across countries.

For the sake of our robustness check however, the results in Table 11, which limits the analysis to positive temperature anomalies and negative precipitation anomalies, are heartening. First of all, the coefficient on our newly introduced visa variable is highly significant while its sign is in the predicted direction. If countries mandate nationals of foreign countries to apply for a visa to enter their borders, then the migrant rates between this country-pair will, on average, be 55 percent lower. Because the visa data refer to temporary migrations (tourism and social visits), while instead the migration data refer to permanent migration flows, and because decennial flows are calculated as the difference in migrant stocks, this reduction in rates can be attributed to factors other than those already captured in estimation. Importantly, the direct effects remain insignificant with the inclusion of the visa variable, which therefore provides additional evidence as to the exogeneity of the network effect.

Indirect Effects of Environmental Factors

As emphasized previously, the estimations results based on equation (8) only capture the direct effect(s) of environmental factors on international emigration. However, an absence of direct effects does not rule out the existence of indirect effects. Such indirect effects might operate through the mechanism of wages at origin being affected by climatic shocks, which in turn widens the gap between domestic and foreign wages. The fact that we find a robust and stable positive elasticity of international migration flows with respect to the wage differential suggests that this channel might be operative. Previous evidence in favor of this channel has been provided in particular contexts.[25]

Using our measures of environmental factors, in terms of both short-term and longer-term shocks, we explore the existence of an indirect channel in our full sample of origin and destination countries. Building upon the dyadic nature of our variables, we run the following auxiliary regression:

$$\ln\left(\frac{w_{j,t}}{w_{i,t}}\right) = \beta_1 \ln(E_{i,t}) + \beta_2 \ln(Pol_{i,t}) + \beta_3 \ln(Dep_{i,t}) + \alpha_i + \alpha_{j,t} + \epsilon_{ij,t} \tag{10}$$

in which the same notations of the variables apply as before. The environmental long-run factors are once again captured by rainfall and temperature anomalies.[26] As before, we use five different samples: the full sample of countries and subsamples based upon our conditioning variables, which are hotter initial climate, countries that are more dependent upon agriculture, countries with low endowments of groundwater, and countries located closer to the equator.

Table 12 reports the estimation results. The results yield three principal messages. First, we find a very robust result for natural disasters, suggesting that the occurrence of natural disasters puts downward pressure on domestic

[25] To name but a few studies, in the case of Mexico–US migration, Munshi (2003) shows that rainfall affects local labor market conditions, which in turn begets further emigration to the US. Mueller and Quisumbing (2011) find that the 1998 “flood of the century” in Bangladesh induced significant wage losses in affected areas. Mueller and Osgood (2009) conduct a similar analysis in the case of droughts that took place in Brazil .

[26] We focus here upon rainfall shortages and excess temperature, as in Table 3, because these deviations deliver a natural interpretation in terms of economic impact. The theoretical impact of excess rainfall and temperature shortage is less intuitive. However, including those anomalies does not change the current results. Those additional results are available upon request.

Table 12. *Indirect effects of climate shocks: impact on the wage ratio*

Variables Conditioning	(1) Full	(2) Temp.	(3) Agricult.	(4) Water	(5) Latitude
Constant	−0.510	−0.357	−0.452	−0.218	−0.418
	(0.304)	(0.296)	(0.313)	(0.266)	(0.331)
Dependency	0.0123***	0.0128***	0.0055***	0.0109***	0.0123***
	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Intern. Violence	0.052***	0.064***	−0.002	−0.088***	0.032***
	(0.003)	(0.004)	(0.003)	(0.006)	(0.003)
Natural Disasters	0.033***	0.074***	0.050***	0.048***	0.049***
	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)
Temp. anomaly	−0.031***	−0.056***	−0.044***	−0.027***	−0.053***
	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)
Rain anomaly	−0.0003	0.006***	0.007***	0.011***	0.009***
	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)
Orig-count FE (α_i)	Yes	Yes	Yes	Yes	Yes
Dest–year FE (α_{jt})	Yes	Yes	Yes	Yes	Yes
No. of observations	71,696	35,069	42,937	28,399	35821
R^2	0.980	0.977	0.982	0.976	0.980

Notes: The dependent variable is the (log of) wage ratio between origin and destination. Anomalies refer to excess temperatures and rainfall shortages. The estimation period is 1960–2000. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively. Robust standard errors are provided in parentheses.

wages, thereby widening the wage differential. The positive impact holds for all samples, although it is found to be stronger in countries that can be expected to be more vulnerable. For instance, this is the case in countries with hot climates and those with a relatively large share of agriculture in GDP. Secondly, for these vulnerable countries, we also find a positive and robust impact of rainfall shortages on the wage differential. This is consistent with the results documented in the microeconomic literature (e.g., Munshi, 2003). In line with the theoretical expectations, the impact is found to be stronger in countries that have fewer groundwater resources. When all countries are considered, with developed countries included, this effect disappears, which is intuitive given the importance of economic activities that are insulated from the influence of rainfalls. Finally, the results concerning anomalies in terms of excess temperature are much less intuitive and suggest that the channel through which temperature can affect local labor market conditions is much more complex.[27]

These results are suggestive of an econometric strategy to deal with the potential endogeneity of wage differentials. Our framework is founded upon

[27] The results might relate to the fact that the relation is not linear. If the main impact of temperature is on agriculture, its effect is usually measured by degree days (the number of days the temperature exceeds a threshold value), and a linear deviation (or anomaly) that is used is less prone to capture that. Unfortunately, this type of data is not, to our knowledge, directly available. We leave this for further investigation.

dyadic data, which strongly mitigates the potential endogeneity of wages with respect to international migration. With few exceptions, there is no bilateral flow whose magnitude is large enough to generate an impact on the wage at origin or/and at destination. Nevertheless, this concern might be more relevant in studies using unilateral data (i.e., analyses that aggregate all destinations by origin). Our benchmark and current results suggest that natural disasters (and, to a lesser extent, rainfall variations) are suitable instruments of the domestic wage level. On the one hand, the presence of indirect effects suggests that these variables qualify as strong instruments. On the other hand, the benchmark results emphasizing the absence of direct effect on the magnitude of emigration supports the validity of the exclusion restriction.[28]

VI. Internal Migration Hypothesis

The previous results provide little support for the hypothesis that long-run climatic factors or our aggregate measure of natural disasters spurred significant international migration. While we find some role for those phenomena under particular circumstances, the overall impact remains limited. In any case, our results question the idea that climatic factors will create a large rise in the number of international (environmental) migrants/refugees. In particular, we provide evidence that environmental factors play little role compared to economic, political, demographic, and social variables. Does this imply that climatic factors do not increase individual's mobility? Not necessarily. One possibility is that people adversely affected by climatic factors move internally rather than internationally. This possibility might be particularly relevant in developing countries, where people are likely to be financially constrained. If climatic factors tend to depress income, then liquidity constraints might prevent people from moving internationally because international migration costs are significantly larger. In that case, internal migration might be preferred.

In this section, we investigate whether there is empirical support for a relationship between climatic factors and internal migration in our sample. A direct test in the previous econometric framework we relied upon is impossible, because no data on internal migration are available for all countries for the period of our investigation. Data on migration within the same country definitely exist in some countries. Data on interprovincial migration flows in Canada are, for instance, available over a 20-year period.

[28] As suggested by the results of Table 8, the validity of this exclusion restriction can be challenged in the case of migration to the global South and if we condition the coefficient on rainfall and temperatures. In general, the restriction should hold in unconditional regressions involving migration from developing to developed countries.

Nevertheless, at the world level, there are no data on internal migration that are comparable across countries and over time.

An alternative way of capturing internal migration is to use the evolution of urbanization of countries. The idea is that internal movements of people, dominated by rural to urban migration, lead to an increase in the urbanization rate. This idea has been implemented by Barrios *et al.* (2006), who look at the impact of climatic factors on the pattern of urbanization in sub-Saharan African countries. They look specifically at the role of the change in rainfall that, in the context of water shortages, leads people from rural areas to migrate to cities. Their sample comprises developing countries although they focus upon sub-Saharan African countries. We extend their work by looking at the role of our climatic variables for the complete sample of countries over the full investigation period. We account for the traditional determinants of the urbanization process identified in the empirical literature (e.g., Davis and Henderson, 2003). The controls include the level of democracy, the level of income, population density at the country level, as well as openness. The estimated relationship takes the form,

$$\ln(Urb_{i,t}) = \beta_1 \ln(X_{i,t}) + \beta_2 \ln(E_{i,t}) + \alpha_t + \alpha_i + \epsilon_{i,t}, \tag{11}$$

where $X_{i,t}$ comprises the controls of urbanization of country i at time t, and $E_{i,t}$ includes, as before, the environmental factors. The model includes country and time fixed effects controlling for the time-invariant country-specific factors and for the country-invariant time-specific factors, respectively. The model is estimated for two samples over the full period (1960–2000) again using decennial data. The first sample includes all countries, while the second includes only developing countries. Because the inclusion of $X_{i,t}$ significantly reduces the number of observations because of missing data, we start with the full model but also present the results of more parsimonious specifications. Regarding our long-run climatic factors, we implement those that capture excess temperatures and rain shortages.[29]

The results of Table 13 provide some interesting insights. First, the process of urbanization is found to be significantly different between developed and developing countries. This is not surprising given the importance of factors such as income or industrial development. With respect to the sensitivities of internal migration (as proxied by urbanization), there are also some significant differences. Climatic factors play little role at the world level (i.e., when mixing up developed and developing countries). In contrast, for developing countries, natural disasters are found to increase urbanization, even when accounting for its traditional correlates. The positive

[29] We obtain similar results with excess of rain and negative deviations of temperature as well as with volatility measures, in the sense that we do not find any significant effect. These are available upon request.

Table 13. *Internal migration and environmental factors*

	Full sample			Developing countries		
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.913***	2.311***	2.230***	1.419***	2.044***	2.186***
	(0.258)	(0.121)	(0.096)	(0.295)	(0.117)	(0.097)
Natural disasters	0.028	0.016	0.054***	0.045**	0.035**	0.070***
	(0.017)	(0.015)	(0.013)	(0.020)	(0.016)	(0.014)
Rain shortages	−0.011	−0.008	−0.007	−0.019	−0.005	−0.003
	(0.009)	(0.007)	(0.007)	(0.010)	(0.009)	(0.008)
Excess temp.	−0.017*	−0.015*	−0.007	−0.004	−0.015	−0.003
	(0.009)	(0.008)	(0.008)	(0.010)	(0.010)	(0.009)
Pop. density	0.034***	–	–	0.013*	–	–
	(0.005)			(0.007)		
Income	0.034	−0.012	–	0.061***	0.033*	–
	(0.020)	(0.016)		(0.023)	(0.016)	
Democracy	−0.0012**	–	–	−0.0010**	–	–
	(0.0005)			(0.0005)		
Openness	0.0009*	–	–	0.0009*	–	–
	(0.0005)			(0.0006)		
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
No. of observations	570	828	1,010	468	713	895
R^2	0.955	0.939	0.933	0.951	0.939	0.932

Notes: The dependent variable is the (log of) urbanization rate. The estimation period is 1960–2000. ***, **, and * denote statistical significance at the 1, 5, and 10 percent levels, respectively. Robust standard errors are provided in parentheses.

elasticity of urbanization to the number of natural disasters is consistent with the fact that people from rural areas affected by natural disasters tend to migrate primarily to the cities of their country. This is also consistent with the fact that potential migrants from developing countries favor domestic destinations that involve lower migration costs, which in turn implies that liquidity constraints might be binding for a significant number of movers.

VII. Conclusion

In this paper, we first derive a simple utility maximization model, which incorporates environmental factors at origin. We then test this model using a previously unexploited panel dataset of bilateral migration flows, which cover the period 1960–2000. We account for all classifications of usual determinants of migration, and additionally implement origin-specific and destination country–year fixed effects to account for numerous unobserved factors. To date, this is arguably the most sophisticated macroeconomic bilateral model used to assess the effects of climatic factors on international migration.

First, we find little support for any direct relationship between either short-run or long-run climatic factors and international migration. These results are robust when further considering migrants returning home and the potential endogeneity of our network variable. While our findings are certainly at odds with the macrolevel literature, our results offer support to much of the microlevel climate literature, which instead argues that the environmental factors tend to result in shorter, internal movements. Further conditioning our regressions upon origin-country characteristics, we find evidence that shortfalls in precipitation constrain migration to developing countries from countries that rely more heavily upon agriculture, and spur movements to developing countries from countries with fewer groundwater reserves.

We subsequently use the rate of urbanization as a proxy for internal migration and find strong evidence that natural disasters beget greater flows of migrants to urban environs. Finally, although our results show that climatic factors have little direct effect upon long-run international migration, we find evidence of the indirect effects of climatic factors. In particular, natural disasters and rainfall shortages at origin are found to result in a widening gap between wages at origin (in countries already vulnerable to climate change) and at destination.

Appendix: Lists of Countries

Destinations (166)

Afghanistan, Albania, Algeria, Andorra, Angola, Antigua and Barbuda, Argentina, Australia, Austria, Bahamas, Bahrain, Bangladesh, Barbados, Belgium, Belize, Benin, Bhutan, Bolivia, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Costa Rica, Cote d'Ivoire, Cuba, Cyprus, Democratic People's Republic of Korea, the Democratic Republic of the Congo, Denmark, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Ethiopia, Federated States of Mongolia, Fiji, Finland, France, Gabon, the Gambia, Germany, Ghana, Greece, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, Iceland, India, Indonesia, Iran, Ireland, Islamic Republic of Iraq, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Kiribati, Korea, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Libyan Arab Jamahiriya, Luxembourg, Madagascar, Malawi, Malaysia, Maldives, Mali, Malta, Marshall Islands, Mauritania, Mauritius, Mexico, Micronesia, Morocco, Mozambique, Myanmar, Namibia, Nauru, Nepal, the Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, the Philippines, Poland, Portugal, Qatar, Republic of Kuwait, Romania, Russian Federation, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, San Marino, São Tomé and Príncipe, Saudi Arabia, Senegal, Serbia and Montenegro, Seychelles, Sierra Leone, Singapore, Solomon Islands, Somalia, South Africa, Spain, Sri Lanka, Sudan, Suriname, Swaziland, Sweden, Switzerland, Syrian Arab Republic, Tanzania, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkey, Tuvalu, Uganda, UK, United Arab Emirates, United Republic of Thailand, Uruguay, US, Vanuatu, Venezuela, Vietnam, Yemen, Zambia, Zimbabwe.

Origins (137)

Afghanistan, Albania, Algeria, Angola, Argentina, Australia, Austria, Bahrain, Bangladesh, Belgium, Benin, Bhutan, Bolivia, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Costa Rica, Cote d'Ivoire, Cuba, Cyprus, Democratic People's Republic of Korea, the Democratic Republic of the Congo, Denmark, Djibouti, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Ethiopia, Fiji, Finland, France, Gabon, the Gambia, Germany, Ghana, Greece, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, India, Indonesia, Iran, Ireland, Islamic Republic of Iraq, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Korea, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Libyan Arab Jamahiriya, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nepal, the Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, the Philippines, Poland, Portugal, Qatar, Republic of Kuwait, Romania, Russian Federation, Rwanda, Saudi Arabia, Senegal, Serbia and Montenegro, Sierra Leone, Singapore, Solomon Islands, Somalia, South Africa, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Syrian Arab Republic, Tanzania, Togo, Trinidad and Tobago, Tunisia, Turkey, Uganda, UK, United Arab Emirates, United Republic of Thailand, Uruguay, US, Venezuela, Vietnam, Yemen, Zambia, Zimbabwe.

Visa Destinations (47)

Afghanistan, Albania, Algeria, Angola, Argentina, Australia, Austria, Barbados, Belgium, Brazil, Bulgaria, Canada, Chile, China, Denmark, Egypt, Finland, France, Germany, Greece, Hungary, Indonesia, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Morocco, Nigeria, the Netherlands, New Zealand, Norway, Pakistan, the Philippines, Poland, Portugal, Russia, Saudi Arabia, South Africa, Spain, Sweden, Switzerland, Turkey, US, Vietnam.

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