Migration and Environment

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Abstract

The concept of environmental migrants occurs frequently in the policy debate, in particular with regard to climate change and the incidence of such migration in low-income countries. This article reviews the economic studies of environmentally induced migration. It includes recent empirical analyses that try to link environmental change to migration flows and the spatial distribution of population. A consensus seems to emerge that there is little likelihood of large increases in international migration flows due to climate variability. The evidence to date shows that regional migration will be affected, however, either on the African continent or internally, within country borders. Theoretically, environmentally induced migration can be analyzed using different frameworks: the classical Harris-Todaro model of rural-urban migration, new economic geography models, models grounded in environmental economics of pollution externalities with free factor mobility, and the new economics of labor migration. I review some of the latest attempts to analyze environmentally induced migration theoretically and the policy-relevant conclusions that can be drawn.

1. INTRODUCTION

1.1. From Environmental "Refugees" to Studies of the Vulnerability of the Population Exposed to Environmental Hazards

Both recent and historical events remind us that environmental change can induce migration. The dust storm series that affected the US and Canadian Great Plains region for almost a decade in the 1930s created an ecological disaster and precipitated huge movements of population following reductions in agricultural output and land values (Gutmann et al. 2005, Hornbeck 2012). More recent events of flooding, like the major floods that struck Bangladesh in 1988 and in 1998, or hurricane damage, like Hurricane Katrina in New Orleans in 2005, as well as drought events in the Sahel have triggered out-migration. Because the scientific consensus on climate change is that the incidence of extreme weather events will only increase in the future (IPCC 2014), migration is increasingly seen as one potential adaptation strategy. This article reviews the literature on environmentally induced migration and the more recent empirical work specifically devoted to climate change and migration. I also review the theoretical models that may be used to analyze population mobility and environment.

Most of the recent attention to environmentally induced migration follows from climate change impact reports (Black et al. 2008). Originally, the concept of "environmental refugees" was coined by El Hinnawi (1985), then UNEP representative, and was popularized by Myers in several articles (e.g., Myers 1997). Most current scientific debate on the issue agrees not to confuse the legal definition of refugees[1] but rather analyzes environmental change as one factor among many that may induce migration. Therefore, estimating future projected environmental migrant flows is difficult. Initially, El Hinnawi (1985) claimed that 30 million people were climate migrants, and Myers (1997) quoted a figure of 25 million people. More recently, *The Stern Review* suggested that by 2050 there would be 200 million people who would be affected by adverse climate events that could induce migration (Stern 2007). A much publicized report by the nongovernmental organization Christian Aid predicted that up to one billion people could be displaced by environmental causes by 2050 (Christian Aid 2007). These are the kind of figures that analytical work—both theoretical and empirical—has to confront and test to frame the debate in such a manner that we can better understand the origin of projected migration figures and their exact causes. The fifth assessment report on adaptation issued by the Intergovernmental Panel on Climate Change (IPCC) does point out that there is low confidence in quantitative projections of future migration flows, although there is a high likelihood of migration occurring (IPCC 2014). Current analyses of environment and migration therefore try to include and interact environmental factors with different socioeconomic characteristics that may explain why some households are more vulnerable than others and why some choose to migrate rather than staying in the origin area or adapting through other means.

A current broad definition of environmental migrants is the one formulated by the International Organization for Migration (IOM 2009): "Environmental migrants are persons or groups of persons who, for compelling reasons of sudden or progressive change in the environment that adversely affects their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country or abroad." This definition encompasses voluntary and forced migration, temporary and permanent migration, and internal and international migration.[2] Above all, it acknowledges the

[1] As Gemenne (2011) points out, there is currently no legal definition of environmental refugee.

[2] See also Piguet (2010) for an insightful discussion of the concept of environmental migrants.

many different types of environmental factors that may be linked with migration. Environmentally induced migration may bring forth images of natural disasters, such as flood waves and hurricanes, but as seen from the above definition, such migration also includes environmental factors that act over the long term, such as soil erosion and degradation of water availability and quality. Water availability as such imposes limits on human settlement. The analysis of LeBlanc & Perez (2008) finds a positive correlation between rainfall and population density on the African continent below an annual rainfall of 900 mm. The regions under strong water stress are eastern Africa; southern Sahel; and the border regions of Niger, Nigeria, and Chad. Nevertheless, natural hazards are one important subset of environmental factors that can induce migration, and as Wisner et al. (2004) point out, the consequences of natural hazards are not only the result of nature but also determined by economic, social, and political factors. A first categorization of environmental change can nevertheless be done according to whether the environmental change is endogenous or exogenous. The older literature on migration and environment often studied endogenous measures such as soil erosion and forest degradation. Examples of exogenous events (at least on the timescale of a few decades) are hurricanes, rainfall, and temperature anomalies. Such environmental factors are exogenous to the individual or the household making the migration decision, which is important for empirical analysis. Degradation of forests and loss of biodiversity, soil erosion, and water quality degradation have economic and social origins and are thus harder to analyze because the environmental change is endogenous. This review focuses on results from articles that analyze a one-directional causality: that is, environmentally induced migration.

1.2. The Economic Importance of Migration and Environment

The issue of migration and environment is important because, although the occurrence of exogenous events is random, the impacts of natural disasters and climate change are the largest in the poorest countries that have the least institutional capability to cope with natural disasters and that are located at low latitudes (Tol et al. 2004, Kahn 2005, Mendelsohn et al. 2006). Some recent evidence points to the possibility that more frequent exposure to tropical cyclones reduces the marginal damage costs from an event (Hsiang & Narita 2012), but such adaptation is costly and may recover only a small part of overall damage costs. Hsiang & Jina (2013) indeed show evidence of a long-lasting negative effect on economic growth of cyclones. Also, because the impacts on agricultural productivity from climate change are potentially large (Mendelsohn & Dinar 2009), migration, through its indirect effect on agricultural income, may be more significant in developing countries with a high share of agriculture.

On a larger social and political scale, there is some evidence that droughts and floods are positively correlated with conflict (Homer-Dixon 1991). In particular, Bai & Kung (2011) analyze historical data over more than 2,000 years from China on recorded droughts and floods and find that lower precipitation was associated with more frequent nomadic attacks on China. The link between current conflicts and distress migration caused by sudden environmental disasters has been criticized, however, because most such migrants tend to be poor and powerless (Raleigh et al. 2008). The link is thus an indirect one, working through the effect of climate variability on income and income growth (Miguel et al. 2004), an effect analyzed by Dell et al. (2009) and Barrios et al. (2010), among others. The literature on conflict and climate, in particular, has developed into its own field and was recently surveyed by Burke et al. (2014).

1.3. Limitations of the Review and Outline

The review has two main limitations: the focus on environmentally induced migration, at the exclusion of natural population growth, and the exclusion of empirical studies on environmental

factors as amenities. As mentioned above, the current survey is limited to studying one-directional causality, i.e., environmentally induced migration. Migration flows may in turn affect the environment in the destination regions, but the problem of how migration affects the environment is not treated here. The review also abstracts from linkages between environmentally induced migration and natural population growth (see Bhattacharya & Innes 2008) because population dynamics is too complex a topic for the parameters of this review.

The review is structured as follows. Section 2 reviews empirical studies. In Section 2.1, I survey the relevant analyses in development economics that analyze migration as one of many potential coping strategies. Then in Section 2.2, I review local and national studies that focus on either slow-onset environmental factors (Section 2.2.1) or sudden-onset environmental factors (Section 2.2.2). Section 2.2.3 discusses what conclusions can be drawn from these studies and underlines methodological issues for future research. Section 2.3 reviews studies of international migration. Section 3 discusses theoretical modeling of environment and migration, and Section 4 presents conclusions that suggest some directions for future research.

2. WHAT DOES THE EMPIRICAL EVIDENCE TELL US?

The existing literature can be categorized according to the method and the theoretical framework that is used or by the type of environmental change that is studied and the regions covered. Here I choose to present the evidence according to type of environmental factor and the level of study: local and national internal migration versus international migration. This organization also allows one to distinguish between the methods that are used. I start with the country-level analyses and discuss them according to the type of environmental change considered: slow-onset environmental change or sudden-onset environmental events. Slow-onset environmental change includes drought and land degradation that occur over a longer time period, as opposed to sudden-onset events such as hurricanes or earthquakes. These local or regional studies are based mainly on household survey data on those directly affected by the environmental change. It is thus useful to take a step back and recall the rich literature in development economics on coping with exogenous shocks. In Section 2.3, I review the studies on international migration, which focus mainly on climate change and incorporate rainfall and/or temperature data or the occurrence of natural disasters. These studies use highly aggregated statistical data on migration flows and measure both direct and indirect general equilibrium effects.

2.1. Analyses Rooted in Development Economics: Migration as One Among Many Potential Coping Strategies

Some of the early empirical work on environmentally induced migration originates from the geographical sciences and social sciences other than economics. The Roncoli et al. (2001) survey of households in the year following a severe drought that occurred in Burkina Faso in 1997 is a good example of such work. Such empirical work is often based on detailed household surveys with a wealth of useful information to understand particular local conditions, but it remains largely descriptive without statistical analysis of data. Whereas the geographical sciences started to study environmental migration early on, a rich literature in development economics is devoted to studying the impact of shocks, which include environmental disasters or changes in exogenous weather factors. Environmental change affects agriculture both directly, because weather can be seen as an input into the production function (as modeled, for example, in Barrios et al. 2006 and Marchiori et al. 2012), and indirectly, via income effects transmitted to off-farm markets through wage adjustments and other general equilibrium effects.

Environmental change is, of course, not the only type of shock that a household may be exposed to; idiosyncratic shocks like illness or death in the household need to be controlled for in the estimation of the migration decision. But the extent of the environmental shock matters in the sense that it cannot be insured away though traditional means, especially if it touches an entire region. In response to an environmental shock, farmers can use several strategies to adapt. Among these, one may distinguish ex ante strategies from ex post strategies. Ex ante, a household may adjust by increasing its savings or by diversifying its crop choice and input allocation. The household may also send one member or more as migrants in anticipation of future remittances. For a strategy of migration to be effective, the destination region has to have uncorrelated weather variability. The earliest evidence of this is probably the analysis by Rosenzweig & Stark (1989) on Indian villages and the migration of daughters for the purpose of marriage into locations with spatially uncorrelated rainfall. Evidence from different countries shows that farmers adapt their crop portfolio to decrease its variance but thus also their expected profits. In fact, weather risk can lead to suboptimal input choices. For example, less fertilizer may be applied when the variability of rainfall increases (Alem et al. 2010). Irrigation is often a substitute for poor land quality, and households that have access to irrigation are less likely to migrate when facing environmental distress (e.g., Shah 2010). Most importantly, long-term profitability may be affected through the impact on investment decisions (Rosenzweig & Binswanger 1993).

Are there other adaptation strategies that may be more beneficial to the household? Migration is only one choice among many for the household ex post. Another coping strategy is to increase off-farm labor market participation (Kochar 1999, Barrett et al. 2001, Rose 2001). In the case of Ethiopia, Bezabih et al. (2010) find that off-farm labor market participation was indeed positively correlated with rainfall variability. Other coping strategies involve using credit, either formal or informal, or selling assets (Fafchamps et al. 1998), although Kazianga & Udry (2006) show that households suffering from severe drought in Burkina Faso did not resort to selling livestock but were rather using them as a buffer stock for future droughts. Fisher et al. (2010) show that poor households may also rely on forest resources, if available, as an ex post strategy to cope with famine following droughts or floods. In fact, as Meze-Hausken (2000) show for Ethiopia, migration may well be the last strategy to be used by the household after having tried other alternatives like selling off assets or obtaining credit. Di Falco et al. (2012) arrive at a similar result in a survey of 1,000 households in the Nile Basin of Ethiopia. Less than 5% of the households' self-reported strategies to adapt to climate change concerned migration or changing to nonagricultural sector work. Frequently cited adaptation strategies were instead doing nothing (more than half of the sample for temperature changes and more than 40% for rainfall changes), changing crop varieties, undertaking soil conservation measures, and planting trees.

2.2. Local and National Studies

I now examine in more detail the national studies that analyze either slow-onset environmental change or sudden-onset environmental events. The earliest of these studies follow the development economics literature in using weather variables as instruments to identify shocks, whereas the most recent studies focus directly on the link between environmental factors and migration.

2.2.1. Slow-onset environmental change. Several studies on coping strategies for income shocks in developing countries exploit the exogenous variation in rainfall as a means to identify the impact of such coping strategies on consumption (and thus welfare), labor market participation, or migration. One well-known study is that of Munshi (2003), who instruments for migrant network in the destination by using past absolute levels of rainfall in the origin. Beegle et al. (2011)

use rainfall deviation over 10 years interacted with being male and in the 5–15-year age group to instrument for migration in a panel study of Tanzanian households. Their first-stage results show a statistically significant impact of rainfall shocks on migration. Most of these studies are firmly rooted in the new economics of labor migration that sees the household as the decision unit (Stark 1993). In this kind of model, migration can be seen as an insurance strategy, as found by Yang & Choi (2007) for Philippine households with overseas migrants. Using panel data from 1997 and 1998, Yang & Choi instrument for income changes by exogenous changes in rainfall to test whether remittances serve as insurance to offset income variability. Their results indicate that for households with overseas migrants, remittances can offer full insurance for income shocks.

Concerning long-run environmental change, such as drought, the Dust Bowl that occurred over a decade and created severe soil erosion provides historical evidence to exploit. In their study of the Dust Bowl, Gutmann et al. (2005) find evidence of temperature and rainfall deviations acting as push factors for migration in the US Great Plains counties during the 1930s and the combined 1950s and 1960s. Hornbeck (2012) finds that adaptation through changes in crop choice was relatively minor and that adaptation occurred mainly through migration. Of particular interest to study empirically and theoretically are how the impact is transmitted from the farm sector to the off-farm sector, how to capture the indirect effects of environmental change, and how to deal with potential endogeneity. To this end, it is useful to separate studies according to whether they analyze a direct effect or an indirect effect on agriculture. Studies that measure direct effects on agriculture can use a production function model, use a Ricardian land rent model on cross-sectional data (Mendelsohn et al. 1994), or directly measure the impact of climate on agricultural profits on time series data by exploiting the within variation of yield per land area (Feng et al. 2010, 2012). The advantage of the Ricardian approach is that farmers' adaptation is accounted for in the resulting measure of net rent because all input costs are included in the measure. Feng et al. (2012) is a recent study of the indirect effects on the population distribution from climate change, working through its impact on agricultural productivity. Feng et al.'s (2012) results show that crop shocks are negatively associated with out-migration from the US corn belt and that the effect is stronger for young adults. Feng et al. (2012) confirm the role of indirect general equilibrium effects through a regression of state-level agricultural and nonagricultural employment on weather-instrumented crop yields. Recent work has applied this analysis to developing countries. In particular, Viswanathan & Kumar (2015) apply the methodology of Feng et al. (2012) on data from 15 major states of India and show that weather-induced shocks to the net state domestic product of agriculture increase out-migration rates for employment purposes.

Few studies on environmentally induced migration at the country level separate the type of migration response by distinguishing local and international migration. One exception is the study of Gray (2009), who separates local rural-rural migration and internal rural-urban migration from international migration in a study on Ecuador. Gray finds that mean annual rainfall did not affect local migration but had a negative impact on internal and international migration. Harvest fluctuations, in contrast, increased local and regional migration, but not international migration. He concludes that international migration is the least influenced by environmental conditions, which confirms the literature's ex ante hypothesis that migration costs increase with the distance migrated. Gray also finds that the probability of international migration increased with land ownership, which confirms the hypothesis of wealth being important in financing long-distance migration. Using panel data on Ethiopia, Gray & Mueller (2012a) find that men's labor migration increases significantly after a drought but that women's marriage-related mobility decreases following a (self-reported) drought. These results confirm earlier studies by Ezra & Kiros (2001) on significant out-migration (mostly rural-to-rural migration) from communities vulnerable to food shortage in the regions of North Shoa, Wello, and Tigray during 1984 to 1994.

Among the studies that use temperature rather than rainfall is the study of Dillon et al. (2011) on Nigeria. Following Rose (2001), Dillon et al. measure the household's migration response to ex ante risk, defined as the coefficient of variation of rainfall, and ex post risk, measured as the standard deviation of temperature degree days. They find a statistically significant effect of ex ante risk on male migration only, and they find that the probability that the household sends at least one male migrant also increases with the ex post risk and that the effect is more pronounced for hotter shocks. Whether degree days or rainfall is the appropriate measure for impacts in an agricultural region is highly dependent on the region studied. In general, robustness tests including both measures should be done, as rainfall and temperature may be spatially correlated (Auffhammer et al. 2013).

Finally, some authors use agent-based models to simulate the impact of climate change scenarios on future migration flows at a country level, for example, Kniveton et al. (2011) on Burkina Faso and Hassani-Mahmooei & Parris (2012) on Bangladesh. Hassani-Mahmooei & Parris (2012) use detailed district-level agent-based modeling to estimate the number of interdistrict migrants in Bangladesh to between 3 and 10 million people over the period 2010–2015. The challenges with this kind of simulation stem mainly from the inconsistency between the decision rules for the agents and the economics of migration. The agent (who may represent several thousand people) is assumed to first assess the various push factors (of which environmental factors may be one). If and only if those factors result in the agent's migration threshold being exceeded, the agent then compares the pull factors in each of the possible migration districts and moves to the closest district with the best socioeconomic conditions. Hence the choice is not based on a direct comparison between the characteristics in the origin district and those in the destination district.

2.2.2. Sudden-onset environmental events: natural disasters. The type of environmental change matters for the kind of migration to expect. In fact, earthquakes and hurricanes destroy capital and may thus also decrease a household's capacity to send migrants. This is referred to as the liquidity constraint hypothesis in the literature. In addition, there may also be direct damage to roads and transportation networks such that short-term migration is prohibitively costly. Whereas Halliday (2006) finds that agricultural losses increased the probability of migration to the United States of rural households in El Salvador, earthquakes had a negative effect on the same migration flows, and this negative effect held for both wealthy and poor households. He thus argues that the liquidity constraint hypothesis cannot explain on its own why sudden-onset events tend to decrease migration. An alternative hypothesis is that labor is needed at home to reconstruct after the earthquake, a hypothesis that is compatible with international studies on natural disasters and bilateral migration (Alexeev et al. 2011). In another article, Halliday (2012) disentangles the differences in female and male migration responses within the household. Agricultural losses increase male migration, whereas earthquakes decrease female migration but have no effect on male migration from rural households in El Salvador.

A negative effect of natural disasters on migration is also found in a study on migration from Nicaragua following Hurricane Mitch in October 1998 (Carvajal & Medalho Pereira 2009). The authors use data on almost 3,000 households from before and after the hurricane to identify its potential impact on the households that migrated between 1999 and 2001. Exposure is measured as the intensity in rainfalls after the hurricane compared with the yearly daily average, because households whose houses are hit by a tornado have less ability to protect themselves from such rainfalls. The study shows that adaptive capability also depends on households' socioeconomic characteristics and location. Exposure on its own is never significant in explaining the probability of a household having a migrant during the years studied. Interaction variables with the household's wealth are significant, however, and indicate a nonlinear interaction between exposure, vulnerability,

and adaptation via migration. Rural households, in particular poor households, that were more exposed to rainfall after the hurricane were less likely to migrate. The opposite outcome occurred for urban households: If they were not the poorest and were heavily exposed to rainfall after the hurricane, the probability to migrate increased (Carvajal & Medalho Pereira 2009).

Bohra-Mishra et al. (2014) analyze the effect on migration of several types of disasters—earthquakes, floods, landslides, and volcanic eruptions—by using Indonesian household panel data (the Indonesian Family Life Surveys) aggregated up to the province level. The impact is measured by the number of deaths, and the financial damage caused, in addition to a count index of the occurrence of each type of disaster. Bohra-Mishra et al. also include temperature and rainfall in absolute value and squared (to test for a nonlinear effect). The migration variable is defined as migration of the entire household and can thus be interpreted as permanent migration. The results do not indicate a statistically significant effect of disasters, apart from landslides, whose effects are marginally significant. The authors find a large significant effect on internal migration from temperature, however, and a smaller but also significant effect from rainfall; both effects are nonlinear. This evidence is thus compatible with the literature on sudden-onset disasters inducing temporary migration but not always permanent migration (Perch-Nielsen et al. 2008). The study does not test explicitly for the mechanism behind the significant large nonlinear effect of temperature (and the smaller effect of rainfall). In separate regressions of the effect on the value of households' assets, the authors find that households' assets are negatively correlated with temperature (but not with rainfall or disasters, apart from landslides), a result that may be compatible with an indirect economic mechanism, rather than a direct amenity effect, explaining their main result.

Several findings from either tornado or flood events indicate that households may not necessarily migrate following such an event. Paul (2005) reports results from a survey of 291 individuals from eight tornado-struck villages in Bangladesh. No one stated that a member had migrated to other areas, and the main reason given for not migrating was effective disaster aid and its proper distribution. Different migration responses to different types of natural disasters do indeed depend on existing government insurance or warning schemes. As Boustan et al. (2012) argue, government flood control schemes that began to be installed in the 1910s may explain why, during the 1920s to 1940s, US areas with floods had net in-migration, whereas tornado-struck areas experienced out-migration.

Perch-Nielsen et al. (2008), in their review, focus specifically on floods and sea level rise. The evidence reviewed by the authors indicates that flood responses often take forms other than migration and that, if migration occurs, it is temporary. In particular, results from a large household survey undertaken by IFPRI in rural Bangladesh over 1994–2010 show that exposure to floods did not statistically increase long-term migration compared with the case for non-flood-related crop failure, which was a more significant explanatory factor (Gray & Mueller 2012b).

An underresearched topic is return migration. If people move temporarily following a sudden-onset event, then what factors determine whether they return? Paxson & Rouse (2008) use pre–Hurricane Katrina data and do a follow-up survey of 355 of the same individuals between May 2006 and March 2007 (after the hurricane). Exposure to floods is the single statistically significant factor in determining whether a migrant did not return to New Orleans after the disaster. Still, 36% of those who did not suffer flooding had not returned to the area at the time of the survey. This finding may be interpreted in favor of the importance of expectations. Individuals who did not suffer flood damage may reassess their expectations of future flood damage and may choose not to return for those reasons.

2.2.3. Conclusions of the national migration studies and issues for future research. **Table 1** gives an overview of the econometric studies reviewed on migration and environmental change that use exogenous environmental variables on representative country samples, in addition to those studies reviewed in the text. What do we learn from the micro-level empirical studies summarized in this review? Most of the local studies tend to confirm that environmental change acts as a push factor. Some studies moderate this view, however. Henry et al. (2004a,b) show that the proportion of households that migrated from villages in Burkina Faso was higher among those living in areas with land degradation than among those living in areas affected only by low rainfall. The results on the impact of environmental factors on migration thus very much depend on the country or region that is studied, on the data that are used, and on the definition of the environmental variable. In some countries, adjustment is done through seasonal migration, as in Mali (Findley 1994).[3] In a cross-sectional study on Malawi, Lewin et al. (2012) reject the hypothesis of rainfall shortage acting as a push factor for migration of the household head. The results instead indicate a lower probability of migration, consistent with the hypothesis that severe weather shocks reduce a household's income and stock of capital so much that the household does not have the funds necessary to migrate. Such results may depend on the use of self-reported shock data, however. Conclusions from cross-sectional data should also be considered with caution, but the effect of rainfall variability may well be nonlinear.

The review of existing country studies raises some major methodological issues for future research. First, attention needs to be paid to the definition of the environmental change. Interpreting the empirical results is difficult when the environmental data used as explanatory variables are not perfectly matched with the timing of migration. Because most household surveys used for analysis are not aimed at analyzing environmentally induced migration, the data that would allow one to exactly link the migration decision with respect to the growing and the harvesting seasons may be missing.

Second, the spatial matching of data is also important. The commonly used data from the Climate Research Unit of the University of East Anglia are on a large grid scale (0.5 degrees latitude and longitude), and use of more finely disaggregated data from local weather stations is much needed, because the use of large grid-level data introduces noise into the measurement of a shock and does not allow one to distinguish covariant shocks from local weather shocks. Lower-level weather data exist for the tropical countries through the Tropical Rainfall Measuring Mission, which provides data on a 0.25-degree level. On a country level, some recent studies on adaptation strategies other than migration use very finely meshed climate data at the farm level. For example, Di Falco et al. (2011) use spatially extrapolated data from local weather stations in Ethiopia. But this example is a cross-sectional study, and obtaining longer time series of weather data at a local level is often difficult. A promising example in that direction is the study of the impact of natural disasters in Vietnam by Thomas et al. (2010), who use monthly rainfall grids at a 0.1-degree resolution and elaborate detailed spatial measures by distance and elevation weighting.

Third, several studies rely on self-reported shocks, which may be biased if the report of the shock (e.g., data on its magnitude and impact) is correlated with household characteristics. Many of the early studies include as an environmental variable irrigation, cropland, or arable land, each of which is endogenous and mixes environmental change with the outcome or adaptation measure. The most rigorous recent studies use objective, exogenous measures of environmental

[3]In the study by Findley (1994) on Mali, circular or short-cycle migrants are defined as migrants who left for 1 to 6 months before returning.

Table 1 Econometric studies on environmentally induced migration that use exogenous environmental variables and representative country samples

Authors	Area	Data	Environmental change measure(s)
Individual country studies			
Bohra-Mishra et al. (2014)	Indonesia	Indonesian Family Life Surveys (IFLS): 1993, 1997, 2000, and 2007	Natural disaster damage by type: earthquakes, eruptions, floods, landslides, rainfall, and temperature
Boustan et al. (2012)	United States	Census data for 1920–1940	Counts of disaster events by type: earthquakes, hurricanes, floods, and tornados
Carvajal & Medalho Pereira (2009)	Nicaragua	Nicaraguan Living Standard Measurement Studies (LSMS), 1998 and 2001	Rainfall exposure during Hurricane Mitch
Dallmann & Millock (2013)	India	1991 and 2001 census	Frequency of months with the SPI[a] either more than 1 or less than −1, duration of drought or excess rainfall, and magnitude
Feng et al. (2012)	United States	Five-year-period census data for 1970–2009	Temperature degree days[b]
Gutmann et al. (2005)	United States	County census data for 1930–1990	Rainfall, temperature, and environmental amenities: elevation, lakes
Hornbeck (2012)	United States	1910–1997 US county-level census data	Drought (Palmer Drought Severity Index) and temperature variables in the 1930s
Lewin et al. (2012)	Malawi	Malawian Living Standard Measurement Study (LSMS), 2004–2005 (cross section)	Combinations of absolute rainfall and CV[c] compared with past 30-year average, self-reported droughts/floods
International studies			
Afifi & Warner (2008)	172 countries	The bilateral migration stock matrix of the DRC[d] (base year 2000)	13 dummy variables for environmental degradation
Alexeev et al. (2011)	178 countries	OECD nonstandardized migration flow data for 1986–2006 and the USINS[e]	Weather and nonweather disasters: numbers of disasters, people affected and killed
Beine & Parsons (2015)	166 destination and 137 origin countries	Flows calculated as differences of bilateral migrant stock data from Özden et al. (2011) for 1960–2000	Rainfall and temperature deviations and anomalies[f], natural disasters
Coniglio & Pesce (2015)	29 OECD destination countries and 128 origin countries	OECD nonstandardized migration flow data for 1990–2001	Rainfall and temperature surplus and deficit, interannual rainfall variability
Marchiori et al. (2012)	Sub-Saharan Africa	US Census Bureau, 1960–2000 data	Rainfall and temperature anomalies[f]

(*Continued*)

Table 1 (*Continued*)

Authors	Area	Data	Environmental change measure(s)
Naudé (2009)	45 sub-Saharan African countries	UN population division net migrant data, 5-year averages for 1960–2005	Counts of natural disasters
Reuveny & Moore (2009)	15 OECD destination countries	OECD nonstandardized migration flow data for the 1980s–1990s and the USINS	Weather-related disasters

[a]The Standardized Precipitation Index (SPI) is a standardized measure of drought allowing for comparisons across different locations.
[b]The number of days in an agricultural season when temperature exceeds the minimum growing requirements.
[c]CV denotes coefficient of variation.
[d]The DRC refers to the Development Research Centre on Migration Globalisation and Poverty at the University of Sussex.
[e]The USINS refers to the Statistical Yearbook of the US Immigration and Naturalization Service.
[f]Such anomalies are defined as the deviation in the variable from the long-term mean, divided by the long-term standard deviation.

anomalies. A commonly used indicator of ex ante risk is the coefficient of variation of the variable in question, whereas ex post risk is measured as the difference between the realization of the variable and its long-term mean. In a panel data analysis, to be able to define the length of an event, in addition to its occurrence and its magnitude, is useful. This approach is feasible only by using meteorological indicators, such as the Palmer Drought Index or the Standardized Precipitation Index (SPI). Conceptually, such variables amount to using a z score for the deviations, but they allow one to define exactly the beginning and the end of a drought or a flood period. One example is the study of Dallmann & Millock (2013), who construct variables measuring the frequency, the duration, and the magnitude of either drought or excess precipitation by using the SPI. Using the complete census data to construct bilateral migration rates, Dallmann & Millock find that interstate migration in India increases with the frequency of drought in the state of origin but is unaffected by the duration and the magnitude of the drought and by any measure of excess precipitation.

Finally, the choice of method and econometric specification needs to account for the endogeneity in the decisions to participate in the off-farm labor market, to migrate, and to send remittances. As shown in the theoretical household decision model by Mensah-Bonsu & Burger (2008), the migration decision affects agricultural productivity. The sign of this effect is not obvious: The loss of an extra laborer to the household may be quite small in a situation of surplus labor, whereas such a loss may be large in another situation. Panel data are thus necessary to avoid problems of reverse causality. Finding good instruments for some endogenous variables, such as wages, remains a challenge. The literature shows that off-farm labor market participation can diversify away idiosyncratic shocks, such as crop failure on individual farms (Kochar 1999), but weather risk is spatially covariant. A weather shock that depresses farm income will then have negative effects on off-farm labor demand due to market effects. Badiani & Safir (2010) study ICRISAT household panel data from six villages in India and show some evidence that households turn to migration when local labor markets are hit by a covariant shock.

Overall, the findings of the country or regional studies are heterogeneous, and the migratory response depends on the type of environmental change. The advantage of this kind of study, however, is the level of detail of the data and the possibility of studying the interaction between exposure to the environmental variable and socioeconomic characteristics of the household and the policies or institutions that may intervene to mediate the impact. The results of any particular study may be difficult to generalize outside of the particular country, however, compared with studies of international migration, to which we now turn.

2.3. Regional Population Distribution and International Migration

One of the first studies to link climate change and migration analyzes the impact of rainfall on urbanization, rather than migration directly. Data on the distribution of population over time are indeed more readily available than time series data on migration. Barrios et al. (2006) compare urbanization patterns in sub-Saharan African (SSA) countries with urbanization patterns in the rest of the developing world. Barrios et al. use a specific-factor model of production with capital, labor, and land, where rainfall determines the effective land input. In such a setting, a decline in rainfall should increase the urbanization rate. The authors use an unbalanced panel of 78 countries from 1960 to 1990 to test the hypothesis of scarce rainfall pushing people out of rural areas into urban areas. The results indicate that a 1% fall in normalized precipitation increases the urbanization rate by 0.45%. Estimations with an interaction effect for SSA countries and separate estimations on the group of SSA countries and non-SSA countries show that rainfall has an effect only on the urbanization rate in SSA countries, and not on the urbanization rate in other

developing countries. The coefficient on the interaction effect between rainfall and the dummy for SSA countries is much stronger than the coefficient for the entire sample, although the sample size is quite low for statistical inference for the SSA (36-country) group.

The studies on international migration that followed the study of Barrios et al. (2006) first focused on natural disasters. Naudé (2009) finds evidence of natural disasters acting as a push factor on migration in SSA, but not elsewhere, in a study on data from 1960 to 2005. His study is one of the first to address a potential link between natural disasters and international migration, and it includes the total number of natural disasters during a 5-year period, using data from the Centre for Research on the Epidemiology of Disasters (CRED). The estimated effect from natural disasters on migration in the SSA is not large in terms of statistical significance and may be linked to the use of a count variable that does not measure the magnitude of the impact of the disasters. However, Naudé also notes and tests for the link between disasters and conflict, which turns out to be a significant driver of international migration in his sample.

Alexeev et al. (2011) study the impact of natural disasters on bilateral migration flows on a larger sample consisting of 178 countries but that excludes south-south migration. They use a combination of natural disaster variables from the GEO Data Portal for the period 1986–2004 and from the EM-DAT database of the CRED for 2005 and 2006. The dependent variable is bilateral migration flows, and natural disasters both in the state of origin and in the state of destination are used as explanatory variables. Alexeev et al.'s results indicate that natural disasters act as a push factor in the state of origin but as a pull factor in the state of destination. Their analysis further shows that foreign aid mitigates the expected migration flows. The migration data used by Alexeev et al. are the OECD nonstandardized data, however, so there may be much noise in the definition of the bilateral migration flows.

The most recent studies on climate change–induced migration have attracted the most attention. Marchiori et al. (2012) analyze the theoretical framework of rural-urban migration leading to a wage decrease in the urban area that would push workers from urban areas into international migration. At the same time, on the basis of economic geography arguments, Marchiori et al. argue for an agglomeration effect that would increase the urban wage rate. The agglomeration effect could then induce still more rural-urban migration, all else equal. The authors thus emphasize the existence of a direct amenity channel for climate-induced migration flows (e.g., health impacts) and an indirect channel through wage effects following rural-urban internal migration. They test these hypotheses through two-stage least-squares fixed-effect estimations with instruments for the endogenous wage rate and urbanization rate. Their empirical analysis confirms that weather anomalies lead to increased migration flows from the rural to the urban sector in SSA and that weather anomalies have a significant impact on GDP per capita. Their estimations also confirm a secondary effect on an increase in international migration from a higher GDP per capita and a higher urbanization rate. These authors estimate that 5 million people moved between 1960 and 2000 due to weather anomalies in SSA.

Beine & Parsons (2015) is arguably the most comprehensive study of international migration and environment to date. Beine & Parsons use the recently developed data by Özden et al. (2011) on bilateral migration stocks corresponding to five rounds of census data to estimate bilateral migration flows on the basis of a random utility model including environmental factors. The data include the period 1960–2000 for 166 destination countries and 137 origin countries. This is one of the few papers on environmentally induced international migration to include south-south migration. The authors control for both sudden-onset environmental factors, such as natural disasters, and slow-onset climatic factors, which are calculated as positive and negative temperature and rainfall deviations from the long-term mean. Beine & Parsons also include rainfall and temperature anomalies, measured as in Marchiori et al. (2012) as the deviation from the

long-run mean of the variable divided by the long-run standard deviation. Given the high percentage of zero observations in bilateral migration flow data, Beine & Parsons estimate the migration equation by using a Poisson pseudo-maximum-likelihood estimator. The results show no evidence of a significant effect of either temperature or rainfall deviations or anomalies on international bilateral migration flows. When one conditions on origin country characteristics, there is evidence that shortfalls in precipitation decrease migration to developing countries from countries specialized in agriculture but increase migration to developing countries from countries with few groundwater sources. In contrast, Beine & Parsons find that natural disasters have a significant positive effect on rural-urban migration in developing countries (but not in developed countries), as measured by the urbanization rate. Contrary to the findings of Barrios et al. (2006) and Marchiori et al. (2012), Beine & Parsons find that rainfall deviations are never significant in explaining the urbanization rate in developing countries. The results are quite strong, given that south-south bilateral migration flows are included in the sample, but when interpreting them one must bear in mind that the data come from 10-year stock data and that extrapolation over a long time period tends to smoothen out any variation in environmentally induced variation in migration over the time period studied. In this sense, the result may be seen as evidence against increases in long-term migration averages. Although Beine & Parsons control for bilateral migrant networks and do several robustness tests, there may be unaccounted-for omitted-variable bias from the existence of insurance in the form of bilateral remittances if remittances vary with the temperature and rainfall deviations (as Yang & Choi 2007 show for the Philippines) and help to smoothen the environmental shocks. The authors do not test for environmental factors in the destination states, which may be relevant here, given that the sample includes south-south migration.

Coniglio & Pesce (2015) further refine the analysis by using more detailed definitions of the weather variables. They separate positive and negative anomalies during the dry season and the rainy season and include interannual variability of rainfall, defined as the mean absolute deviation over the long-term mean absolute deviation for each of the three lags considered in the analysis (1, 3, and 5 years before the observed migration flow). The other major difference from the work of Beine & Parsons (2015) is the use of the yearly OECD bilateral migration flow data. These are unbalanced panel data on bilateral flows between 29 OECD countries and 128 origin countries over the period 1990–2001, thus excluding south-south migration, in contrast to Marchiori et al. (2012) and Beine & Parsons (2015). The data are problematic because the definitions of migrants are not standardized, but the same data are used for other international migration studies (Ortega & Peri 2009, Mayda 2010), and Coniglio & Pesce do a robustness test on alternative data: yearly migration flows from the UN Population Division. The results show a statistically significant effect of the variability of rainfall on out-migration to OECD countries, especially for origin countries with a large agricultural sector. If variability mainly affects income (and, in particular, agricultural income), the income variable should be instrumented, but Coniglio & Pesce do not choose this approach. Apart from the wide set of weather variables, the other contribution of Coniglio & Pesce is that they emphasize the importance of migration corridors by interacting interannual rainfall variability with dummy variables for each origin-destination country pair and show a different impact according to each specific migration corridor.

To conclude discussion of the international studies, Barrios et al. (2006), Naudé (2009), Marchiori et al. (2012), and Beine & Parsons (2015) include south-south migration (or study only such migration) in their samples, whereas Alexeev et al. (2011) and Coniglio & Pesce (2015) focus on data from OECD in-migration only. The main difference in results between the international studies thus stems from the data used: whether the data are extrapolated from migrant stock data or from higher-frequency data. Migration flow data inferred from migrant stock data give averages over 5- or 10-year intervals and cannot capture return migration or migration to third countries in between. The use of more frequent data on actual flows catches short-term variability

in migration flows and allows for a more direct causality between the time of the change in the environmental variable and the migration flows, but this approach is subject to more noise because these data are not standardized and they also do not currently include south-south flows. The other main difference comes from the environmental variables included: natural disasters only, or both natural disasters and slow-onset environmental factors, such as long-term changes in climate. Some studies develop an underlying theoretical framework and hypotheses to test. In particular, Marchiori et al. (2012) propose a theoretical argument for the link between internal migration and its impact on international migration. This study is also the only one that coherently tests for internal migration and international migration in the same model and that instruments for the endogenous variables (the per capita wage and the urbanization rate). Beine & Parsons (2015) and Coniglio & Pesce (2015) are the only studies to include migrant networks, a very important factor in migration. Alexeev et al. (2011) include overseas aid, which also seems important to account for. However, no existing study includes remittances. Remittances from the existing network may decrease the probability of migration (because they provide the household with another coping strategy), whereas migrant networks in the existing studies are interpreted only as a factor that reduces the cost of migration, thus increasing the probability of migration.

Finally, to predict future migration flows, a recent development is the adaptation of dynamic general equilibrium models to include an explicit spatial dimension for evaluating climate change impacts. Brock et al. (2014) develop an energy balance climate model that links heat transportation with growth models to assess the spatial distribution of climate change impacts. Labor is not mobile in this model, however. Desmet & Rossi-Hansberg (2012) develop a spatial model of the Northern Hemisphere with perfect labor mobility across sectors and within countries. The model is calibrated on current data and is used to simulate, over 200 years, the welfare impact of temperature increases across latitudes (where all locations at the same latitude share the same welfare). Restrictions on migration increase the welfare loss from global warming, as expected, because it restricts adaptation via mobility and changes in specialization patterns across regions. Desmet & Rossi-Hansberg assess the welfare loss from migration restrictions by allowing free mobility within the north and within the south, but not between the two regions. Under this scenario, the north benefits from global warming, whereas the south suffers a welfare loss. In an extreme scenario with free mobility (and zero transportation costs, implying free trade), the population-weighted average welfare loss is 0.38%, whereas with complete migration restrictions (between the north and south and within each of the two regions), the welfare loss is 5.38%.

3. WHAT CAN WE LEARN FROM THEORETIC MODELING?

Compared with the large body of empirical work, theoretical modeling of environmentally induced migration is scant. The classical Tiebout (1956) model assumes that individuals sort over space according to the income net of transfers and the level of the local public good provided. If environmental quality is included, it is always as a local public good. The approach has notably been used to analyze the environment as an amenity and to explain internal migration on the basis of either weather characteristics in certain locations or local waste problems. An important recent contribution to this literature is that of Banzhaf & Walsh (2008), who test the Tiebout hypothesis directly on census data from California from 1990 and 2000 and find strong evidence that migration is correlated with the toxic airborne emissions listed in the Toxic Release Inventory.[4]

[4]Cameron & McConnaha (2006) also empirically test whether there were demographic changes at the census tract level in locations near four Superfund sites of environmental hazard.

This approach can thus treat locally confined pollution problems without spillovers across regions but seems less adapted to the current problem of global environmental change. The environmental good that is relevant in this case—the climate cycle—is a global good, and the realization of the environmental shocks may be spatially correlated. In reviewing theoretical approaches to environmentally induced migration, I instead focus on four different approaches. Following the empirical evidence, I start with an overview of models adapting the Harris-Todaro model of rural-urban labor migration. Next, I review the recent modeling incorporating environmental damage into new economic geography models. Then I see what insights can be gained from models of population mobility with interregional environmental externalities and open-economy models with pollution externalities. Finally, the most recent theoretical modeling aims at coupling migration dynamics with economic growth models using dynamic systems of equations.

3.1. Rural-Urban Migration Models

In the best-known model for studying rural-urban migration flows, i.e., the Harris-Todaro model (Todaro 1969, Harris & Todaro 1970), migration depends on the difference between the wage in the agricultural rural sector and the expected wage in the urban sector; the expectation is based on the probability of finding work times the exogenous wage in the urban sector (possibly set by regulation in the form of a minimum wage). Tawada & Nakamura (2009) extend the Harris-Todaro model to include a negative environmental externality from manufacturing on the productivity of the agricultural sector. The environmental damage thus affects production but does not directly affect the utility of individuals or households. Tawada & Sun (2010) then extend the Harris-Todaro model to include also the direct impact of environmental conditions on the representative individual's utility. In Tawada & Sun's model, pollution affects productivity in the urban sector but also urban workers directly through disamenity effects. The indirect utility in the rural sector also depends on environmental quality, but it is assumed to be exogenous and constant in the model. Under the stability condition that the urban area is more capital intensive than the rural area, Tawada & Sun show that a decrease in emissions—through better technology, for example—increases output in the manufacturing sector, decreases output in the rural sector, and increases unemployment in the urban area while improving environmental quality. The explanation for the result for urban unemployment lies in the increase in indirect utility from the improved urban environment that can be compensated for only by a decrease in the expected wage in the urban sector. Although Harris-Todaro models can analyze general equilibrium effects, the results hinge on the nonadjustment in the rigid urban wage rate. The model is also static and cannot account for feedback effects that may be important for environmental change.

Another complementary approach is the household models used in development economics. These models cannot include general equilibrium effects but have been frequently used to model microeconomic decisions in rural-urban migration. Such models are compatible with the new economics of labor migration, in which the decision is typically based on utility maximization of the household. Hence, Mensah-Bonsu & Burger (2008) propose a typical household model in which the labor migration decision is ultimately based upon the arbitrage between the expectation of remittances sent by a potential migrant and her or his contribution to the marginal productivity of labor in agricultural production. The result is an arbitrage equation that determines upper and lower bounds on the amount of remittances that have to be sent to compensate for the loss of a marginal worker. Environmental factors (in this case soil quality) are included in the production function for agriculture.

3.2. Economic Geography Models

Some recent papers introduce a more explicit spatial component of environmental damage, production, and migration of labor by using new economic geography modeling. Elbers & Withagen (2004) and Lange & Quaas (2007) analyze agglomeration economies, using a core-periphery model that includes local pollution (see also Hosoe & Naito 2006). These models incorporate a direct effect on utility from the environmental bad (pollution), and skilled workers migrate according to the difference in indirect utility that they obtain in the two locations. Plant location is endogenized because of the mobility of skilled labor that is affected by pollution. Although there is no direct externality on production as such, high environmental damage acts as a spreading force and can result in an effect similar to that when transportation costs are high. The conclusions from incorporating environmental damage into this kind of model are that it normally weakens the aggregating forces because pollution can be seen as a congestion problem, and the result is a larger number of potential equilibria. This purely positive analysis does not include potential policy instruments. In another analysis of biodiversity and land use, Eppink & Withagen (2009) show that the consideration of biodiversity makes industrial clustering less likely in a model in which skilled workers are mobile. Eppink & Withagen compare cooperative and strategic policy between the governments in the two regions, which is a necessary feature to incorporate into the analysis of environment and migration. Kyriakopoulou & Xepapadeas (2013), in contrast, analyze the use of emission taxes in a spatial model of location with knowledge spillovers, transportation costs, and atmospheric dispersion of local air pollution that enters negatively into the indirect utility of the homogeneous labor force. As in the other models of this kind, migration of workers is a consequence of the endogenous location choice of firms. In this setting, Kyriakopoulou & Xepapadeas show that environmental taxes act as a centrifugal force and decrease agglomeration. In an extension of Elbers & Withagen (2004) and Lange & Quaas (2007), Ciucci (2014) uses the core-periphery model, with skilled workers who are mobile across regions and unskilled workers who are not, to analyze environmental policy as a noncooperative Cournot game in emission taxation between regional governments. This kind of modeling seems to be a very promising approach for analyzing environmentally induced migration and its equity aspects.

3.3. Population Mobility and Interregional Environmental Externalities

Environmental economics has dealt much with the problem of interregional environmental externalities and strategic choices through decentralized decision making by local government. Wellisch (1994, 1995) introduces the study of the role of household mobility for decentralized environmental policy. In such models, migration is not a problem; rather, perfect household mobility can make governments internalize transboundary externalities. Silva (1997) analyzes a unidirectional externality and shows that pollution abatement in the upstream region reduces the average individual's incentives to move into the region (because the public good of pollution abatement is financed by a head tax). Population mobility thus appears to be a potential solution to the problem of coordinating environmental policies when there are transboundary externalities. These models thus capture the important interlinkage between environmental policies and migration policies that affect the cost of migration and thus population mobility. Hoel & Shapiro (2003, 2004) show that with perfect population mobility the socially efficient allocation of emission reduction can be supported as a Nash equilibrium of the policy game between independent regional authorities setting decentralized policies. However, other Nash equilibria may exist. These analyses do not deal with the dynamic aspect of migration, which may occur with some delay and is costly. In fact, Hoel & Shapiro's work generalizes several of the earlier models of

transboundary pollution to more general assumptions on the form of the pollution externality. However, all these models are static.

Haavio (2005b) conceptualizes migration dynamics in a model of a stock pollutant with costly migration. In this dynamic setting, household mobility enables the households to evade responsibility for environmental damages by moving away. The combination of environmental damage that accumulates over time and costly migration leads to overpollution, and the efficiency result from the earlier models breaks down. International policy coordination is thus necessary to reduce environmental damage, even when the damage is local and has no regional spillovers. Haavio (2005a) shows that the result relies on the type of instrument used in environmental policy and on whether there are congestion effects. If there are congestion effects, for example, the country could choose to tolerate a higher level of environmental damage if it encourages outmigration. The model developed by Haavio (2005a,b) constitutes an important contribution to modeling environment and migration because it takes into account both the accumulative nature of environmental damage and imperfect mobility in a dynamic game between governments and shows how these interact to yield incentives to deteriorate the environment more than what would have been optimal in a cooperative equilibrium.

As shown in this review, the link between environmental and migration policies is important and could be further explored. If migration depends in part on environmental conditions, an obvious hypothesis is that migration policies and environmental policies are interlinked and cannot be optimally designed without their effects on one another being taken into account. Sandmo & Wildasin (1999) develop this intuition in an early paper. They use a two-sector model in which one of the industries pollutes proportionally to its output and imposes an externality on all identical domestic residents. The supply of immigrants into the domestic economy is a function of the wage rate, net of any transfers to immigrants, and the domestic pollution level. The domestic pollution level is dependent on domestic production but also on transboundary pollution created by production abroad, which is not modeled and is assumed to decrease in immigration. Labor markets clear, and government imposes output taxes on the polluting industry and distributes fiscal transfers in addition to financing a public good. Sandmo & Wildasin show that, in the presence of a binding immigrant quota, the optimal pollution tax exceeds the level that internalizes the marginal cost of pollution to the country's residents. The explanation of this result lies in the assumption of domestic resident ownership of the firms: The reduction in the domestic wage rate benefits domestic residents in terms of their share in the profits of the domestic firms and hence results in the redistribution of income from immigrants to domestic residents. If government can differentiate its transfers to residents and immigrants, immigration quotas are welfare dominated by taxes. In an alternative policy, relying on this differentiation in transfers, Sandmo & Wildasin show that the optimal pollution tax takes the preferences of immigrants into account, although the model supposes a government with the objective of maximizing only the welfare of its own residents. The linkage occurs through the transboundary pollution that is determined by the levels of mobile labor in each country. The domestic government does not take immigrant welfare into account but must optimize taking their preferences into account because immigration levels will change the equilibrium supply of the public good and fiscal transfers. As the authors suggest, the two industries could be interpreted as the rural sector and the industrial sector if one assumes free migration between the rural sector and the urban sector. The model can thus be applied to study rural-urban migration and even regional development if all factors are assumed to be mobile. The limitation of the analysis is that it relies on the assumption of a small economy whose government maximizes the welfare of its own citizens, with no strategic interactions between governments. The welfare of immigrants and determinants of migration are not examined, whereas the migration literature would make migration a function of the difference in the wage rates between the two

countries, rather than only the domestic wage rate as here. The model is static and does not account for costs of migration and adjustment over time. Explicit modeling of the environmental damage function and possibilities to abate emissions could also be possible extensions.

Marchiori & Schumacher (2011) extend the analysis of environmental and migration policies by using a dynamic model of costly international migration with both environmental and immigration policies. The authors analyze the steady state of a two-country overlapping-generations model of international migration from the south to the north. Greenhouse gas emissions are modeled as a production externality from the stock of capital in the north; the higher the north's capital stock, the higher is the increase in temperature that negatively affects the productivity in the south, all else equal. Feedback effects from increased migration from the south to the north can have an indirect effect on climate change and can further reduce productivity in the south (through the emissions from the increased output in the north). Marchiori & Schumacher study in detail two policy options for the north: (*a*) border control that increases the costs of migration for migrants from the south and (*b*) investment in green technology in the north. Both policy options are assumed to be fully financed by the levying of taxes on the output in the north. In particular, Marchiori & Schumacher study the impact on equity resulting from the choice of the two policies. One of the many interesting results of the model is that the welfare impact of investment in green technology is ambiguous in both the north and the south, although it may reduce the pollution stock that causes climate change and may reduce the number of migrants. In fact, even if there is a direct positive effect on productivity in the south from the resulting smaller temperature increase, the subsequent smaller migration from the south to the north implies a reduction in utility because of the model's assumption of decreasing returns to scale in production, and overall, the utility in the south may decrease.

3.4. Open-Economy Models with Environmental Externalities

The empirical work reviewed in Section 2 is split into analyses at the country or regional level and models of international migration. The first studies of international migration and environment lack theoretical foundation and are based directly on reduced-form gravity equations. Others use structural equations to derive the gravity estimations, in particular the study of Gröschl (2012), who adapts Anderson's (2011) migration model to environmentally induced migration. The norm for studying international migration and environment is now the analysis of bilateral (dyadic) migration flows on the basis of random utility models that assume that the individual's or household's probability of migration is a function of the relative ratios of wages and other socioeconomic characteristics in the origin state and the destination state. This approach, as seen in Section 2, allows for the inclusion of bilateral factors such as networks and migration policies. Theoretically, open-economy models with labor mobility could also be used to give structure to the empirical work. Classical two-sector, two-factor, two-region trade models may incorporate damage from manufacturing production as an externality to the agricultural sector (which may be interpreted as any sector that relies upon the natural environment as a production factor). This approach is indeed a rather classical formulation of pollution as a production externality analyzed by Copeland & Taylor (1999). They use a Ricardian model and show that trade can spatially separate a polluting industry from the sector that suffers its externality when there is no factor mobility. Attempting to extend the Copeland & Taylor (1999) model to include migration, Kondoh (2006, 2007) models a polluting manufacturing sector that imposes an externality on agriculture. Migration occurs because of a wage differential. No direct effect on utility from environmental damage is included in the model. These models have not been used so far to explain environmentally induced migration, but instead they capture the other causality: how migration

may affect pollution. Kondoh (2006), for instance, shows that migration increases world pollution by increasing world demand for the manufactured good via a wage effect.

As some of the empirical papers reviewed in Section 2 show, property rights matter in exploring the relations between migration and environment. One of the few theoretical papers to include property rights in the analysis is a paper using a Heckscher-Ohlin model of international trade and natural resources as a production factor. Chichilnisky & Di Matteo (1998) build a simple two-factor, two-sector, two-final-good model and introduce a migration decision equation in the form of the ratio of net wages. Because the model of Chichilnisky & Di Matteo includes, as production factors, only labor and a natural resource, they can study the feedback effects of migration on natural resource use in the resource-rich region (the south). One of their main results is that migration can decrease exploitation of the natural resource in the south, where it was previously overexploited, because of unenforced property rights.

3.5. Coupled Models of Migration Dynamics and Growth

Finally, recent work situated in a wider effort to couple ecological and economic models aims at jointly modeling the dynamics of migration and economic growth to measure the impacts of migration on the receiving and sending regions. As reviewed in Section 2.3, one strand of this literature develops dynamic general equilibrium models to measure climate change impacts on the spatial distribution of economic activity (Desmet & Rossi-Hansberg 2012, Brock et al. 2014). Petracou et al. (2014) describe and test a model with a population balance equation and a weight function, including the probabilities of migrating from region i to region j. The population balance equation is then coupled to a standard Solow growth model, giving rise to a dynamic system that can be simulated. Migration depends on macroeconomic conditions but affects those same variables. If the model is accurately calibrated, it can be used to assess the impact of migration on the economic outcomes in the sending and receiving countries. One challenge with this kind of theoretical approach is how to define the matrix of migration probabilities. The coefficients used need to be inferred from econometric discrete choice modeling. An advantage of the approach is that the transition probabilities of migration can be modeled as random. The solution to the dynamic system normally requires simulations, however, and depends on the quality of the available data.

4. CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

This survey attempts to give a comprehensive overview of the existing literature on migration and environment, with particular emphasis on recent results in the economic literature. This focus obviously limits the review because a complete analysis of migration and environment would draw on many disciplines, such as climatology, geography, political sciences, and social sciences such as anthropology. The focus is on the contribution of economic modeling to the debate and on the extensions of current models that could be done to yield further insights into the problem of environmental change and migration. In particular, spatial models of land use with mobility of labor offer some interesting directions for future research. The policy conclusions of much of the current modeling also need to be made more explicit through the incorporation of explicit policy instruments into the models and through an analysis of the links between environmental and migration policies. One important aspect of such an analysis would be to study in more detail the impact on equity of proposed policies to deal with the environment-migration nexus. Including heterogeneity among agents with regard to adaptation capabilities and migration costs would be another useful direction for future research because indirect general equilibrium effects may cause

migration by agents who have not been directly affected, whereas the directly affected populations may be too poor to incur the costs of migration. Finally, more explicit modeling of the expectations of agents seems important because the migration decision is made on the basis of the agents' perceptions of the environmental change and their expectations on the duration of its impact. Some existing empirical research shows that previous exposure to environmental shocks is significant in determining who migrates and who does not.

On the empirical side, several recent analyses propose structural econometric models of migration flows into the OECD or use population distribution data on a regional level (e.g., Africa) to better analyze the impact of environmental change. All the most robust studies use exogenous measures of rainfall, temperature, or degree days as explanatory variables (as opposed to self-reported shock data or ad hoc measures of environmental change). Although such data have been very useful for testing the hypothesis of climate variability as a push factor for international migration, there are still problems with the coverage of such data, which are sometimes on too high a level to be relevant for local country studies. In such cases, the matching of detailed household data with spatially aggregated weather data introduces unnecessary noise and may bias the results if the data do not coincide at the relevant spatial level. More empirical work that uses finely disaggregated data and that takes into account spatial factors seems necessary.

Overall, the existing theoretical and empirical research makes clear that migration is only one of several potential strategies used by households to cope with environmental change. Whether this strategy is superior to others, such as increasing off-farm labor market participation, needs to be assessed in models that take market potential into account. This constitutes yet another challenge for empirical work based on new economic geography models. Current research also gives some indication that the use of migration as an adaptation strategy depends on the frequency of exposure to droughts and on the existence or not of public policy aimed at reducing the risk of a disaster (e.g., early warning systems) or at providing assistance after the event.

This review focuses on methods, rather than on the actual estimated or future predicted numbers of environmental migrants. Although such estimations are in much demand for policy purposes, it is crucial to understand by what means such estimations are done, to define which methods need more improvement, and to identify the areas in which future research might be directed. The UK government's *Foresight* report (Government Office for Science 2011) helps in this effort to produce new research on the migration-environment nexus. As Black et al. (2011) discuss, migration is increasingly being seen as a possible means of adaptation to environmental change, and not as only a fatality, and more research efforts are directed at understanding how to reduce the vulnerability of exposed populations. Poor households may migrate to environmentally vulnerable locations or may contribute to exacerbating the environmental risk in some urban areas. This other causality, which this article does not discuss in detail, is one important area for future research.

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