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► **To cite this version:**

Katrin Millock, Cees Withagen. Climate and Migration. Anil Markandya; Dirk Rübelke. Climate and Development, 1, WORLD SCIENTIFIC, pp.309-342, 2021, World Scientific Series On Environmental, Energy And Climate Economics, 978-9811240546. 10.1142/9789811240553_0010. hal-03513161

HAL Id: hal-03513161

<https://hal.science/hal-03513161v1>

Submitted on 5 Jan 2022

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Chapter 1

Climate and Migration

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We review some of the recent estimates of the effect of weather and climate on migration, and articles examining the historical evidence of such links. We identify four issues that have received less attention in previous reviews on the topic. The first one is general equilibrium effects of climate change and migration. The second one concerns accounting for thresholds in the climate-migration relationship. Some of the articles that we review incorporate non-linear effects, but only in the relation between income and migration, and in the relation between weather, climate and migration. Other thresholds are not yet incorporated into the literature. A third issue where much work remains to be done relates to climate change and conflict, and their influence on migration. Finally, we conclude with some reflections on the implications of the results for economic development.

1. Introduction

Environmental migration, in particular migration induced by climate change, has become an urgent policy concern. Migration is increasingly seen as a means of adaptation to climate change (Black *et al.*, 2011a), both as a response to gradual changes in temperature and precipitation and slow-onset processes such as land degradation, drought and desertification, but also to rapid-onset events, such as tropical storms and floods. The image of huge migration flows across international borders being driven by climate change has been tempered somewhat, as most migration across borders

is costly and surrounded by policy barriers (see, *e.g.*, Beine and Parsons, 2015). Human mobility is normal and takes many forms, including both international and internal migration, either temporary or permanent, circular migration (Findley, 1994) and also involuntary displacement or immobility. Indeed, Boas *et al.* (2019) call for reframing the research on climate-induced migration to ask how and to what extent climate change affects established patterns of mobility.

There is much evidence though, both historically and currently, of internal and regional migration due to climatic events. Hugo (1996) discusses the millions displaced by the extreme droughts that occurred in Sub-Saharan Africa from 1968 to 1973 and from 1982 to 1984. The World Bank's Groundswell Report, issued in 2018, quantified the number of projected internal migrants in Sub-Saharan Africa, South-East Asia and Latin America as 145 million by 2050 in the worst case scenario (Rigaud *et al.*, 2018). These numbers, although impressive, have to be put in perspective with actual migration patterns. In 2019, there were 272 million international migrants, representing 3.5% of the world population. In addition, at the end of 2018, there were 25.9 million refugees displaced involuntarily across international borders. A small part of internationally displaced persons are asylum seekers, who can seek legal protection from the government of the destination country on the bases of recognized motives for leaving and not being able to return to their country of origin. The International Organization for Migration (2020) counts 3.5 million asylum seekers at the end of 2018, mainly from a small set of conflict-ridden origin countries. Given the costs of crossing international borders, most migration is internal, though, and has been estimated to at least twice the number of international migrants. Whereas migration is seen as a voluntary choice, displacement captures involuntary mobility. The Internal Displacement Monitoring Center (IDMC) estimates the stock of internally displaced people to 41.3 million people at the end of 2018 (Internal Displacement Monitoring Centre, 2020). Disasters have always been linked with human displacement, in the best case of temporary nature (Perch-Nielsen, Bättig and Imboden, 2008; Berleemann and Steinhardt, 2017). In 2018 alone, 28 million people were displaced within national borders, of which 17.2 millions were linked with disasters and 10.8 million linked with conflict (abstracting from any potential link between the two).

In addition to these absolute estimates of future migration flows, the empirical literature on climate change and migration gives estimates on the share of past migrants that can be inferred to weather shocks or cli-

mate variability, as well as projections of future flows. Marchiori, Maystadt and Schumacher (2012) estimate that temperature and rainfall anomalies caused a total displacement of 5 million people in Africa during the period 1960-2000, *i.e.*, a minimum of 128,000 people every year. The projections based on their estimations predict 11.8 million additional migrants in Sub-Saharan Africa by 2099. For India, Dallmann and Millock (2017) find that an increase in the frequency of droughts leads to an increase in the bilateral inter-state migration rate of 1.5 % on average, and by 1.7 % in agricultural states. Applying these estimates to past migrant flows over 5 years, they find 11.96 million additional migrants due to drought, or a yearly mean of 2.4 million displaced by drought alone during 1996 to 2001. For comparison, the IDMC states that 3.7 million people were displaced due to natural disasters in India in 2015 alone.

International studies give estimates of the changes in current migration rates that may be expected from increases in temperature. Cai *et al.* (2016) estimate that each 1° C increase in temperature implies a 4.7% increase in outmigration from the top 25% agricultural countries, whereas Backhaus, Martinez-Zarzoso and Muris (2015) estimate that a 1° C higher average temperature in the countries of origin is associated with a 3.3 % increase in migration flows between a country pair over one year. This estimate is a one-year elasticity and only for countries with a large share of value added in agriculture. Cattaneo and Peri (2016) separate the response by income status and estimate that each one percent increase in temperature increases international migration rates by 4% in middle-income countries, whereas it decreases emigration rates in poor countries by 16%, *ceteris paribus*. These numbers imply that the migration rate from middle income countries would increase from 4.2% to 5%, whereas the migration rate from poor countries would decrease from 1.8% to 0.4%. When assessing these numbers, it is useful to recall that the current migrant stock constitutes 3.5% of the world's population (International Organization for Migration, 2020). Finally, Misirian and Schlenker (2017), who use UNHCR data on asylum demands specifically, project an increase of 28% in asylum applications to the European Union by 2099 (98,000 additional applications) under Representative Concentration Pathway (RCP) scenario 4.5 and by 188% (660,000 more) under RCP 8.5.

Following this overview of some of the estimates of the role of past weather variability and climatic factors in migration and the projected future migration flows, we will devote this chapter to review and discuss a few issues that have not received much attention in the literature so far, and

that have not been covered in reviews such as Millock (2015), Berlemann and Steinhardt (2017) or Cattaneo *et al.* (2019). These include general equilibrium effects of migration in destination and source countries, and implications for economic growth, the issue of non-linearities in response and thresholds, and the links between climate-induced migration and conflict. We start by briefly recalling some of the conclusions that can be drawn based on historical evidence.

2. Historical evidence

Learning from major climatic events or disasters in the past is one way to assess human mobility responses to climate change. Some studies use historical data from ancient China to better understand human responses to extreme events. Bai and Kung (2011) argue that low rainfall may have induced nomadic tribes from the steppes to invade Han Chinese regions. The nomadic economies relied heavily on rainfall and in normal circumstances their society was sustainable. However, with shocks in rainfall their economy could be severely hit, leading them to invade China's central plains, the "old" agricultural China. The study of Bai and Kung (2011) covers the period 220 BC till 1839 AD. The main finding is a positive correlation between nomadic invasions and incidence of droughts. Hence, more invasions with more severe droughts. Another historic example concerns the fall of the Roman empire, which has been argued to be related to the same causes (Brooke, 2014; Harper, 2017). The fall of Rome, from 700,000 people living there in 400 AD to 20,000 a few decades later has fascinated many historians. Many hypotheses have been proposed to explain this disaster and the further decline of the Roman empire, but more and more attention is given to natural changes as well as pandemics. Volcanic eruptions made the years 536-545 very cold, and there were also severe droughts that drove the Huns towards the West and South. In addition there were pandemics, that could relatively easily spread through the network of roads. See also Büntgen *et al.* (2011).

Using population data from preindustrial Iceland, Turner *et al.* (2012) estimate that adverse climate change reduced steady-state population levels during the 18th and 19th century by 10 to 26 % for every 1° C temperature. Boustan *et al.* (2020) gathered centennial data from the USA on disasters and estimated that the effect of a severe disaster entails a 1.5 percentage point increase in the net county migration rate. They find further that these effects differ across disaster categories. On the one hand, floods

induce net in-migration, consistent with their early work (Boustan, Kahn and Rhode, 2012), probably because an infrastructure of levees and storage reservoirs had been developed for flood. On the other hand, wildfires and hurricanes lead to net out-migration, which would be consistent with the lack of protection infrastructure in the form of early warning systems at the time. Less severe disasters have no such effects. Still, these numbers are much smaller than those found for some well-known extreme events, such as the 1927 Great Mississippi flood. The 1927 Mississippi flood followed heavy rainfall and failure of the levee system. The disaster led to large out-migration of black Americans from flooded states to the North, in part because it affected the existing labour structures at plantations but other mechanisms could also have been important. Using county-level data from 1900 to 1970, and individual data from the years around the flood, Hornbeck and Naidu (2014) show that flooded counties experienced more outmigration than non-flooded counties compared to a base year of 1925 or 1920. They also find that in the following decades landowners in flooded countries use more capital-intensive production methods compared to similar landowners in non-flooded counties. Although this consequence cannot be characterized as labour-saving technological change, it is evidence of disaster-induced migration having major impacts on the agricultural sector and its production technology. As for general equilibrium effects, which we discuss in the next section, the authors find very small local spillovers of this major flood.

Another more recent example in history comes from analyses of changes in mobility patterns and on-farm adaptation during the American Dustbowl experienced in the Midwest counties of the USA in the 1930s (Hornbeck, 2012; Long and Siu, 2018). In an analysis of agricultural adaptation in the short and long run to this major event of soil erosion, Hornbeck (2012) found little on-farm adjustment in the form of capital investments. This limited adaptation on-farm may be evidence of important adjustment costs, and of severe credit constraints following the Great Depression, which limited capital investment. Instead, population seems to have been the main margin of adjustment. In an analysis using historic county migration rates from the 1920s up to the 1950s, Long and Siu (2018) decompose the net decrease in population rates to show that it stems mainly from lower in-migration rates into affected counties rather than from higher out-migration rates. They also find marked differences in the destination choices and in the characteristics of the migrants that left the counties affected by the Dust Bowl compared to the migrants who left the same counties before the

Dust Bowl. Compared to migrants from the same counties in the decades before the Dustbowl, the Dustbowl migrants had children and worked in non-farm occupations. Instead of migrating far away (for example to California) most migrants moved to nearby counties, probably reflecting the relative costs of different moves. This detailed analysis of the historical data thus pokes holes in some of the myths surrounding the typical Dustbowl migrants and their destinations. It provides relevant evidence of how major extreme events can reshape existing migration patterns in different directions.

3. Climate-induced migration and its effects on the economy

In this section we review several general equilibrium models of the relationship between climate change and the economy. General equilibrium models are not widely used in the climate-migration nexus literature. Most models found in the literature are of a partial equilibrium nature, where migration is mainly driven by wage differentials between rural and urban regions, or between low-income and high-income countries and these differentials are taken as given. However, so-called general equilibrium effects can be relevant. Some examples are the following. Migration has an impact on the labor market in the region from where migration takes place as well as on the labor market in the region where migrants move to. Also the housing market in both regions or countries can be affected. The same holds for agricultural production in the regions from where people leave. Many more examples exist. Hence, these effects can have feedback on the decisions to migrate, and they should not be neglected if one wants to give a full picture.

First, we briefly sketch some of the theoretical models that provide additional insight. Then, we mention some applied general equilibrium models and their empirical findings. A broad distinction can be made according to governments being active or inactive in promoting the welfare of their residents.

One of the first papers on migration and transboundary environmental problems is by Hoel and Shapiro (2003). They consider a given number of countries or regions that all emit a pollutant that is uniformly mixing. Production in each region is increasing in population and emissions. Preferences are identical across all agents and depend on consumption and (country-specific) damages from aggregate emissions. The model is static in nature. Governments aim to maximize the welfare of their residents,

including migrants. Clearly, with fixed populations in the countries, a non-cooperative equilibrium has higher emissions levels than Pareto-efficiency would dictate. However, if there is unrestricted population mobility and if migration is costless, then an equilibrium will entail equal utilities for all agents in all countries. It is shown by Hoel and Shapiro that there exists a Nash equilibrium that is Pareto-efficient, in which the individual governments use environmental policy and transfers. This is a strong result. However, the game can have multiple Nash equilibria, so that coordination is needed to pick the right Nash equilibrium. Moreover, the efficiency result no longer holds if interregional transfers are ruled out. All in all, the study offers an optimistic view on migration and welfare, but only under special conditions. Also Silva (1997) and Wellisch (1994, 1995 and 2000) reason along the same lines.

However, Haavio (2005) argues that optimism is no longer warranted in the presence of migration costs and if dynamics is introduced into the model. These are important and relevant generalizations. In Haavio's model a country's emissions are proportional to consumption with factor of proportionality equal to unity. The consumer good is produced by environmental commodities only. Individual welfare depends on per capita consumption and local environmental quality, which is decreasing in the pollution stock (since our focus is on climate change we assume here that the pollution stock is global and we will call it CO₂). The atmospheric CO₂ stock decays at a constant rate. Migration is costly. The cost of migrating from one country to another depends on the number of people who are also leaving the (origin) country and on the number of people entering the (destination) country. The last part of this cost captures the fact that the new labor market cannot immediately absorb all supply, whereas the first part may be motivated by *e.g.* the fact that selling a house that is left behind is more difficult when more people leave. Governments maximize social welfare of their residents, and they do so at all instants of time, given the state of the economy. With perfect (=costless) mobility the Nash equilibrium produces a social optimum, as before. But, with constant reoptimizing, based on the current state, and with costly migration, there is too much pollution in the steady state, even more than without migration. With perfect commitment, imperfect mobility is better than perfect mobility. These results are important, also because they show that thinking in general equilibrium terms may shed new light on issues like migration.

The work by Mason (2017) adds several interesting insights to this literature. In his model local governments only care about the welfare of

their "own" citizens (hence not about the welfare of the migrants). The North is emitting CO₂, the South is not. Most damages from emissions are suffered by the South. The difference, if large enough to compensate for the migration cost, may induce Southern citizens to move to the North. A special feature of the model is that immigration may not be appreciated by the more industrialized country. In this setting it is shown that the Northern government has an incentive to set a policy to reduce CO₂ emissions, and hence damages in the South. Hence, this presents another example where the option of migration may give rise to a climate policy that turns out to be beneficial, be it that in the case at hand migration per se is not appreciated by the local population in the North, which is the driving force for this policy. Interestingly, such policy trade-offs have been tested in economic experiments by Marotzke, Semmann and Milinski (2020), who find that wealthy subjects in the experiment may want to limit migration by increasing their mitigation efforts (see also Kline, 2020).

Another general equilibrium approach couples migration to the New Economic Geography (see *e.g.*, Fujita, Krugman and Venables, 2001). This issue has been largely ignored. To our knowledge, Eppink and Withagen (2009) were the first to use such an approach to the environment. Although their article does not directly address climate change it can be reinterpreted in that way. They assume perfect costless migration, where migration is steered by individual welfare considerations. In each country there is agricultural production by means of a fixed amount of unskilled immobile labor. Also land available for agriculture is given. Industrial production requires skilled labor and land which competes with land for *e.g.* afforestation (biodiversity in the paper). The central idea is that more domestic industrial production may lead to positive agglomeration effects, but it also leads to less land for combating climate change. Industrial production is made up of a large number of varieties. This set-up leads to new views on the equilibrium in the two countries. One conclusion is that a Nash equilibrium may be first-best. However, as we have seen before, also here multiple Nash equilibria exist. The analysis leads to the conclusion that mobility and environmental welfare considerations can drastically alter the general equilibrium characteristics.

Marchiori and Schumacher (2011) develop a two-country (North and South) general equilibrium model to explain international migration. The novelty of their model concerns overlapping generations, be it that they focus on the steady state. In each country there is a representative firm using capital and labor in a Cobb-Douglas production function. Total fac-

tor productivity (TFP) is constant in the North, whereas in the South TFP decreases with higher temperatures above some threshold (see also the threshold models in next section). The production elasticities of capital and labor are identical across countries. Preferences are loglinear in present and future consumption, where future utility is discounted by a common rate of time preference. We omit for the time being the distinction between countries. The analysis is restricted to the steady state so that initial endowments do not count. Utility maximization given life time income yields demand for consumption when young and demand for consumption when old. Suppose in the steady state a certain fraction of the agents live and are employed in the South and the others live in the North. Some of the residents in the North are migrants. Upon migration, when they were young, they had to bear a cost which constituted a fraction of their (labor) income. Since we are in the steady state, no new migrants enter. If capital is immobile, then for the North as well as for the South we have that total savings must equal available capital. Moreover, the interest rate follows from the optimal input of capital. It follows that the interest rates are the same in North and South. If capital is mobile then of course the same holds. This yields as an equilibrium condition that marginal products of capital are equal across both regions. In a steady state a Southern resident must be indifferent between staying in the South and moving to the North. A couple of assumptions are made: TFP in the South is decreasing in temperature and initially TFP is larger in the North. Moreover, initially the South is more populated than the North. The main conclusion is that climate change, if substantial enough to trigger migration, leads to migration and is detrimental to welfare in the North as well as the South. Because of higher temperature TFP in the South is getting small, which leads to more migration and more inequality. This is another channel than the channel described by Mason (2017), where immigration *per se* has a negative impact on welfare by the North. In addition, here each government cares for the welfare of each resident.

A general (spatial) equilibrium is also used as a vehicle in an empirical paper by Oliveira and Pereda (2020) who study internal migration in Brazil. They convincingly show that in practice general equilibrium forces are relevant. They put forward that "ignoring these (general equilibrium) effects leads to overestimation of the overall impact of climate change on internal migration". Let us therefore go into the model to some detail. The country has a given number of locations, each with two types of activities: agriculture and non-agriculture. All individuals have identical preferences and

they inelastically supply one unit of homogeneous labor. The initial distribution of people over the regions is given. Preferences are Cobb-Douglas and they depend on consumption of the agricultural good and housing with the sum of the elasticities of marginal utility equalling unity. Preferences are exponential in local amenities, consisting of climate and non-climate features, and amenities depending on the sector of employment. Living in a particular location that is not the original location and working in a sector brings along migration costs. Moreover, every agent has a stochastic taste shock that is time-, location- and sector-dependent. Given these characteristics one can calculate the probability of an agent in a certain region having a particular occupation to move to another region with, possibly, a different occupation. Production uses only labor and the technology is sector- and region-specific, with a TFP that depends on climate in the region (not for the non-agricultural sector) Then, equilibrium in the housing market is established by demand and supply, where supply is driven by the interest rate. The effect of climate change can be identified and general equilibrium effects through labor and housing markets are shown to be significant and region- and sector-specific shocks. Workers choose the location as well as the type of work. The conclusion is that the Northeast of Brazil, a poor region, will lose population and welfare, whereas the Southeast, that is already more prosperous, will gain in population size and welfare.

Desmet *et al.* (2018) study sea level rise in a spatial general equilibrium world model based on Desmet, Nagy and Rossi-Hansberg (2018). Agents have preferences over consumption and (local) amenities. They derive income from supplying labor and land. The existing technology allows for technological progress giving rise to agglomeration effects. The model is dynamic and allows for agents moving from one region to another. The existence of a general equilibrium is established. The model is calibrated for the world economy and the effects of (exogenous) sea level rise are investigated. These effects vary widely across the globe. The projected sea level rise will lead to a considerable loss in world GDP. These are upper bound estimates, though, since no adaptation efforts are accounted for in the model. Especially coastal countries or cities are hit economically: Vietnam, Shanghai, Hong Kong. Another striking outcome of this general equilibrium model is that the outcomes would be far worse if there were no mobility possible whatsoever, even though migration is costly.

Shayegh (2017) is one of the few papers to account for the fact that demography may be an important endogenous variable in migration decisions. The model describes an economy with overlapping generations. The

young generation decides on current consumption and and future consumption. Future consumption is related to the number of children each agent decides on and their expected wages. These wages depends on whether the children are skilled or unskilled and on where they are employed: in the home country or abroad, which is an endogenous decision which in turn depends climate (temperature) and the cost of moving (surprisingly foreign wages do not play a role). Young households can decide on whether they have a skilled or an unskilled child. The likelihood of migration depends on whether children are skilled or unskilled. Skilled children require more time to educate than unskilled children. Given the model structure total time to be devoted to children is exogenous. Hence, the household faces a tradeoff between many low-skilled children and a few high skilled children. Production includes agriculture, requiring less skilled workers, and manufacturing, requiring skilled workers, with the production functions linear in labor and also depending on temperature and exogenous technological progress. Temperature itself is not endogenous. This model cannot be solved analytically, even in the steady state (or a state of steady growth), because it results in a complicated set of differential equations. Simulations with a calibrated model show that there is a strong general equilibrium effect: the possibility of migration decreases fertility, but agents choose to have more skilled children. Skilled children have better opportunities to migrate and will therefore earn more in equilibrium. The author also claims that migration may alleviate negative impacts of climate change. At a minimum, if the channel described in the model operates, income inequalities will be reduced in the country of origin.

Finally, Burzynski *et al.* (2018) develop an overlapping generations model that is in some regards similar to the one studied by Shayegh (2017). There are two generations: children and adults (the retirement period is neglected). A distinction is made between low-skilled and high-skilled adults to account for the fact that their migration probabilities are different. Labor is the only input in production. Each economy has two sectors: agriculture and non-agriculture, producing the same good (contrary to what Shayegh assumes). Changes in relative prices are thus not accounted for in the model. Moreover, each region has two areas (flooded or non-flooded). The size of these areas is endogenous. TFP depends on temperature (exogenous) and the average schooling level of employed workers. There is also a skill-bias in technology. The distinction between flooded and non-flooded areas is important, and one of the advantages of this model is its ability to distinguish between forced displacement, following flooding through sea level

rise, and voluntary migration driven by economic incentives. Finally, the study advocates more coherent policies when it comes to migration, development and the environment. The study produces a prediction of voluntary and forced migration of about 200 million people. But the largest part will move internally and only 19% will want to move to OECD countries. These figures are in the interval of the estimates of internal migration by Rigaud *et al.* (2018), and again, they project mainly internal migration rather than mass-migration to OECD countries. The main reason behind this result are existing barriers to migration in high-income countries. The model also accounts for conflict-driven migration and show that climate-related conflicts is an important channel which can increase future international migration pressures to OECD countries to a large extent, although current migration flows do not reflect it to the same extent.

To conclude, general equilibrium models give more insight. They are also useful in developing testable hypotheses. Moreover, it turns out that general equilibrium effects are prevailing and may be significant. More is to be done. In particular, since most existing general equilibrium models are essentially static in nature, and since migration is essentially a dynamic phenomenon much work is waiting. This also concerns policy. Migrants have an effect on the destination country, positively or negatively. In both cases this has an impact on policy. For example, climate policy can account for the migration flow from countries affected by climate change. Also, the functioning of labor markets may require extra attention.

4. Climate-induced migration and thresholds

Climate-change induced migration has been shown to react differently to slow-onset events such as gradual changes in temperature and precipitation, and to sudden-onset events, such as disasters and other extreme events. In the latter case one typically sees a sudden increase in migration (see *e.g.*, Cattaneo *et al.*, 2019). However, an issue that has received less attention so far is the fact that large parts of the globe could become uninhabitable if recent trends in temperature increases continue, and then mass migration may occur. If the average temperature in the Sahel region reaches above the limit of human life, this would induce involuntary displacement because people are obliged to move for survival. The heatwaves in India and in Pakistan during the summers of 2018 and 2019, with temperatures around 50°C, present another example that reminds us that some regions may become uninhabitable, either because temperatures exceed the limits for

health or because drought decreases water supply below subsistence levels. In this section, we will discuss how thresholds are taken into account in the literature, using some empirical examples.

McLeman (2018) surveys the issue of thresholds in climate migration. McLeman makes a distinction between six types of thresholds with, in our interpretation, increasing damages from climate change, summarized as follows: adaptation becomes necessary; adaptation becomes ineffective; substantive changes in land use/livelihood become necessary; *in situ* adaptation fails, migration ensues; migration rates become non-linear, and, finally, rates cease to be non-linear. All these thresholds are time-specific and space-specific, but the prevalence of the thresholds applies to many circumstances. McLeman (2018) gives several interesting examples. With a low severity of climate hazard, no adaptation may be necessary and no migration takes place. However, if the severity increases, *e.g.*, more drought and higher temperatures in Canada's Prairie provinces in the 1930s, agricultural activities came under pressure because the crop may fail, so that irrigation became necessary. However, drought and high temperatures may be so persistent that irrigation becomes ineffective (Adger, Lorenzini and O'Brien, 2009). So, irrigation is no longer eligible then as an adaptation measure and farmers may rely on other measures such as adopting drought-resistant crops. Still, no migration needs to take place. The next threshold becomes relevant in case the climate conditions get so hard that wheat production is no longer possible, whatever measures are taken. In that case the farmer must look for other means of earning an income, which depends on market conditions, the farmer's skills, *etc.* This is what the third threshold is about: the necessity of finding other types of land use or economic activity. One way to be prepared for and realize such alternatives is to develop resilient systems. This can obviously be very challenging, as illustrated by the case of communities heavily depending on coral reefs (for fishing or tourism), but that can hardly change the conditions under which coral reefs are "productive". The next threshold is the condition under which mass migration takes place. Migration can be permanent or temporary, and it can apply to entire communities or families or just to parts of it, in which case one or two family members leave. McLeman describes the conditions under which migration took place from the Canadian Prairies in the 30s: the collapse in agricultural market prices, the collapse of financial institutions, and lack of off-farm employment. However, this threshold is not absolute, in the sense that now all agents would move. This may be due to lack of financial means to move. This aspect of migration plays a

key role in early work by Stark (1984) and Stark and Bloom (1985), two of the seminal papers of the new economics of migration. It concerns the necessity of being above a certain threshold of income to sustain the cost of migration. Because not all agents move, some nuance is needed here. For example, migration may be seasonal, over short distances (in case of flooding) and temporary. Thus, much depends on the nature of the climate hazard.

We now discuss a few recent studies on migration where thresholds are relevant. The first relevant non-linearity in existing migration studies is the U-shaped relationship between migration and income.

The study by Bazzi (2017) on Indonesian temporary international migration flows provides detailed evidence of income-related thresholds. He finds that, overall, more outmigration takes place for higher incomes in villages with a larger share of small landowners. These are relatively poor communities. The increase in migration is due to the fact that the real cost of migration becomes smaller. But migration decreases as there is a positive income shock, due to subsidies on rice, in richer communities. This suggests that there is a critical income level for an increase or a decrease of migration. The trade off between opportunity cost (the cost of giving up income) and liquidity cost (direct migration cost) explains this difference.

In the specific context of climate-induced migration, Cattaneo and Peri (2016) estimate a reduced form model of how international migration responds to temperature and rainfall. They include 115 countries in the analysis. They start out with the observation that agricultural productivity is inverted U-shaped as a function of temperature (as established *inter alia* in Schlenker and Roberts, 2009). Therefore, since agriculture is an important source of income and employment in many poor countries, there is likely a non-linear relationship between income and temperature. The main finding then is that in terms of migration poor countries react differently to temperature change: in poor countries liquidity constraints will worsen and migration will decrease with higher temperatures. These predictions are confirmed by the empirical analysis.

Cai *et al.* (2016) also study international migration flows, taking into account the bilateral ties between countries, with data from 42 destination countries and 163 origin countries. They find a statistically significant positive relationship between outmigration and temperature, but only in countries that depend heavily on agriculture. A policy implication would be that in order to reduce migration flows, policy should be directed specifically to countries that depend on agriculture.

Recently, Peri and Sasahara (2019) explore the issue further, following up on Cattaneo and Peri (2016). Both studies consider multiple countries. Peri and Sasahara cover the whole world with grids of 0.5x0.5 square degrees. They fit population data, temperature and precipitation data to each cell for the period 1970-2000 at 10 year intervals. The model employed is in a sense neoclassical in that it exploits differences in (random) productivity and therefore in wages. Moreover, an increase in temperature decreases productivity, mainly in agricultural activities. In order for an individual to migrate two conditions need to be satisfied. First, her productivity must be high enough so that net earnings after migrating to an urban area are higher than before, including the cost of migration itself. Second, the earnings must be high enough to pay the migration cost out of the previous earnings in the rural area. The authors make a distinction between poor, lower-middle income and upper-middle income countries. The findings extend and confirm earlier results (see also Cattaneo and Peri (2016)) for rural-urban migration. Migration from rural to urban mainly takes place in countries that are at an intermediate level of economic development. The reason is that the rural population in low income countries lacks the means to migrate, whereas the rural population can afford the cost of migration in higher income countries. Peri and Sasahara (2019) predict that a large group of people will get trapped in poverty if temperature increases persist.

The other specific feature related to climate-induced migration is non-linearities in the climatic variables. Depending on the type of weather data that are used, most empirical studies in reduced form test for quadratic terms in temperature and precipitation, or, if daily data are available, by using degree days, that is counting the number of days with temperature within a certain range, and then creating variables for each range ("bins"). In one major study of permanent (full) household migration between Indonesian provinces over a 15-year period, Bohra-Mishra, Oppenheimer and Hsiang (2014) find a U-shaped relationship between temperature and rainfall on the one hand and permanent migration on the other hand, with the threshold being at about 25 ° C. For natural disasters there are either no or relatively small effects on permanent migration. Bohra-Mishra, Oppenheimer and Hsiang (2014) also find that the effect of rainfall is non-linear. In originally dry circumstances less rainfall increases migration, whereas with wetter initial conditions more rainfall increases migration. This seems to contradict the presence of migration costs, but given that it is internal migration that is estimated, with relatively low migration costs, the direct effect of temperature may dominate.

Another standard way of accounting for nonlinearities is to use a dummy variable to account for extreme temperatures and precipitation or use the quartiles of the distribution of the variables. In this manner, for example, Mueller, Gray and Kosec (2014) find that male internal migration in rural Pakistan increases when temperatures are in the fourth quartile only, with no statistically significant effect of other temperature intervals.

In another country study, focussing on internal rural-urban migration in Mexico, Nawrotzki *et al.* (2017) explore non-linearities and thresholds. They find a nonlinear relationship between cumulative exposure to drought and rural-urban migration. For moderate temperature increases (and sufficient rainfall) they find a decrease in migration. It is only when a threshold for temperature is reached that rural-urban migration increases (as in Bohra-Mishra, Oppenheimer and Hsiang, 2014). In another country-level study, focussing on rapid-onset hydro-meteorological disasters and emergencies in Costa Rica, Robalino, Jimenez and Chacón (2015) show that less severe disasters have a positive effect on rural migration. Large disasters (in terms of the number of lives lost) decrease rural migration, and may thus actually impede people from migrating. This result is consistent with earlier results on migration following earthquakes (Halliday, 2006) and may indicate that disasters limit households' wealth so much that they can no longer defray the costs of migration.

Earlier work on environmental migration also reflect such nonlinearities, but less precisely measured. Gray and Bilsborrow (2013) find that large distance domestic migration is non-monotonic in severity and that only high temperatures drive migration. Few studies have explored the role of income variability itself, though (stemming from increases in climatic variability). Marchiori, Maystadt and Schumacher (2015) is an exception. They find, however, that, for migration between 39 Sub-Saharan countries, it is not significant as a driver for migration. They also find that agricultural dependence interacts with temperature and precipitation to explain international migration.

It would be difficult to assess all thresholds mentioned by McLeman (2018) in one single empirical model. The studies conducted so far, and mentioned above, mainly address the income threshold for migration and (strongly related) the nonlinear dependence of agriculture on precipitation and temperature.

5. Climate, migration and conflict

The relationship between climate change, migration and conflicts can be seen from different angles. First, climate change may lead to invasions and, therefore, conflict, for instance water wars. There exists appealing anecdotal evidence for the link between climate and conflict through migration. The two historic events considered in section 2, the migration into China and the one into the Roman empire (Brooke, 2014; Harper, 2017), caused major disruptions as a consequence of climatic changes. Second, climate change may lead to conflicts, without there being a violent invasion. The causal link between climate change, migration and conflict can occur on smaller scales than international. They can be local or regional, as described in detail by *e.g.*, Reuveny (2007). We will go into this in due course. In the case we have in mind here the conflict is mainly within the country or the region where climate change and its negative effects occur. A third way to look at the link is where the deterioration of environmental circumstances and the subsequent migration gives rise to conflicts in countries that receive the displaced persons. One example was already mentioned when we discussed the negative externality caused by immigration in the work by Mason (2017). In this section we will briefly go into all three aspects of the link, acknowledging that some of them are politically sensitive and delicate.

Reuveny (2007) lists a number of reasons for conflicts. He mentions competition for resources, especially in the absence of well-defined property rights. There might also be ethnic tensions. Another driver might be what Reuveny calls distrust: a receiving country might be afraid of penetration and the origin country might think migrants are mistreated. Reuveny also mentions fault lines. For example, migrants and residents may compete over jobs. Finally, he mentions that if the receiving country is poor and migrants cannot be offered acceptable living standards, they may join rebel groups. Reuveny argues that "environmental migration crosses international borders at times and plays a role in conflict".

Reuveny also lists a large number of environmentally induced migration that led to conflicts. In most cases the driving environmental forces have to do with water (droughts, floods, ownership) and concern ethnic conflict, or conflicts between nomads and farmers. Hsiang, Burke and Miguel (2013) review 60 quantitative studies and find a strong causal relationship between climate and human conflicts, many of which have to do with migration of groups of people. Salehyan (2014) also stresses the potential importance

of the relationship. There exist other studies (*e.g.*, Bhavnani and Lacina (2015) and Salehyan and Gleditch (2006)) that suggest that the presence of refugees could enhance conflict in the receiving country. This could even be the case if such refugees are not admitted to the country they want to settle in, the argument being that they will end up in a less preferred country where a conflict may arise that can spread to the original country. However, the evidence is mixed.

When testing the hypothesis on international bilateral migration data for 117 countries over the period 1970-2000, Cattaneo and Bosetti (2017) find no significant relationship between climate-induced migrants and civil conflict in the destination countries, however. They use a measure of high level conflict, accounting for more than 25 deaths, and also find the same results when testing for civil war, but they do not test the possibilities of low-level social conflict. The recent paper by Bosetti, Cattaneo and Peri (2020) tests two hypotheses : a) whether there are more climate-driven conflicts in countries with low migration propensity, and b) whether the presence of climate-induced migrants lead to conflict in the destination country. To do so, they use the same long run data on migration as in Beine and Parsons (2015) and Cattaneo and Peri (2016) over the period 1960 to 2000, together with the UCDP/PRIOD dataset, as in Cattaneo and Bosetti (2017), but here the focus is on low-level conflict. The estimation accounts for endogeneity in the relation by predicting migration using typical gravity equations for climate-induced migration as an instrumental variable. They use a dummy for a low stock of migrants in 1960 to assess the effect of having a lower propensity of migration on the conflict probability in the country of origin. The empirical results indicate that poor countries with a low stock of external migrants in 1960 are more likely to experience climate-driven conflict, compared to other poor countries, an effect that the authors interpret as migration acting as a safety valve. As in Cattaneo and Bosetti (2017), they find no statistically significant effect of inflows of migrants on the probability of conflict in the destination country.

Hence, further research seems necessary here. The findings of such research are important for policy making as is described by Mason (2017), discussed earlier, and by Prieur and Schumacher (2016). Both contributions stress the fact that climate policy and migration policy should be coupled. Prieur and Schumacher consider two conflicts in their theoretical model. One is the internal conflict arising when refugees are accepted in the region, and one that is called external conflict, arising when refugees are not allowed in. They find support in the work by Reuveny (2007) who argues that

“environmental migration crosses international borders at times and plays a role in conflict”. In order to control the flow of migrants and to contain conflicts it might then be instrumental to have a climate mitigation policy in place.

Some studies address asylum seeking directly. Abel *et al.* (2019) consider yearly bilateral asylum seeking flows (these are not identical to refugees) between a large group of countries (157) covering the years 2006-2015. They also have climate data (drought conditions) as well as conflict data (battle related deaths) for many countries. Other variables that play a role include GDP, ethnic polarization measures, level of democratization, distance between country of origin and country of destination (the model is a gravity model) and whether these share a common language. The authors claim that their model in principle allows for a causal interpretation. The main conclusions read as follows. Drought episodes may enhance conflict and consequently outmigration, particularly in a specific period of time, namely 2010-2012 (Arab spring) in countries with some form of democracy. The authors claim that conflict in such countries may arise from a government not adequately reacting to climate change. There is also another possible link, namely that immigration may, through the competition over resources, lead to conflict in the receiving regions. Abel *et al.* (2019) argue, however, that the empirical evidence for these narratives is scarce.

We agree that one should be very careful with anecdotal evidence and ad hoc modeling. Current work has started to test hypotheses carefully on real data. More work is definitely to be done. It maybe goes too far to say that adequate climate policies, at least in (semi-) democratic countries may help to avoid conflicts. In addition, high-income countries can effectively do something against forced migration, and its negative consequences, by helping more vulnerable countries with adaption to climate change or by mitigating their own emissions (although the latter will only work in the long run).

An alternative view is presented by Boas *et al.* (2019). In policy circles it is widely assumed that climate change will be a major driver of mass migration, which needs to be averted because it may lead to aggravating conflicts (UN security council). The authors say that predicting large numbers of climate refugees may be a false narrative. Research programs are now developed that should try to contain migration “at the source”. There is also a call, *e.g.*, within the EU) to strengthen border control. All this can be interpreted as examples of “securization” policies. The authors argue that a new research agenda should be developed, one that recognizes

that there are other reasons for migration than climate change, and that migration is part of the general phenomenon of globalization.

6. Implications for economic growth

It is widely recognized that poverty and climate change are the two main challenges for policy (Stern, 2016). It is also well-known from the literature that rural-urban migration plays a key role in economic growth. Understanding the indirect implications of climate change-induced migration on growth is thus crucial in a context of accelerating climate change.

A well-known conjecture attributed to Thomas Schelling indicates that economic growth may be the best means of adaptation for developing countries (Schelling, 1992). What has been termed the Schelling conjecture has since been questioned, as even poor countries may be relatively better off by investing in small levels of adaptation capital (Millner and Dietz, 2015), although the optimal mix of investment in productive capital and adaptation capital investments depends on the adaptation efficiency and the initial amount of adaptation capital.

As discussed in the review, several mechanisms explain the economic effects of climate change: conflicts, rural-urban migration, food security. These may spur migration, but climate-induced migration will in its turn have consequences for the possibilities for economic growth and human development. Despite measurement problems, the empirical evidence attests to a lower productivity of workers employed in the agricultural sector compared to the non-agricultural sector (Gollin, Lagakos and Waugh, 2014). If we add to this that capital is unequally allocated geographically between rural areas and urban areas, especially in developing countries, it implies that climate change will affect growth not only directly but also through the indirect channel of internal and international migration. In the past, lower rainfall tended to increase urbanization, in particular in Sub-Saharan Africa (Barrios, Bertinelli and Strobl, 2006). Henderson, Storeygard and Deichmann (2017) show that the attraction of urban areas for climate-induced migrants depends on the capital structure and possibilities of manufacturing jobs to substitute for lost productivity in agriculture. In areas with manufacturing, rural-urban migration increases following increases in temperature, whereas such migration decreases in urban areas that are essentially agricultural market towns, which also suffer the direct impact of the shock to agriculture. Recent work building on this literature shows that higher temperatures risk to reduce possibilities of sectoral reallocation

through rural-urban migration. On long-term data over six decades from India, Liu, Shamdasani and Taraz (2020) show that higher temperatures reduce rural-urban migration, and that this effect is not present in rural areas with dense road networks. The authors argue that the evidence in the long run would imply that such possibilities of sectoral reallocation by geographic mobility are limited unless policy measures reduce the potential barriers to rural-urban migration by, for example, strengthening transport networks. Without such policy measures, climate change would only reinforce the role of barriers to sectoral re-allocation that occurs spatially. Poor countries that are also more vulnerable to climate change because of their geographic location may thus be susceptible to indirect effects leading to poverty traps.

7. Conclusion

This review has pointed to some of the areas of recent research which are relevant for the policy discussion around climate-induced migration. In a world where climate-induced migration is increasingly becoming a political topic of security concern, it is important to replace the discussion in the larger context of the new economics of migration. Such migration shares the same characteristics as other forms of migration in involving trade-offs in expected improvements in living conditions compared to relative costs of mobility according to distance. Hence, natural responses may include sheltering in place, for the very poor, and short-distance internal migration, sometimes of temporary nature. Climate-induced migration has some novel features though, that include non-linear effects from increases in temperature and changes in precipitation patterns. We have reviewed some examples of how such thresholds effects have been taken into account in recent analyses.

Whereas the link between climate-change induced conflicts and migration is still a matter of intense scientific debate, we have reviewed some of the recent work on this topic. It is surely one of the mechanisms between climate change and migration that will be more developed over time.

Another issue that is largely absent from the literature is the existence of tipping points which make some areas uninhabitable. The current literature incorporates non-linear responses to climatic variables, which establish thresholds (in terms of temperature, for example) for migration of some groups of individuals, but not really the existence of tipping points where entire geographic areas become uninhabitable. Current work on sea

level rise and mobility captures this phenomenon to some extent, but more modelling of this issue would be useful. This is one of the future risks that could change current predictions and lead to mass migration.

Acknowledgements

We thank Ingmar Schumacher and an anonymous reviewer for their helpful comments.

REFERENCES

- Abel, G., Brottrager, M. Cuaresma, J. and Muttarak, R. (2019): "Climate, conflict and forced migration", *Global Environmental Change* 54, pp. 239-249.
- Adger, W., Lorenzini, I. and O'Brien, K. (2009): "Adaptation now", in W. Adger, I. Lorenzoni and K. O'Brien (eds.), *Adapting to Climate Change: Thresholds, Values, Governance*, Cambridge University Press, Cambridge, pp. 1-22.
- Backhaus, A., Martinez-Zarzoso, I. and Muris, C. (2015): "Do climate variations explain bilateral migration? A gravity analysis", *IZA Journal of Migration* 4 (3), pp. 1-15.
- Bai, Y. and Kung, J. (2011): "Climate Shocks and Sino-nomadic Conflict." *Review of Economics and Statistics* 93, pp. 970-981.
- Barrios, S., Bertinelli, L. and Strobl, E. (2006): "Climatic change and rural-urban migration: The case of Sub-Saharan Africa", *Journal of Urban Economics* 60, pp. 357-371.
- Bazzi, S. (2017): "Wealth heterogeneity and the income elasticity of migration", *American Economic Journal: Applied Economics* 9, pp. 219-255.
- Beine, M. and Parsons, Ch. (2015): "Climatic factors as determinants of international migration", *Scandinavian Journal of Economics* 117, pp.723-767.
- Berlemann, M. and Steinhardt, M. (2017): "Climate change, natural disasters and migration – A survey of the empirical evidence", *CESifo Economic Studies* 63, pp. 353-385.
- Bhavnani, R. and Lacina, B. (2015): "The Effects of Weather-Induced Migration on Sons of the Soil Riots in India", *World Politics* 67, pp. 760-794.
- Black, R., Bennett, S., Thomas, S. and Reddington, J. (2011): "Migration as adaptation", *Nature* 478, pp. 447-449.

Boas, I., Farbotko, C. Adams, H., Sterly, H., Bush, S., Geest, van der, K., Wiegel, H., Ashraf, H., Baldwin, A., Bettini, G., Blondin, S., Bruijn, de M., Durand-Delacré, D., Fröhlich, C., Gioli, G., Guaita, L., Hut, E., Jarawura, F., Lamers, M., Lietaer, S., Nash, S., Piguet, E., Rothe, D., Sakdapolrak, P., Smith, L., Furlong, B., Turhan, E., Warner, J., Zickgraf, C., Black, R. and Hulme, M. (2019): "Climate migration myths", *Nature Climate Change* 9, pp. 901-903.

Bohra-Mishra, P., Oppenheimer, M., and Hsiang S. (2014): "Nonlinear permanent migration response to climatic variations but minimal response to disasters", *Proceedings of the National Academy of Sciences* 111, pp. 9780–9785.

Bosetti, V., Cattaneo, C. and Peri, G. (2020): "Should they stay or should they go? Climate migrants and local conflicts", forthcoming in *Journal of Economic Geography*.

Boustan, L., Kahn, M. and Rhode, P. (2012): "Moving to Higher Ground: Migration Response to Natural Disasters in the Early Twentieth Century", *American Economic Review* 102, pp.238-244.

Boustan, L., Kahn, M., Rhode, P. and Yanguas, M. (2020): "The Effect of Natural Disasters on Economic Activity in US Counties: A Century of Data", *NBER Working Paper 23410*.

Brooke, J. (2014), *Climate change and the course of global history: a rough journey*, Cambridge University Press, Cambridge.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., Kaplan, J., Herzig, F., Heussner, K., Wanner, H., Luterbacher, J. and Esper, J. (2011): "2500 years of European climate variability and human susceptibility", *Science* 331, pp. 578-582.

Burzynski, M., Deuster, Ch., Docquier, F. and Melo, de J. (2018): "Climate Change, Inequality and Migration", *Discussion Paper 2019-14* UCL Louvain.

Cai, R., Feng, S., Oppenheimer, M. and Pytlikova, M. (2016): "Climate variability and international migration: the importance of the agricultural linkage", *Journal of Environmental Economics and Management* 79, pp. 135-151.

Cattaneo, C. and Bosetti, V. (2017): "Climate-induced international migration and conflicts", *CESifo Economic Studies* 63(4), pp. 500-528.

Cattaneo, C. and Peri, G. (2016): "The migration response to higher temperatures", *Journal of Development Economics* 122, pp. 127-146.

Cattaneo, C., Beine, M., Fröhlich, C., Kniveton, D., Martínez-Zarzoso, I., Mastrocillo, M., Millock, K., Piguet, E. and Schraven, B. (2019): "Hu-

man migration in an era of climate change", *Review of Environmental Economics and Policy* 13, pp. 189-206.

Dallmann, I. and Millock, K. (2017): "Climate variability and interstate migration in India" *CESifo Economic Studies* 63(4), pp. 560-594.

Desmet, K. and Rossi-Hansberg, E. (2015): "On the spatial economic impact of global warming", *Journal of Urban Economics* 88, pp. 16-37.

Desmet, K., Nagy, D. and Rossi-Hansberg, E. (2018): "The geography of development", *Journal of Political Economy* 126, pp. 903-983.

Desmet, K., Kopp, R., Kulp, S., Nagy, D., Oppenheimer, M., Rossi-Hansberg, E. and Strauss, B. (2018): "Evaluating the economic cost of coastal flooding", *CEPR Discussion Paper 13128*, forthcoming in *American Economic Journal: Macroeconomics*.

Eppink, F. and Withagen, C. (2009): "Spatial patterns of biodiversity conservation in a multiregional general equilibrium model", *Resource and Energy Economics* 31, pp. 75-88.

Findley, S. (1994): "Does drought increase migration? A study of migration from rural Mali during the 1983-1985 drought", *International Migration Review* 28, pp. 539-553.

Fujita, M., Krugman, P. and Venables, A. (2001), *The Spatial City: Cities, Regions and International Trade*, The MIT Press, Cambridge.

Gollin, D., Lagakos, D. and Waugh, M. (2014): "The agricultural productivity gap", *Quarterly Journal of Economics* 129 (2), pp. 939-993.

Gray, C. and Bilsborrow, R. (2013): "Environmental influences on human migration in rural Ecuador", *Demography* 50, pp. 1217-1241.

Haavio, M. (2005): "Transboundary pollution and household mobility: Are they equivalent?", *Journal of Environmental Economics and Management* 50, pp. 252-275.

Halliday, T. (2006): "Migration, risk, and liquidity constraints in El Salvador", *Economic Development and Cultural Change* 54, pp. 893-925.

Harper, K. (2017), *The Fate of Rome, Climate, Disease, and the End of an Empire*, Princeton University Press, Princeton.

Henderson, V., Storeygard, A. and Deichmann, U. (2017): "Has climate change driven urbanization in Africa?", *Journal of Development Economics* 124, pp. 60-82.

Hoel, M. and Shapiro, P. (2003): "Population mobility and transboundary environmental problems", *Journal of Public Economics* 87, pp. 1013-1024.

Hornbeck, R. (2012): "The enduring impact of the American dust bowl: Short and long-run adjustments to environmental catastrophe", *American*

Economic Review 102, pp. 1477–1507.

Hornbeck, R. and Naidu, S. (2014): "When the levee breaks: Black migration and economic development in the American South", *American Economic Review* 104(3), pp. 963–990.

Hsiang, S., Burke, M., and Miguel, E. (2013): "Quantifying the influence of climate on human conflict", *Science* 341, 1235367.

Hugo, G. (1996): "Environmental concerns and international migration", *International Migration Review* 30, pp. 105–131.

Internal Displacement Monitoring Centre (2020): *Global Report on Internal Displacement 2020*. IDMC, Geneva, Switzerland.

International Organization for Migration (2020): *World Migration Report 2020*. IOM, Geneva, Switzerland.

Kline, R. (2020): "Where mitigation and migration meet", *Nature Climate Change* 10, pp. 493–494.

Liu, M., Shamdasani, Y. and Taraz, V. (2020): "Climate change, structural transformation, and infrastructure: Evidence from India", *Preprint*.

Long, J. and Siu, H. (2018): "Refugees from dust and shrinking land: Tracking the dust bowl migrants", *The Journal of Economic History* 78, pp. 1001–1033.

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

Marchiori, L., Maystadt, J-F. and Schumacher, I. (2012): "The impact of weather anomalies on migration in sub-Saharan Africa", *Journal of Environmental Economics and Management* 63, pp. 355–374.

Marchiori, L., Maystadt, J-F. and Schumacher, I. (2015): "Is environmentally induced income variability a driver of human migration?", *Migration and Development* 6, pp. 33–59.

Marotzke, J., Semmann, D. and Milinski, M. (2020): "The economic interaction between climate change mitigation, climate migration and poverty", *Nature Climate Change* 10, pp. 518–525.

Mason, Ch. (2017): "Climate Change and Migration: A Dynamic Model", *CESifo Economic Studies* 63, pp. 421–444,

McLeman, R. (2018): "Thresholds in climate migration", *Population and Environment* 39, pp. 319–338.

Millner, A. and Dietz, S. (2015): "Adaptation to climate change and economic growth in developing countries", *Environment and Development Economics* 20, pp. 380–406.

Millock, K. (2015): "Migration and environment", *Annual Review of*

Resource Economics 7, pp. 35–60.

Missirian, A. and Schlenker, W. (2017): "Asylum applications respond to temperature fluctuations", *Science* 358, pp.1610–1614.

Mueller, V., Gray, C., and Kosec, K. (2014): "Heat stress increases long-term human migration in rural Pakistan", *Nature Climate Change* 4, pp.182–185.

Nawrotzki, R., De Waard, J., Bakhtsiyarava, M. and Trang Ha, J. (2017): "Climate shocks and rural-urban migration in Mexico: Exploring nonlinearities and thresholds", *Climatic Change* 140, pp. 243–258.

Oliveira, J. and Pereda, P. (2020): "The impact of climate change on internal migration in Brazil", *Journal of Environmental Economics and Management*, 103, 102340.

Perch-Nielsen, S., Bättig, M. and Imboden, D. (2008): "Exploring the link between climate change and migration", *Climatic Change* 91, pp. 375–393.

Peri, G. and Sasahara, A. (2019): "The impact of global warming on rural-urban migrations: Evidence from global big data", *NBER Working Paper 25728*.

Prieur, F. and Schumacher, I. (2016): "The role of conflict for optimal climate and immigration policy", *TSE-663*, Toulouse School of Economics.

Reuveny, R. (2007): "Climate change-induced migration and violent conflict", *Political Geography* 26, pp. 656–673.

Rigaud, K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., Schewe, S., Adamo, S., McCusker, B., Heuser, S. and Midgley, A. (2018), *Groundswell: Preparing for Internal Climate Migration*, World Bank, Washington, DC

Robalino, J., Jimenez, J. and Chacón, A. (2015): "The effect of hydro-meteorological emergencies on internal migration", *World Development* 67, pp. 438–448.

Salehyan, I. (2014): "Climate change and conflict: Making sense of disparate findings", *Political Geography* 43, pp. 1–5.

Salehyan, I. and Gleditsch, K. (2016): "Refugees and the Spread of Civil War", *International Organization* 60, pp. 335–366.

Schelling, Th. (1992): "Some Economics of Global Warming", *American Economic Review* 82, pp. 1–14.

Schlenker, W. and Roberts, M. (2009): "Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change", *Proceedings of the National Academy of Sciences* 106, pp. 15594–15598.

Shayegh, S. (2017): "Outward migration may alter population dynamics

and income inequality", *Nature Climate Change* 7, pp. 828-832.

Silva, E. (1997): "Decentralized and efficient control of transboundary pollution in federal systems", *Journal of Environmental Economics and Management* 32, pp. 95-108.

Stark, O. (1984): "Rural-to-urban migration in LDCs: a relative deprivation approach", *Economic Development and Cultural Change* 32, pp. 475-486.

Stark, O. and Bloom, D. (1985): "The new economics of labor migration", *American Economic Review* 75, pp. 173-178

Stern, N. (2016): "Current climate models are grossly misleading", *Nature* 530, pp. 407-409.

Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S. and Crane, D. (2006). *Stern review: The economics of climate change*, Cambridge University Press, Cambridge.

Turner, M. A., Rosenthal, J.S., Chen, J., Hao, C. (2012) Adaptation to Climate Change in Preindustrial Iceland. *American Economic Review Papers and Proceedings* 102(3), pp. 250-255.

Wellisch, D. (1994): "Interregional spillovers in the presence of perfect and imperfect household mobility", *Journal of Public Economics* 55, pp. 167-184.

Wellisch, D. (1995): "Can household mobility solve basic environmental problems?", *International Tax and Public Finance* 2, pp. 245-260.

Wellisch, D. (2000), *Theory of Public Finance in a Federal State*, Cambridge University Press, Cambridge, UK.

Further reading

Baez, J., Caruso, G., Mueller, V. and Nui, C. (2017): "Heat exposure and youth migration in Central America and the Caribbean", *American Economic Review* 107, pp. 446-450. Cambridge University Press, pp. 1-22.

Benonnier, T., Millock, K. and Taraz, V. (2019): "Climate change, migration, and irrigation", Paris School of Economics Working Paper 2019-21.

Black, R., Adger, W., Arnell, N., Dercon, S., Geddes, A. and Thomas, D. (2011b): "The effect of environmental change on human migration", *Global Environmental Change* 21, pp. S3-S11.

Bohra-Mishra, P., Oppenheimer, M., Cai, R., Feng, S., and Licker, R. (2017): "Climate variability and migration in the Philippines", *Population and Environment* 38, pp.286-308.

Colmer, J. (2020): "Temperature, labour reallocation, and industrial production: Evidence from India", forthcoming in *American Economic Journal: Applied Economics*.

Dell, M., Jones, B. and Olken, B. A. (2009): "Temperature and income: Reconciling new cross-sectional and panel estimates", *American Economic Review* 99, pp. 198–204.

Dell, M., Jones, B., and Olken, B. (2012): "Temperature shocks and economic growth: Evidence from the last half century", *American Economic Journal: Macroeconomics* 4, pp. 66–95.

Dillon, A, Mueller, V. and Salau, S (2011): "Migratory responses to agricultural risk in northern Nigeria", *American Journal of Agricultural Economics* 93, pp. 1048–1061.

Drabo, A., and Mbaye, L. (2015): "Natural disasters, migration and education: an empirical analysis in developing countries", *Environment and Development Economics*. 16, pp. 767-796.

Feng, S., Krueger, A. and Oppenheimer, M. (2010): "Linkages among climate change, crop yields and Mexico-US cross-border migration", *Proceedings of the National Academy of Sciences* 107, pp.14257–14262.

Gray, C. and Mueller V.(2012a): "Drought and population mobility in rural Ethiopia", *World Development* 40, pp. 134–145.

Gray, C. and Mueller, V. (2012b): "Natural disasters and population mobility in Bangladesh", *Proceedings of the National Academy of Sciences* 109, pp. 6000–6005.

Gray, C. and Wise, E. (2016): "Country-specific effects of climate variability on human migration", *Climatic Change* 135, pp. 555–568.

Herrendorf, B. and Schoellman, T. (2018): "Wages, human capital and barriers to structural transformation", *American Economic Journal: Macroeconomics* 10, pp. 1–23.

Henry, S., Schoumaker, B., and Beauchemin, C. (2004): "The impact of rainfall on the first out-migration: a multi-level event-history analysis in Burkina Faso", *Population and Environment* 25, pp. 423–460.

Hirvonen, K. (2016): "Temperature changes, household consumption, and internal migration: evidence from Tanzania", *American Journal of Agricultural Economics* 98, pp. 1230–1249.

Hunter, L., Murray, S. and Riosmena, F. (2013): "Rainfall patterns and U.S. migration from rural Mexico", *International Migration Review* 47, pp. 874–909.

Kaczan, D. and Orgill-Meyer, J. (2020): "The impact of climate change

on migration: A synthesis of recent empirical insights", *Climatic Change* 158, pp. 281-300.

Kleemans, M. (2015): "Migration choice under risk and liquidity constraints", *Working Paper*, University of Illinois, Urbana-Champaign.

Koubi, V., Stoll, S. and Spilker, G. (2016): "Perceptions of environmental change and migration decisions", *Climatic Change* 138, pp. 439-451.

Mastrorillo, M., Licker, R., Bohra-Mishra, P., Fagiolo, G., Estes, L. and Oppenheimer, M. (2016): "The influence of climate variability on internal migration flows in South Africa", *Global Environmental Change* 39, pp. 155-169.

Miguel, E., and Satyanath, S. (2011): "Re-examining economic shocks and civil conflict", *American Economic Journal: Applied Economics* 3, pp. 228-232.

Miguel, E., Satyanath, S. and Sergenti, E. (2004): "Economic shocks and civil conflict: An instrumental variables approach", *Journal of Political Economy* 112, pp. 725-753.

Munshi, K. (2003): "Networks in the modern economy: Mexican migrants in the U.S. labor market", *The Quarterly Journal of Economics* 118, pp. 549-599.

Munshi, K. and Rosenzweig, M. (2016): "Networks and Misallocation: Insurance, Migration and the Rural-Urban Wage Gap", *American Economic Review* 106, pp. 46-98.

Naudé, W. (2010): "The determinants of migration from sub-Saharan African countries", *Journal of African Economies* 19, pp. 330-356.

Nawrotzki, R. and DeWaard, J. (2016): "Climate shocks and the timing of migration from Mexico", *Population and Environment* 38, pp. 72-100.

Nawrotzki, R. Riosmena, F. and Hunter L. (2013): "Do rainfall deficits predict U.S.-bound migration from rural Mexico? Evidence from the Mexican census", *Population Research and Policy Review* 32, pp. 129-158.

Neumann, B., Vafeidis, A., Zimmermann, J. and Nicholls, R. (2015): "Future coastal population growth and exposure to sea-level rise and coastal flooding—a global assessment", *PLoS One* 10:e0118571.

Rosenzweig, M. and Stark, O. (1989): "Consumption smoothing, migration, and marriage: evidence from rural India", *Journal of Political Economy* 97, pp. 905-926.

Saldaña-Zorrilla, S. and Sandberg, K. (2009): "Impact of climate-related disasters on human migration in Mexico: A spatial model", *Climatic Change* 96, pp. 97-118.

Stapleton, S., Nadin, R., Watson, C. and Kellett, J. (2017): "Climate

change, migration, and displacement: the need for a risk-informed and coherent approach", *Overseas Development Institute and United Nations Development Programme*, New York.

Suhrke, A. (1993), *Pressure points. Environmental degradation, migration and conflict*, Academy of Arts and Sciences, Cambridge.

Withagen, C. (2014): "The climate change, migration and conflict nexus", *Environment and Development Economics*, pp. 324–327.