Migration and Household Adaptation to Climate: A Review of Empirical Research[1]

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Abstract

This paper reviews empirical research on migration and urban land use associated with climate change. Migration arises due to both changes in economic opportunities in key economic sectors as well as changes in amenity levels resulting from climate change. Throughout the paper, efforts are made to highlight key empirical findings as well as areas in need of additional research. Heterogeneity in preferences and climate change impacts is discussed through the lens of several recent empirical papers. Additional attention is focused on the often complex interconnections between economic sectors in determining household migration. Areas in need of additional research include improving our understanding of the coupling between human and natural systems, accounting for endogenous attributes and payoffs, and incorporating richer characterizations of the tradeoffs driving migration across multiple economic sectors.

Keywords: Climate change; migration; land use

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1. Introduction

This paper reviews the empirical research on migration and land use impacts of climate change highlighting the important role of heterogeneity and market interactions in our understanding of migration in response to climate change. Migration provides a window into the non-marginal adjustments individuals are willing to make as they adapt to climate change. Observing changes in location provides a measure of the implicit costs associated with climate change that induce households to re-locate. Recovering willingness to pay from migration models informs us of the thresholds for these migration inducing costs and the incentives required to adapt. Looking at past actions, migration models tell us how people have previously responded, or not, to climate change and inform us about likely future responses to continued climate change. Predicting the patterns of migration likely to occur as a result of climate change is central to sound policy making and a focus on an emerging body of empirical research.

In 2009 the world population living in urban areas exceeded the population in rural areas for the first time (United Nations, 2009). World population is expected to increase to over 9 billion by the year 2050 with urban areas absorbing the majority of the additional population. Understanding the linkages between climate change, land use change, and migration as a response to climate change presents a number of questions and challenges for applied researchers. Among these is the need to better understand the drivers underlying household migration, assess how these changes in population are likely to influence land use locally and at larger spatial scales, and predict how future changes in climate are likely to alter the relationship between individuals and land use as they adapt to changing conditions. Existing research suggests that these impacts may be substantial and impact a variety of economic sectors. These impacts include the agricultural sector in terms of both trade and productivity (Deschenes and Greenstone, 2007; Schlenker et al, 2005), human health (Pattanayak and Pfaff, 2009), as well as land use and urbanization patterns (Marchiori et al, 2012).

The far-reaching impacts of migration present a host of real-world challenges to both developed and developing countries and underscore the need for improved understanding of human response to climate change and our ability to predict this response into the future. As an example of these complex interactions, Patz and Olson (2006) describe one series of impacts stemming from migration and urbanization in a developing country context. In their east African scenario, migration to urban areas leads to large changes in land use that impact local weather patterns over short time periods. These weather changes are coupled with landscape changes due to alterations in the traditional flows of water and runoff caused by urbanization. To support these population changes, land clearing activities including deforestation are likely to occur. Research has shown that this series of complex interactions results in increased viability for mosquito populations and increases malaria transmission impacting human health. This example is intended to illustrate the often complex interactions associated with climate change and migration which is a recurring theme in this review paper.

Studying climate change is complicated as a result of the public goods nature of climate itself. Obtaining empirical estimates of climate change induced adaptation and economic impacts in areas where markets either do not exist or are not directly influenced by climate is difficult due to the public good (bad) nature of climate that precludes the existence of well-functioning markets. As a result, much of the empirical research on climate change related to migration has focused on the markets for housing, labor, and agriculture as those markets embody climate change and are readily observable. The empirical challenge is then to unbundle and identify the impacts of climate from the myriad of additional factors which are also captured by those markets.

The remainder of this review is structured as follows. The next section presents an overview of conceptual issues associated with migration research and is followed by a discussion of the differences between reduced form and structural modeling and the implications of these econometric choices for migration research. The fourth section examines literature linking migration to changes in economic opportunities with an emphasis on changes in the agricultural and labor sectors driving migration. The fifth section reviews the literature on climate as an (dis) amenity influencing household location choices.

The sixth section describes efforts to incorporate both economic opportunity and amenity driven migration in a unified empirical framework. The final section discusses the lessons learned and challenges and opportunities that lie ahead.

2. Adaptation through migration

Behavioral incentives underlying climate change migration are the focus of an emerging body of empirical research. This research largely seeks to address two core hypotheses. First, to what extent do households migrate in response to changes in economic opportunities that arise due to the influences of climate change on important economic sectors in the economy. Examples of sectors disproportionately influenced by climate change include agriculture, due to the strong reliance on weather and precipitation, as well as labor markets resulting from changes in productivity and labor supply shifts as migration occurs. If households' economic opportunities are altered by these changes, they have an incentive to relocate. The second empirical hypothesis focuses on the response of individuals to climate as an amenity emanating from the "vote with your feet" notions described by Tiebout (1956). In this context, household preferences are directly associated with climate and climate change alters the utility maximizing decisions of households, potentially resulting in relocation if changes in utility are large enough to offset the costs of migration.

Migration involves both a starting and ending point. While researchers may focus their attention on the endpoint, beginning point, or both; defining these points and designing an identification strategy around those is a key feature of empirical migration research.[2] In structural and reduced form models of the migration process, the migration outcome can be measured as changes in population across locations only if both starting and ending points are defined. Indirect measures of migration are observed through distributions summarizing populations such as incomes, prices and wages. These are associated with beginning and ending points with most research focusing on changes between these points or the endpoint itself.

[2] Dynamic models of migration could include discussion of flows and paths between these points.

Defining the beginning and ending points of migration raises important questions about the migration process. That is, does migration represent a form of disequilibrium? While the theoretical underpinnings outlined by Tiebout (1956) provide a mechanism that drives adjustment, modeling the adjustment process itself involves notions of equilibria. To evaluate migration, particularly structurally, requires a model of equilibrium of which migration is the process to move from one equilibrium point to another point within an equilibrium framework. Focusing only on end points often assumes an equilibrium has been reached, while focusing on beginning points assumes that one has not yet left an initial equilibrium.

Empirical research frequently begins by selecting an econometric specification that defines the spatial scale and distributional impacts of migration as a function of climate change. The heterogeneity introduced into econometric specifications takes on a variety of forms including the potential for differential impacts across subsets of populations, the influence of spatial scale on our ability to tease out heterogeneous responses, as well as differences in short versus long run response that may arise due to mobility constraints. To address these issues, empirical researchers have relied on a variety of econometric methods ranging from reduced form estimates of key parameters to fully structural models of the behavioral process. Regardless of empirical perspective, the observed location patterns of individuals play a central role in identifying migration responses to climate change.

The quality of life literature has long recognized that climate plays an important role in individual's rankings of locations. For example, Blomquist (1988) finds substantial evidence that climate is a key determinant of quality of life along with other factors such as environmental quality and urban conditions. For climate change researchers, an important insight from this research is the degree to which climate and other quality of life measures are correlated. Blomquist reports correlations in quality of life of nearly 0.5 between urban conditions such as crime and student teacher ratios and climate while that correlation drops to 0.21 when associated with environmental quality. This correlation suggests that the influence of climate is not easily separated and identified from other factors that are likely to influence decision making. Further, tradeoffs are likely to reflect heterogeneous preferences and underscore the finding that "the ranking for households who value only a subset of amenities can be quite different…."

3. **Reduced form and structural modeling**

Reduced form and structural models applied to climate change present a variety of tradeoffs to the empirical researcher. Reduced form models, often starting with an underlying theory of behavior and deriving a key statistic or result from that theory, are characterized by their careful and clear identification strategies which make them attractive for measuring key parameters. These methods have their origins in the early hedonic and wage-hedonic literature of Rosen (1974) and Roback (1982). Structural models of location choice draw from the early insights of Tiebout (1956) who recognized that households face a public goods counterpart to the private market shopping trip. Households choose communities or locations that differ not only in housing prices but also in other amenities such as public goods and climate. The location choices made by these individuals provide insights into their preferences. As heterogeneous households sort across space, they not only determine housing prices, but are likely to impact other markets, the provision of amenities, as well as climate through their collective actions.

Empirical applications have increasingly focused on the role of spatial and temporal unobservables that when left unaccounted for, are likely to confound estimates of key parameters. These concerns are well-warranted in the case of migration and climate change as it is generally established that agents choose locations for a variety of factors which are often correlated as shown by the quality of life rankings discussed previously. As a result, much of the econometric innovation in both reduced form and structural models relies on the validity of identification strategies and the development of instruments.

The reduced form empirical literature can be grouped into categories reflecting the key sources of identification used in each study. These categories include historical time-series panel data, cross sectional models, and event based analyses. Historical time-series data often implicitly assume the beginning point for migration is the start of the study period. Cross-sectional studies frequently model the endpoint of migration and focus on key economic distributions including wages and housing prices.

Event based analyses define beginning points and ending points explicitly on either side of the event. These differences largely define what is measured in each study ranging from actual migration to indirect measures of outcomes including the effect of migration on other markets (housing and labor).

The increasing use of event studies reflects the appeal of quasi-random experiments which are designed to improve identification by controlling for unobservables using notions of random assignment drawn from the program evaluation literature. Quasi-experimental approaches rely on naturally occurring climatic events or shocks that allow identification of treatment and control groups. These events often occur over short time periods and/or involve severe weather such as hurricanes or tornados which may cause localized damages and flooding to which economic agents respond. The central identification assumption is that the locations and agents impacted by these events are randomly assigned. Using this random assignment, one form of quasi-experiment relies on difference-in-difference estimation strategies to compare the outcomes experienced by the impacted group relative to the non-impacted group both before and after the event to achieve identification.

In general, reduced form approaches derive an outcome variable or relationship, denoted by Q_{jt}, from underlying economic theory that varies over location j and/or time period t. This variable could reflect population levels, population flows, wage rates, housing prices, or any other readily observable measure or outcome of human behavior. The determinants of this outcome are obtained through decomposition into climate and non-climate explanatory factors as shown in (1)

$$(1) \quad Q_{jt} = \alpha_j + \boldsymbol{C_{jt}\beta^{C}_{jt}} + \boldsymbol{X_{jt}\gamma_{jt}} + \epsilon_{jt},$$

where $\boldsymbol{C_{jt}}$ is a spatially and temporally varying measure of climate such as precipitation, temperature, or even timing and impact of severe weather. $\boldsymbol{X_{jt}}$ are additional, non-climate related control variables that differ depending on the likely sources of omitted variables that may confound estimates of key parameters.[3]

[3] The specific strategies used to perform this decomposition vary widely and often involve the use of extensive fixed effects in the $\boldsymbol{X_{jt}}$ term.

The exact specification of (1) depends in large part on the nature of the empirical question and data availability. In many cases, long panels of climate and economic behavior data are difficult to obtain leading researchers studying long-run impacts to rely on aggregate data on populations and climate to estimate time series models. With long panels of high quality data limited, the majority of empirical migration research uses short-time period cross-sectional data that enables researchers to focus on smaller spatial scales while incorporating heterogeneous responses to climate change that would be difficult to capture with more aggregate data. The use of shorter time period data couples well with empirical research designs centered on random events or climate fluctuations that serve as a type of natural experiment and are arguably exogenous.

While reduced form models provide key insights in the study of climate change, there are several potential problems associated with their use for studying climate change and migration. Rosen (2002) outlines one particular challenge noting that reduced form models rely on a number of strong a priori assumptions about equilibrium including limited or no market frictions and the absence of endogenous payoffs and attributes. A further challenge is that reduced form methodologies are not well-suited to providing long-run predictions or for scenarios that vary substantially from the observed equilibrium used in estimation. To overcome some of these challenges, researchers have turned to structural modeling of the behavioral process itself, rather than reduced form implications of underlying behavior.

The decision to migrate in response to climate change is likely confounded by households' initial state at the observed beginning point of migration. That is, individuals are likely to face significant moving costs associated with changing locations including psychological costs, informational costs in adapting to new labor markets, and social costs associated with leaving one's birth region or family. In addition to overcoming these frictions, the sorting process itself may lead to endogenous outcomes of key policy metrics including wage distributions. As Roback (1982) showed, wage rates are partially determined by idiosyncratic features of households and the composition of households in an area is likely to depend on non-labor market features of the area, such as amenities. Failure to account for both sources of sorting leading to observed wage distributions would confound traditional wage-hedonic measures.

For research aimed at predicting migration responses to climate change over long time periods, accounting for frictions in sorting and especially the potential for endogenous payoffs and attributes are key areas of emerging empirical research.

Empirical sorting models as developed by Bayer et al. (2007) and Epple and Sieg (1999) present one type of structural approach which can embed sorting frictions and endogenous payoffs and attributes in a framework capable of providing welfare measures and migration implications for non-marginal changes in climate that alter the baseline equilibrium. Equilibrium sorting models involve structural assumptions linking the spatial landscape to heterogeneous household (firm) preferences. A utility (profit) maximizing problem is then specified as a function of household demographics, locations, housing, and structural parameters for preferences. Using revealed preference data, often focused on the end point of the migration process, the econometrician is able to recover the distribution of these preferences in the population. Obtaining direct estimates of preferences is a distinguishing feature of structural models and allows for complex simulation and prediction of behavioral responses. For climate change research and policy that frequently involves non-marginal changes occurring over long periods of time, the ability to use preference estimates to simulate new equilibria and incorporate complex feedbacks makes them an attractive choice to empirical researchers.

Equilibrium sorting models are one example of structural models that have been applied to local housing markets to value environmental amenities with examples in the open space literature (Klaiber and Phaneuf, 2010; Walsh, 2007) as well as air quality (Bayer et al, 2009; Sieg et al., 2004), among others. While specific implementation of these models varies widely, one class of these models is derived from McFadden's (1974) random utility framework and is discussed below. The use of structural models necessitates an explicit characterization of the choice set and extent of market. This characterization in turn dictates the types of model outcomes which include migration, distributions of key parameters, and influences on equilibrium prices and wages. Consistently modeling joint outcomes in a structural model depends crucially on the definition of the choice set and is an area to explore further in future research.

The econometric specification for this class of structural models begins by defining an indirect utility function shown in (2) for person i choosing location j.

(2) $$V_j^i = \alpha_h^i h_j + \alpha_g^i G_j + \alpha_p^i p_j + \xi_j + \epsilon_j^i.$$

Households are assumed to receive utility from housing, h, public goods or climate, G, and housing price, p with additional elements of indirect utility observed by the researcher included as controls. Preference heterogeneity is incorporated using observable demographics. As an example, preferences may vary for climate following a decomposition of parameters as $\alpha_G^i = \alpha_G^0 + \alpha_G^1 d^i$ with d^i identifying individual specific attributes such as income or birth region. These interactions allow researchers to incorporate initial conditions and frictions into the migration process.

Controlling for unobservables is accomplished in part by including an alternative (location) specific unobservable, ξ_j, in addition to the observable components of indirect utility and the traditional idiosyncratic term ϵ_j^i. Inclusion of an alternative (product) unobservable has its origins in the industrial organization literature (Berry et al., 1995) and provides numerous desirable properties. Among these is that inclusion of alternative specific unobservables control for many sources of omitted variables and result in clean identification of heterogeneous parameters introduced through interactions with demographic characteristics. Berry (1994) showed that for certain classes of models, this feature also results in exact replication of aggregate choice probabilities which can be used to facilitate estimation. The ability to perfectly replicate observed choice patterns is central for replicating equilibria and predicting new equilibrium outcomes following non-marginal changes in attributes.

Estimation of the model proceeds in two stages. First stage estimation recovers mean indirect utility, θ_j, along with parameters interacted with demographics denoted by a 1 superscript. The second stage of estimation decomposes the estimated mean indirect utility parameters to recover preference parameters common to all households. This partitioning is given by (3a) and (3b).

(3a) $$V_j^i = \alpha_h^1 d^i h_j + \alpha_g^1 d^i G_j + \alpha_p^1 d^i p_j + \theta_j + \epsilon_j^i$$

(3b) $$\hat{\theta}_j = \alpha + \alpha_h^0 h_j + \alpha_g^0 g_j + \alpha_p^0 p_j + \xi_j$$

First stage estimation of (3a) often follows the multinomial logit model by assuming that the idiosyncratic errors are type-I extreme value. The probability of person i choosing to live in location j is then given by the closed form expression (4)

$$(4)\quad Pr_j^i = \frac{\exp(V_j^i)}{\sum_l \exp(V_l^i)}.$$

Equilibrium population shares of individuals living in location j are simply the sum of the individual probabilities as shown in (5)

$$(5)\quad pop_j = \frac{1}{N}\sum_{i=1}^{N} Pr_j^i,$$

where N is the total number of individuals. Second stage estimation of (3b) presents several econometric challenges. The primary identification challenge arises because prices, and potentially amenities, are likely to be correlated with the error term in (3b), confounding OLS estimation. This has resulted in numerous extensions to the literature exploiting the sorting process itself to form instruments as well as the use of traditional instruments.[4]

Overall, it is clear that both reduced-form and structural models present opportunities and challenges for empirical researchers studying climate change. While each method provides valuable input into the migration and adaptation responses to changes in climate, they each service slightly different yet potentially complementary roles in the overall analysis of climate change and migration. Chetty (2008) recently advocated merging the two empirical strategies to improve identification of key "sufficient statistics" of interest. While there are few examples of this strategy applied to climate change and migration, this is one potential avenue for future empirical research that may prove productive.

Migration and Economic Opportunity

Climate change impacts a wide variety of economic sectors. For example, changes in rainfall and temperature are likely to influence agricultural productivity and the labor market in areas experiencing

[4] See Bayer and Timmins (2007) and Murdock and Timmins (2007) for examples of exploiting the structure of the model to form instruments.

those changes. These changes may cause households and individuals to re-optimize if the impacts of those changes are expected to persist. The re-optimization process will undoubtedly result in some households choosing to relocate to areas where their economic outlook is sufficiently high to offset the costs of relocating to that new location. This logic describes migration as a response to differences in economic opportunities that arise due to climate change and is well established in the empirical literature (see, e.g. Borjas et al., 1992). In what follows I highlight key empirical aspects of several recent studies in this vein of migration and climate change research.

Feng et al. (2012) examine internal migration in the United States driven by climate change impacts on the agricultural sector of the economy. They employ a reduced form strategy to identify a key parameter of interest, the semi-elasticity of migration with respect to crop yield, that when estimated is used to provide predictions of long-run population change associated with changes in agricultural productivity driven by climate change. Estimation of the semi-elasticity embeds a measure of "net" migration rather than defining migration as originating at one point and ending at another. In recovering net migration, both out-in and in-out migration is occurring. There is no reason to expect that each migration direction has the same underlying choice set in the implicit behavioral model of migration. The tradeoffs inherent in avoiding the potentially different sources of migration and differences in underlying behavioral processes are an interesting question for future research.

The estimation strategy employed is similar to many reduced form studies and relies on county level data spanning 1970 through 2009. The authors estimate a variant of equation (1) defined as

(6) $m_{it} = \alpha + \beta x_{it} + f(t) + c_i + \epsilon_{it}$

where m_{it} is a measure of out migration for location i in time period t. x_{it} is a measure of agricultural yield with β the key parameter of interest measuring the semi-elasticity of net migration. Controls for unobservables are included in the terms $f(t)$ and c_i with an idiosyncratic error defined by ϵ_{it}. Identification challenges arise if factors influencing agricultural productivity change across time and are omitted from the specification in (6) resulting in a correlation between x_{it} and ϵ_{it}. The authors address this concern in several ways. First, they restrict their sample to specific, arguably exogenous, yield changes in soybeans and corn. Second, they exploit the exogenous incidence of weather shocks to form instruments for x_{it} as these shocks are linked with the endogenous variable yield but argued to be unlikely to influence out migration. The assumption of exogeneity assumes that individuals do not locate on the basis of climate shocks. It also implicitly assumes that risk perceptions are not altered by these shocks to the extent that location is a function of future expected risk. This does not preclude individuals from choosing locations based on longer run differences in climate and is appropriate if climate shocks used as instruments do not fundamentally change the expectations of long run climate enough to induce migration directly.

The authors report a semi-elasticity of -0.17 which suggests a 10% decline in yields would result in a 1.7% reduction in population due to migration. Carrying this estimate forward in time, the authors predict the future impact of climate change using yield predictions obtained from the B2 scenario of the Hadley III model. In this scenario, a significant outflow of working aged individuals leave rural areas in the Corn Belt of the United States, 3.7% by 2049. The authors also find evidence of heterogeneous responses with young individuals having the largest response and virtually no response for retired households.

In a study of emigration, Saldana-Zorrilla and Sandberg (2009) exploit weather shocks measured using recurring natural disasters as a determinant of out migration in Mexico. Unlike the previous study exploiting weather shocks as instruments, the authors explicitly model migration as a response to those shocks. Focusing on the adaptive capacity and coping ability of populations, the authors explore whether income heterogeneity results in different patterns of migration. Their study is based on the assertion that recurring natural disasters reduce future income expectations, especially for those populations that have the least adaptive capacity such as the poor and rural. Because agriculture employs a large proportion of the Mexican population (~25%) but is responsible for only 4% of GDP this sector is likely to reflect a large proportion of poor households and is over exposed to natural disasters.

The authors assemble data on nearly 2,500 municipalities that include natural disaster incidents, income of households, agricultural prices, and spatial location. The authors use this data to estimate a spatial regression model controlling for spatial lags and spatial error processes where the dependent variable is a measure of out-migration between 1990 and 2000. This setup is representative of cross-sectional studies applied to migration and climate change that lack long time panels with high quality data. The use of a spatial Durbin model is designed to capture unobserved spatial correlation in the data, where spatially varying attributes are potentially correlated with spatially varying explanatory variables to account for similar migration responses of nearby municipalities in responses to natural disasters. These suggest the presence of social interactions may influence overall migration. Their key findings are that declining incomes, higher educated individuals and increasing numbers of natural disasters lead to higher levels of out-migration. The finding that higher educated individuals are more likely to migrate suggests that initial conditions or barriers to migration exist for low-educated individuals.

Migration seeking economic opportunities that arise due to climate change is not limited to recent events. Using historical data on climate shocks provides opportunities to gauge the short and long run migration impacts of changes in economic opportunities caused by climate change. Understanding the adjustment process to move from one equilibrium point to another is fundamental to long-run planning given the long time scales over which climate change occurs. Addressing this issue directly, Hornbeck (2012) uses the dust bowl during the 1930s to study the lasting impact on agriculture and populations resulting from the severe decrease in agricultural productivity in a quasi-experimental setting. Treated counties are those which experienced high levels of erosion while control counties are those with very little or no erosion resulting from the dust bowl.

Given the long-time frame under consideration and scale of the dust bowl, the author uses a Roback (1982) model to describe the likely implications over the long run for the agricultural and industrial sector in both impacted and non-impacted areas. Each sector of the economy is assumed to use land and labor as factors with land fixed in a given location and labor a function of population. As a result, changes in agricultural productivity resulting from the dust bowl are expected to depress wage rates and agricultural land rents in the impacted areas. In a general equilibrium setting, even non-impacted areas are influenced through changes in labor resulting from migration. However, if the impacted area is small, the author argues that these migration effects would be suppressed and this assumption is used in the paper. In the absence of this assumption, it is likely the author's estimates would overstate the differences between treated and non-treated areas.

The econometric strategy uses a series of regressions to measure changes in agricultural values, changes in agricultural production, and changes in population and labor as a function of the treatment, the dust bowl, and other control variables and fixed effects. The basic regression equation is given by

(7) $Y_{ct} - Y_{c,1930} = \beta erosion_c + \theta_t X_c + \alpha_{st} + \epsilon_{ct,}$

where X are control variables, α includes state and time fixed effects and $erosion$ is the treatment indicator. Identification relies on the assumption that counties with and without high erosion were randomly assigned. That is, in the absence of the dust bowl there should be no difference in the outcomes across these counties given the control variables included in the model.

Key findings of the paper are that agricultural adjustments were slow and did not appreciably recover in the long run when land devoted to agriculture was free to adjust to more productive activities. In contrast, migration adjusted substantially in both the short and long run suggesting that migration may play a major role in assessing the future impacts of climate change on land use. Also of interest is the issue of general equilibrium effects. For climate change over long periods, the scale of these effects may play in important role in assessing policy and human responsiveness to climate change through changes in economic opportunities. This research also provides evidence of the speed at which new equilibria may form following non-marginal shocks.

The three papers examined in this section highlight the variety of reduced-form econometric approaches used to understand migration responses to changes in economic opportunities caused by climate change. The papers used a variety of empirical methods including panel data, cross-sectional, and quasi-experimental approaches. In addition, each of these papers employed a different identification strategy to obtain empirical estimates. In the first, climate shocks as instrumental variables were used, the second employed spatial econometrics techniques to control for unobservables, and the third adopted the logic of a quasi-random experiment to achieve identification. In addition to the econometric underpinnings, a recurring theme in these and related papers is the central role of heterogeneity and the complex interactions between multiple economic sectors which determine observed outcomes. When scaling up or adapting theses models to other contexts, the way in which these features are incorporated appear to be important for assessing the impacts of climate change to migration.

Climate as an amenity

Research into households' responses to climate change as an amenity have taken on a variety of approaches that mirror those used in research on the economic drivers of climate change and include the aforementioned quality of life literature, event studies using climate shocks which alter risk perceptions of locations, as well as cross-sectional models using hedonic approaches. A distinguishing trend in this line of literature is the focus on a much broader set of spatial units, with many studies centered on small spatial scales such as a single urban housing market. The focus on smaller spatial scales is amenable to increasing the degree of heterogeneity in both landscape and behavioral responses to provide a more nuanced view of household responses to climate change than can be achieved at more aggregate spatial scales. Identifying these subtle differences present challenges in how to merge these insights with larger scale models while at the same time providing finer scale policy-insights into the potential demand for local resources in urban settings. Complicating this effort is the plethora of complementary and substitute amenities over which households also sort (Smith et al, 2011).

Recent advancements in the quality of life literature have provided new insights into the way households view climate. Costa and Kahn (2003) estimate wage and house price hedonics to explore how implicit valuations of climate have changed in the United States over time. Using climate controls for January and July temperature as well as rainfall attached to metropolitan areas in the United States along with detailed data on individuals living within those metropolitan areas they found warmer winters and cooler summers increase housing prices while increased rainfall lowers prices. From 1970 to 1990, the marginal willingness to pay for climate increased in magnitude. This trend does not repeat itself in the case of worker wages. While there are clear links between climate and wage rates, they appear relatively stable across the study period.[5] The increases in housing values in areas with desirable climate are partially attributed to rising incomes if climate is a normal good. This result suggests that responses to climate as an amenity may be more pronounced in developed countries relative to developing countries.

With increases in housing prices associated with "nice weather," the question of what is behind this apparent migration towards desirable climate is a key question in this line of research. That is, does the introduction of air conditioning or other forms of adaptive measures explain this migration phenomenon? Rappaport (2007) tests this hypothesis using a model of steady state growth to define a series of regressions including climate as a time invariant explanatory variable. The regression model is estimated using county level data and annual population growth measures for U.S. counties from 1970 to 2000 along with average weather (temperature, humidity, and rainfall) over the period 1961 to 1990. To control for changes in other economic sectors, the author includes measures of employment in agriculture, manufacturing and mineral industries as control variables.

While the author's findings that households migrate to locations with warmer winters, cooler summers and less humidity are not surprising, it is of note that when controlling for sectoral employment the author finds that the majority of the migration to nice weather is a function of weather itself, rather than changes in other economic sectors. To further explore this finding, he examines longer time-frame migration dating to the 1880s. He finds that from 1880 through early part of the 20th century people migrated away from desirable climates but this trend reversed in the 1920s, predating the introduction of air conditioning in the 1940s. This finding suggests that the spread of air conditioning is unlikely to account for the entire shift in populations responding to climate as an amenity. Taken together these results suggest that rising incomes allowed households to move more freely to nice weather, and that these increased incomes helped to offset stickiness or frictions in the migration process. In a developing country context, these frictions would likely exceed those of developed countries and may dampen the initial response to climate change as an amenity.

[5] The authors assume that climate variables are uncorrelated with other measures of non-market goods which, if violated, may confound these estimates.

Cross-sectional hedonic approaches provide additional support for climate as an amenity driving location choices, even across relatively small spatial areas. For example, urban heat island effects (Brazel et al., 2007) are characterized by increasing temperatures, in particular nighttime temperatures, as a result of urbanization and the conversion of open areas to heat retaining concrete and asphalt. These temperature differences manifest themselves across relatively small spatial scales making them ideal for cross-sectional models using housing prices and location choices to estimate the response of households to subtle differences in temperature. In this line of research, empirical researchers often focus on the current state of the landscape, defining observed locations as an endpoint of the migration process in order to learn about the distributional impact of climate change on key economic variables.

As with all cross-sectional studies, identification concerns play a central role. Klaiber and Smith (2011) carried out a hedonic analysis of temperature effects on housing prices in Phoenix, AZ using a recent extension to the hedonic literature developed by Abbott and Klaiber (2011). Their hedonic strategy exploits spatial locations as panels and employs the Hausman and Taylor (1981) panel data estimator to those cross-sectional spatial panels. Identification is aided by the creation of instruments internal to the Hausman-Taylor model that exploit the mean of within-varying, exogenous attributes as instruments for between-varying endogenous factors, such as differences in temperature across space. Applying this model to Phoenix, AZ and using subdivisions as the panel dimension, along with numerous demographic, housing, and amenity controls, the authors find a significant willingness to pay to avoid an increase in summer nighttime temperatures of $50 per month for a 1 degree reduction in average summer nighttime temperatures. This finding suggests that even within a relatively small spatial area such as a single metropolitan area climate influences household behavior and location decisions.

The finding of an aversion to increased temperatures in Phoenix, AZ has larger implications for integrating empirical work into additional modeling efforts moving forward. In particular, if households migrate on the basis of climate change, they are in part altering local climates through those collective location decisions. In the case of urban heat island, this endogenous climate response would likely influence the structure and land use of cities over long periods of time. An important question is to what extent the responses observed in a cross-sectional setting reflect long-run expectations about weather. While the authors observe one outcome, for use in long-run predictions a mapping between this outcome and expectations over longer time horizons would be required.

To assess household responsiveness to climatic shocks, rather than stable differences in climate over space, numerous authors have studied the impact of hurricanes on local housing markets (see e.g. Bin and Polasky, 2004; Smith et al., 2006) and have generally found that local studies of housing price responses show a decrease in housing values in areas experiencing the highest damages relative to areas that experienced little damage. These findings suggest that households are updating risk perceptions in response to observed damages. However; larger scale studies of the impact of hurricanes on housing prices often find contrasting results. Graham and Hall (2002) and Beracha and Prati (2008) find little impact on housing prices in more aggregate studies involving multiple hurricanes. Murphy and Strobl (2010) find an increase in housing prices associated with hurricanes when accounting for income dynamics and a wider geographical extent of hurricane impacts using predicted wind impacts that extend beyond the immediate hurricane trajectory. They partially explain this finding by suggesting that housing supply restrictions following hurricanes raise prices, while they do not explicitly model the housing supply response.

Despite the seemingly contradictory findings, these ranges of estimates suggest broad outlines for the types of responses that should be included in future empirical and modeling efforts. At a minimum, these empirical papers suggest that spatial heterogeneity across storms and locations plays an important role in the adaptation responses we observe. Smith et al (2006) examine response heterogeneity using data on damages following Hurricane Andrew in Dade County, Florida coupled with pre-existing risk information derived from FEMA flood maps to examine how households adapt following a natural disaster. They found that the most heavily damaged areas grew faster than areas with less damage, suggesting that households did not flee damaged locations in anticipation of potential future risks.[6]

[6] Similar findings of little responsiveness to climate shocks is found in literature assessing the impacts of rising sea levels and the increasing concentrations of populations in coastal areas.

However, this overall failure to flee masks the heterogeneous population responses the authors find. In particular, they note that different demographics moved out of damaged areas (e.g. white renters) while other demographics (e.g. Hispanics) were likely to move into the damaged areas. These population shifts could be used to provide important insights into different adaptation strategies and risk attitudes across demographic sectors of the population to provide guidance in the appropriate parameterization of structural models of migration.

Linking economic opportunity and amenity driven migration

Efforts to jointly estimate responses to climate that incorporate changes in economic opportunities and changes in amenities have recently emerged in the empirical literature. Timmins (2007) employs a structural sorting model that accounts for changes in labor markets and wage rates in a study of household location choice in Brazil. He introduces a flexible preference specification for indirect utility along the lines of (2) that incorporates initial conditions based on birth locations and preference heterogeneity as a function of education levels. In his model, households are assumed to sort on the basis of differences in climate across regions as well as endogenous labor market outcomes. Wage rates are influenced by climate change through changes in labor demand arising from migration.

To empirically estimate the model individuals are classified into exogenous types or classes based on education levels with preference parameters that vary by type of individual. Climate is included in the utility specification using a non-monotonic relationship allowing preferences to vary across climate attributes such as temperature. Person type and location varying wage rates are incorporated and are endogenous to the sorting process with endogenous wages determined by the composition of labor supply as a function of the equilibrium locations of individuals. Finally, the model includes a measure of migration costs associated with moving away from one's birth location. Including birth location as an initial condition in the model introduces stickiness in the sorting process and avoids having to fully model the behavioral process that gives rise to the initial point of migration.

Using micro-census data that includes wage, housing, and location information, Timmins estimates wage equations to predict incomes for each location/person type combination. He uses 30 year averages of rainfall and temperature to introduce climate into a utility framework that captures location choice from among 495 micro regions. Rainfall is further divided into both fall and spring seasons. Estimation proceeds by first estimating wage regressions for income types and locations and then using the estimated wages along with other variables in a two stage estimation strategy along the lines shown in (3a) and (3b). The share of household types in each location is a key determinant of labor rates and is included in the second stage decomposition of (3b). Because shares are endogenous to the sorting process, instruments are required for identification and are derived following Bayer and Timmins (2007).

Estimation results show that marginal utilities for wages are positive across all education groups, as expected. In addition, initial conditions appear to significantly influence migration as seen by a negative marginal utility associated with leaving one's birth region. Climate enters significantly and is shown to be a direct determinant of location decisions. Using these estimates, along with estimates of wages as a decreasing function of population density, simulations of the impacts of non-marginal changes to Brazilian climate are used to assess the welfare implications for households. Several insights emerge from these simulations that arise directly from the multi-market equilibrium setting of the model and are potentially important in larger modeling or empirical analyses of non-marginal impacts from climate change.

In the absence of labor market and population responses, one would expect that the inclusion of initial conditions through disutility from leaving one's birth location increases the costs of climate change as individuals are unable to freely re-optimize in response to changes in climate. However, the inclusion of general equilibrium effects confounds this intuition as the actions of others influence utility through sorting. For individuals initially living in locations made more desirable by climate change, free mobility would induce greater numbers of people to locate in more desirable locations and drive down utility through increased congestion and lower wage rates. This finding suggests that free mobility may actually increase welfare losses in some areas, while migration costs are likely to significantly impact lower education households.

Overall, several takeaways from this structural approach are relevant for other researchers. First, equilibrium effects are of first order importance in modeling future impacts of migration resulting from non-marginal changes in climate. Second, capturing these effects requires data on multiple markets. Third, initial conditions and endogenous attributes appear to be important in evaluating the non-marginal impacts of climate change and failure to account for these elements of sorting may confound traditional hedonic and wage-hedonic models. Finally, employing birth location as a starting point enables Timmins to ignore the behavioral process which led to the initial equilibrium outcome. Future research could be used to understand how the sorting process leading to starting and ending points are linked and what implications arise from modeling behavior associated with only ending points.

In a reduced form setting Marchiori et al. (2012) link weather anomalies to migration in sub-Saharan Africa using a country level panel. These authors use weather anomalies to explain rural to urban migration and further connect this migration to international migration patterns resulting from economic spillovers across country borders. In a similar spirit to the structural work of Timmins (2007), the authors emphasize the complex linkages that exist between climate change and migration incentives. However, they eschew a structural approach in favor of a theoretical model which gives rise to reduced form estimating equations.

The premise behind the authors' theoretical model is that climate impacts to the agricultural sector are disproportionate to the impacts on manufacturing (IPCC). Because of the enhanced impact on agriculture affecting rural areas, an economic incentive to migrate towards urban communities exists following climate shocks. As with Timmins (2007), increasing populations in urban areas raise labor supply and reduce wages which results in further migration as wage differentials between countries increase. The amenity channel the authors focus on is based on impacts of weather variability on amenities following the logic of Rappaport (2007) discussed previously.

Empirical estimation takes the form of a three equation reduced form model of migration rates, changes in GDP and changes in urbanization. Weather impacts each of these processes both directly and through an interaction with the size of the agricultural sector. Importantly, migration rates are also a function of GDP differentials across countries as well as the level of urbanization. The migration rate for country r in time period t is given as

$$MIGR_{r,t} = \beta_0 + \beta_1 W_{r,t} + \beta_2 \left(W_{r,t} * Ag_r \right) + \beta_3 \log \frac{\widehat{GDP_{r,t}}}{GDP_{-r,t}} + \beta_4 \log \widehat{Urb}_{r,t} + Controls + \epsilon_{r,t},$$

where W indicates weather anomalies and the two estimated terms are obtained from additional estimated equations. In addition to adding control variables to account for unobservables, the authors address the potential for endogenous variables resulting from country specific and time-varying sources of unobservables using instruments.

Given the developing country context and low incomes for much of the population it is somewhat surprising that the results show both amenity driven and economic opportunity driven migration occurs. The authors hypothesize that the amenity driven result reflects health concerns or risk preferences rather than a pure preference for nice weather as would be more likely in a developed country context. They also find evidence that weather anomalies increase urbanization, likely through reduced returns to rural, agricultural areas that are most vulnerable to weather shocks and that this increase in urbanization is likely to lead to additional international migration. Without consideration of multiple economic sectors and the complex transmission of climate anomalies to migration through multiple channels these insights would be difficult to empirically recover from simpler characterizations of climate change response.

Challenges and Opportunities

The empirical evidence supporting both economic opportunity driven and amenity driven migration in response to climate change is strong. Looking ahead, several challenges facing applied researchers include how to better integrate empirical models with underlying natural systems, how to "scale up" or "scale down" the empirical models for prediction purposes, and how to overcome challenges in capturing the variety of endogenous feedback effects that are likely to occur over the long time periods involved in climate forecasting. To meet these challenges, new methods and approaches are needed. I present several examples and suggestions of potential paths to explore below.

For many climate change scenarios, the human responses are compounded by dynamics of the natural environment itself. These dynamics, when unaccounted for, present similar problems to those observed in the empirical work to date that fails to acknowledge the potential for spillovers across markets and endogenous feedback effects. One place where the literature has begun to examine the interactions between humans and the natural environment in a dynamic fashion involves changing coastlines and erosion management (Gopalakrishnan, et al., 2011). The basic motivation for this form of coupled human-natural systems research is the recognition that as humans react to changing landscapes, those actions change the landscapes themselves. Failure to account for either the behavioral response of humans to landscape (climate) change or the changes in landscapes resulting from human actions would confound prediction. Additional integration between natural systems modeling and economic models is one way to better capture these dynamics in climate change research.

Scaling empirical research to fit larger modeling efforts is well-recognized as a challenge (Fisher-Vanden et al, 2011). While it may be possible to isolate key behavioral parameters from empirical models and integrate those into integrated assessment modeling, this task is often difficult due to the unique circumstances under which the empirical work was undertaken as well as scope differences between IAMs and empirical research. One potential path forward is the coupling of structural empirical models with integrated assessment models in an attempt to leverage the strengths of each approach to deliver more robust predictions. For example, in Timmins (2007) work on Brazilian climate response he embeds a relatively simple model of the labor market to endogenously determine wages while developing a rigorous empirical model of household utility optimization. In this context leveraging the more fully specified, in terms of market interactions, models provided by integrated assessment models to derive wages while relying on population predictions from the empirical model potentially provide improvements to both methods. Of course, many challenges remain, including issues of reconciling differences in utility assumptions between each approach.

Finally, a recurring set of themes in the empirical research is the importance of heterogeneity in response as well as the need to account for multiple markets in order to fully capture the migration response of households to climate change. One shortcoming of much of the empirical research is the lack of research on housing supply response and in general on spillovers across a wider range of markets. While some efforts to incorporate and understand the housing supply process are underway (Saiz, 2010; Strobl and Walsh, 2008), additional work is clearly needed in this area. This presents both a challenge and opportunity for empirical researchers and one that may be partially met by integrating empirical research with integrated assessment models that by design include a much wider and richer specification of market sector interaction. The challenge is to make this interface without compromising the richness of response either in heterogeneity or substitution that is likely to play an important role in understanding the long run impacts of climate change on migration and land use.

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