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Modeling equilibrium responses to climate-induced migration*

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ABSTRACT

We construct a quantitative model to simulate the impacts of climate change on U.S. domestic migration patterns. The model consists of an equilibrium framework for modeling counterfactual migration responses and their implications for regional welfare, prices and populations. The model's parameters are estimated using an econometric, locational sorting model, the structural equations of which are a key component of the equilibrium framework. The econometric model is estimated from demographically rich data from the U.S. Census. The parismonious structure of the equilibrium model allows us to incorporate much of this demographic richness in the simulation of the predicted migration flows.

JEL **classifications: D58, Q54, R13**
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1 Introduction

Climate is an important factor in determining where households choose to live. Leaving employment conditions aside, empirical studies of labor migration consistently find that it is among the more important explanatory variables (Kennan and Walker, 2011). Migration may, therefore, be an important behavioral response to climate change.

Climate impacts are predicted to have a strong spatial signature at both global and regional levels with changes in temperature, precipitation and frequency of extreme weather events that differ in sign and magnitude. In the United States, the focus of our analysis, the predicted temperature changes result in the South experiencing an increase in extreme heat days. In the North, the primary effect will be a reduction in extreme cold days. Proximity to oceans and other geographic features also shape the spatial pattern of predicted climate change. The changes are also non-marginal. Under "middle-of-the-road" assumptions (RCP 4.5 emissions scenario and the CESM1-CAM5 member of the CMIP5 ensemble), much of the Southeast is expected to gain over 50 days per year in which the average daily temperature exceeds 28°C.

For the types of non-marginal adjustments in climate expected over the next century, theory predicts equilibrium adjustments in regional labor and housing markets. The in-migration experienced by locations with desirable climates should drive down wages as the local workforce supply grows and drive up rents as demand for housing rises all else equal. Equilibrium is restored when the standard of living households may expect to achieve by moving to this location falls to the point where households are indifferent between moving there and locating elsewhere (Rosen, 1974; Roback, 1982). Indeed, the hedonic method of estimating the value of local amenities is predicated on the notion that full arbitrage occurs — so that differences in equilibrium wages and housing prices across locations reflect the full value of differences in local amenities.

Thus, if the spatial gradient of climate change is sufficiently large and the costs of migration are sufficiently low, households may move to arbitrage differences in living standards, with consequences for regional populations, prices and well-being.

Nevertheless, migration frictions may be considerable at the spatial scales relevant to the study of climate change. Migration research also shows that destination distance is a strong determinant of propensity to migrate, with the large majority of moves for U.S. households occurring within one's state of birth (Bayer et al., 2009; Kennan and Walker, 2011).

Collectively, these features of the problem have a number of implications for the study of regional climate impacts. First, substantial migration frictions would limit the extent to which households can use migration as a form of adaptation, increasing the aggregate cost of climate change relative to a world in which households may move freely to avoid its impacts. Moreover, they would raise the potential for finding important distributional consequences of climate change, producing relative losses or gains in regions that experience unfavorable or favorable changes in climate.

Second, a model that is capable of capturing the adjustments in regional prices from climate-induced migration is justified for analyzing the types of non-marginal changes in

climate predicted to occur over the next century. Welfare estimates of climate impacts that fail to account for adjustments in regional price may overstate costs of climate-disadvantaged regions, for example, by assuming that adjustments in wages and rents fail to compensate households for a poorer climate. They may also fail to reflect the distribution of costs and benefits across regions to the extent that price signals and migration telegraph the consequences of local climate impacts across space.

Third, a corollary of the previous two points is that the extent to which spatial aggregation in models assessing the welfare impacts of regional climate change matters will hinge on the degree to which regional markets are integrated. If migration is relatively costless, it will ensure that quality of life is similar across locations, because households will arbitrage away the gains from especially desireable locations. In this case, it may acceptable to use spatially aggregated models to measure the aggregate welfare implications of spatially distinct climate impacts. If there are important barriers to relocation, then the results of such a model may be misleading.[1]

Conversely, a strategy for valuing climate amenities like the hedonic method — which relies on compensating price differentials — may not perform well to the extent that migration frictions drive a wedge between quality-adjusted prices across locations and bias measurement of the welfare impacts of climate change (Bayer et al., 2009; Sinha et al., 2018).

Finally, climate-induced migration may have important interactions with the underlying population dynamics that drive the regional distribution of people. That is, even if migration has a relatively modest contemporaneous effect on populations, these effects will be compounded over time by adding or subtracting people to the base population to which growth rates are applied. Thus, a small contemporaneous effect can become a large over the long time horizons that are relevant to the study of climate impacts. This issue is the subject of on-going research.

We construct a quantitative model that estimates the impact of climate change on U.S. domestic migration patterns. It combines a strategy for estimating household demand for climate amenities in the presence of migration frictions with a simple, equilibrium framework for modeling counterfactual migration responses and their subsequent impacts on local wages and housing prices and migration patterns across the United States.

Our econometric strategy (Carbone et al., 2021) takes a discrete choice approach to modeling household choice across all Metropolitan Statistical Areas (MSA) in the continental United States and builds on a recent literature estimating household preferences for climate amenities (Albouy et al., 2016; Fan et al., 2016; Sinha et al., 2018; Fan et al., 2018). Detailed demographic data from the U.S. Decennial Census and the American Community Survey are combined with data on historical climates and other characteristics of MSAs to estimate how the decision to migrate is influenced by climate, job opportunities, cost of living and the availability of other amenities. We use the structural equations of our econometric model as the basis for the equilibrium simulation model. This allows us to incorporate much of

[1]This logic is of general importance to the valuation of changes in environmental quality with strong spatial signatures. All of the criteria air pollutants, for example, would likely fit this definition. Therefore, developing a framework that would allows research to determine an appropriate level of aggregation is needed.

the richness from the Census datasets to describe households in the migration simulations, allowing us to track migrants by household composition, age, and occupation.

Fan et al. (2018) use the econometric model estimated in their earlier study (Fan et al., 2016) to link migration responses to a computable general equilibrium (CGE) model of five US macro regions to consider how migration and regional wage feedbacks interact to determine regional welfare and economic impacts. It is, as a result, most similar among the studies in the extant literature to the analysis described here. They find both that migration has an important influence on regional economic outcomes and that wage feedbacks significantly temper equilibrium migration responses relative to a model with no such equilibrium adjustments included.[2]

Our contribution is to consider how migration frictions and equilibrium responses together shape future regional populations, prices and well-being. Our approach differs from Fan et al. (2018) in a number of ways. First, our equilibrium model takes a more parsimonious approach to capturing price feedbacks than a detailed, multi-sector CGE model like the one used in that study. For computational tractability, the authors aggregated their model to the level of five regions spanning the continental US. In contrast, our model explicitly represents 269 Metropolitan Statistical Areas (MSA).[3] The advantage of this approach is that facilitates an exploration of the role of spatial aggregation in shaping the outcomes of interest in the presence of migration frictions. Modeling an aggregated region is equivalent to assuming perfect mobility and market integration across the subregions of which it is comprised. It also allows for theory-consistent welfare estimation using the econometrically-estimated preference functions from Carbone et al. (2021).

Second, our model establishes a new framework for the study of regional equilibrium impacts from changes in environmental quality. Local air pollution, for example, as a strong, spatial pattern driven by weather and differences in rural and urban economies. In this context, being able to model spatial heterogeneity in air quality and regional markets at a fine scale is likely to be important. The framework established here provides one possible method.

In what follows, we first describe the logic of the equilibrium model in section 2. Section 3 describes the our strategy for calibrating the model using census data and the estimated coefficients from the discrete choice model in Carbone et al. (2021).

2 Equilibrium model

2.1 Model logic

Household choice in the equilibrium model follows from the specification used in Carbone et al. (2021). Households of type i maximize well-being, v, by choosing whether or not to move to destination k. Household well-being depends on consumption of a numeraire good,

[2]In a different context, Phaneuf et al. (2009) combine a econometric, discrete choice model with an equilibrium model of congestion effects at recreational sites.

[3]MSAs are defined as geographic areas containing more than 50,000 people and high population density.

housing and an index of climate desireability, c_k. The numeraire good is internationally traded and offered at a constant price normalized to unity. Households are renters and purchase housing on local housing markets at the price of housing services, p_k. They finance their consumption out of wage income, earned by supplying a single unit of labor to the local labor market at wage rate for individual of type i, w_{ik}. The choice of the numeraire implies that wages and housing prices are measured relative to the cost of the consumption good.

Based on this, utility for a household i moving to k can be written as:

$$u_{ik} = \ln v_{ik} = \hat{\alpha} \ln w_{ik} + \hat{\delta}_{ik} + \tilde{\theta}_k + \hat{\beta} p_k + \hat{\gamma} c_k + \hat{H}_{ik} + \epsilon_{ik} \tag{1}$$

where $\hat{\alpha}$, $\hat{\delta}$, $\tilde{\theta}$, $\hat{\beta}$, $\hat{\gamma}$, and $\hat{H}$ represent the point estimates of the corresponding parameters from our econometric model.

We assume that a household head's expected wage is proportional to a common wage level (w_k) at location k, which is determined endogenously in the equilibrium of the model, while the demographic-specific estimate of the individual from the wage regression ($\hat{w}_{ik}$) is exogenous. Hence, $w_{ik} = \hat{w}_{ik} w_k$. This assumption allows us to capture the significant heterogeneity in wages opportunities that exist across space and household characteristics while maintaining the tractability of the equilibrium model.

$\hat{\delta}$ is the migration cost incurred by household i when moving to location k and is parameterized as

$$\hat{\delta}_{ik} = \hat{\mu} d_{ik} + \hat{\mu}^{kid} d_{ik}^{kid}$$

where

$$d_{ik} = \{d_{ik}^{S}, d_{ik}^{R1}, d_{ik}^{R2}\}, \;\; d_{ik}^{kid} = \{d_{ik}^{S,kid}, d_{ik}^{R1,kid}, d_{ik}^{R2,kid}\}$$

d_{ik}^{S} equals one if k, the location a household head i is found to be residing in, is in his or her birth state. Similarly, d_{ik}^{R1} and d_{ik}^{R2} are set to be one if the household head was living in the birth census region and macro region, respectively.[4] The terms labeled "kid" indicate interaction terms that describe the differential cost of migrating for households with children.

It is important to emphasize that our conception of migration frictions is holistic; $\hat{\delta}$ may capture financial outlays associated with moving but it may also capture non-price elements such as the psychic pain a household experiences in moving or cultural differences between origin and destination. It may also capture locational preferences, such as home bias, whereby household tastes are shaped by the characteristics of a location other than those captured by local prices and measurable amenity levels.

$\tilde{\theta}$ is the mean utility of a location after removing the influences of climate amenities and housing cost.

$$\ln \tilde{\theta}_k = \ln \hat{\theta}_k + \hat{\beta} \ln \hat{p}_k - \hat{\gamma} \ln c_k$$

where $\hat{\theta}_k$ is the mean utility of location k estimated in the econometric model.

[4]Census region and macro region are defined by the U.S. Census Bureau. In the U.S., there are nine census regions (i.e., (1) New England; (2) Mid-Atlantic; (3) East North Central; (4) West North Central; (5) South Atlantic; (6) East South Central; (7) West South Central; (8) Mountain; and (9) Pacific) and four macro regions (i.e., (1) Northwest; (2) Midwest; (3) South; and (4) West).

Because it was the most consistently identified climate amenity in the econometric literature, we include only the influence of days over a high temperature threshold in the equilibrium model. In our base case scenario, we set this threshold equal to $28°C$. The $\hat{\gamma} \ln c_k$ term captures the mean impact of climate on household well-being. $\hat{H}_{ik}$ is a preference heterogeneity term which captures the idea that different demographic groups may differ in their climate preferences and is defined as

$$\hat{H}_{ik} = \sum_{d \in \mathcal{I}_i} \hat{\kappa}_d c_k$$

where d indexes the demographic dimensions of heterogeneity, $\mathcal{I}_i$ is the set of demographic categories to which household i belongs. We capture heterogeneity along the following dimensions: climate zone of birth and college education. Following Fan et al. (2016), we use USDA Plant Hardiness Zones for our climate zones.

We assume that ϵ_{ik}, the idiosyncractic taste shifters, are distributed iid Type-I extreme value. Therefore, the probability that a household from i migrates to k takes the multinomial logit form:

$$\pi_{ik} = P(u_{ik} > u_{ij},\ j \neq k) = \frac{\exp(u_{ik})}{\sum_j \exp(u_{ij})} \tag{2}$$

The law of large numbers implies that π_{ik} also represents the share of households of type i who are expected to migrate to k. Thus, the total flow of households from l to k, M_{lk}, can be written as

$$M_{lk} = \sum_{i \in \mathcal{B}_l} \pi_{ik} N_{0i} \tag{3}$$

where $\mathcal{B}_l$ represents the set of households originating at location l and N_{0i} is the benchmark population of households of type i represented in the data. The equilibrium population of households at k, therefore, is $N^k = \sum_l M_{lk}$.

We assume that each household head offers one unit of labor inelastically to the local labor market and other household members do not participate in the labor force. Therefore, total labor supply in location k is also given by N^k. Using equation (3), we can write the labor market clearance condition for location k as

$$\sum_l M_{lk} \geq N_0^k w_k^{\eta_k} \ \perp \ w_k \geq 0 \tag{4}$$

where η_k is the own-price labor demand elasticity and N_0^k is the benchmark population at location k represented in the data used to calibrate the initial equilibrium in the model. The "$\perp$" symbol indicates a complementary slackness relationship between the model equation and the associated model variable (w_k here) and its non-negativity constraint. The left hand side of the equation represents labor supply and the right hand side labor demand.

The common wage level, w_k, is normalized to unity in the benchmark equilibrium. Thus, labor demand is equal to N_0^k and $w_{ik} = \hat{w}_{ik}$ in the benchmark equilibrium. Similarly, we normalize the price of housing services in the equilibrium model such that $p_k = \hat{p}_k$. As a

result, π_{ik} is equal to the predicted share of individuals choosing location k from the solution to the logit estimation problem. Therefore, the equilibrium model reproduces the benchmark location choices.

A single household's demand function for housing, h_{ik}, follows from applying Roy's identity to (1).

$$h_{ik} \equiv -\frac{\partial v_{ik}/\partial p_k}{\partial v_{ik}/\partial w_{ik}} = \frac{\hat{\beta} w_{ik}}{\hat{\alpha} p_k}$$

The market clearance condition for the housing market at location k, therefore, is

$$h_{0k} N_0^k \left(\frac{p_k}{\hat{p}_k}\right)^{\nu_k} \geq \sum_{i \in \mathcal{B}_l} h_{ik} \pi_{ik} N_{0i} \;\; \perp \;\; p_k \geq 0 \tag{5}$$

where h_{0k} is the benchmark per capita demand for housing, and ν_k the own-price elasticity of housing supply at location k. The left-hand side of the equation represents housing supply and the right-hand side housing demand.

The complete model consists of equations (4) and (5). It is a system of $2K$ nonlinear equations and endogenous variables, where K represents the number of locations in the model. In the current application, $K = 269$. We use the same random sample of 100,000 households from the American Community Survey upon which household preferences are estimated in Carbone et al. (2021) to populate the i index in the model.

2.2 Solution concept

The model is classified as a mixed complementarity problem (MCP) (Ferris and Pang, 1997). Simulataneous solution methods, such as the PATH algorithm, are available and readily implemented in numerical optimization software packages such as AMPL or GAMS (Dirkse and Ferris, 1995). However, we find that there is significant computational overhead associated with the use of simultaneous methods for this particular model. The reason for this is the summation over the large number of individual households involved in the calculation of M_{lk} from equation (3).

In response to this challenge, we have developed a iterative approach to solution. It involves solving a sub-problem as an MCP using PATH to determine the equilibrium prices in the model for a candidate set of exogenous bilateral migration flows. The resulting prices are then used to update the migration flows using more efficient methods to executing the summation in (3) in R. Iteration continues until no household wishes to change locations at the price levels obtained in the last iteration of the algorithm.

Bayer and Timmins (2005) show that the existence of an equilibrium in this class of model is guaranteed by Brouwer's fixed-point theorem. They also show that if the nature of the social interaction between households results in a congestion effect, the equilibrium is unique. In our context, a congestion effect arises if in-migration to a location causes it to become less attractive. This follows from out assumption of upward-sloping housing supply and downward-sloping labor demand at each location.

3 Calibration

All preference and migration-friction parameters are populated using point estimates from the econometric analysis described in Carbone et al. (2021). However, we must also choose values for the housing-supply (ν_k) and labor-demand (η_k) elasticity parameters in the model. We use the econometric estimates of metropolitan area housing supply elasticities from Saiz (2010). These estimates are meant to represent long-run supply elasticities, estimated using a long-differences methodology using US decennial census data from 1970-2000. Estimates range from 0.60 to over 5. Lower elasticities values primarily fall in coastal cities with large fractions of undevelopable land and tight regulatory restrictions on new development.

Because our application (end-of-century migration projections) involves a very long time horizon, one might argue that these elasticities underestimate housing supply repsonses, because long-run responses to high housing prices will eventually lead to further increases in supply. In the limit, supply could be perfectly elastic. Nevertheless, we feel that the Saiz elasticities are appropriate for the central case simulations that we explore for a couple of reasons. First, the low estimated elasticities are driven by physical and regulatory constraints on development which we view as likely to remain in place even over very long time horizons. Second, many of these cities are key senders or receivers of climate migrants in our simulations (e.g. Boston (elasticity equal to 0.86), Miami (0.6), New York (0.76), and Seattle (0.88)). As a result, it is important to capture these contraints on the movement of people.

We set the labor demand elasticities equal to -2 for all MSAs. We are not aware of MSA-specific estimates of this parameter. The majority of the studies estimating labor demand elasticities finds values between 0 and -1, with long-run estimates tending toward the lower end of this range (Lichter et al., 2015). The same criticism of the effect of long time horizons on elasticity values applies here. Our choice of a value lower than -1 aknowledges this.

Finally, we also conduct a sensitivity analysis in which we make all housing supply and labor demand elasticities in the model perfectly elastic, thus supressing any price changes induced by migration.

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