Escape the Heat: The Dynamics of Migration as Adaptation to Climate Change

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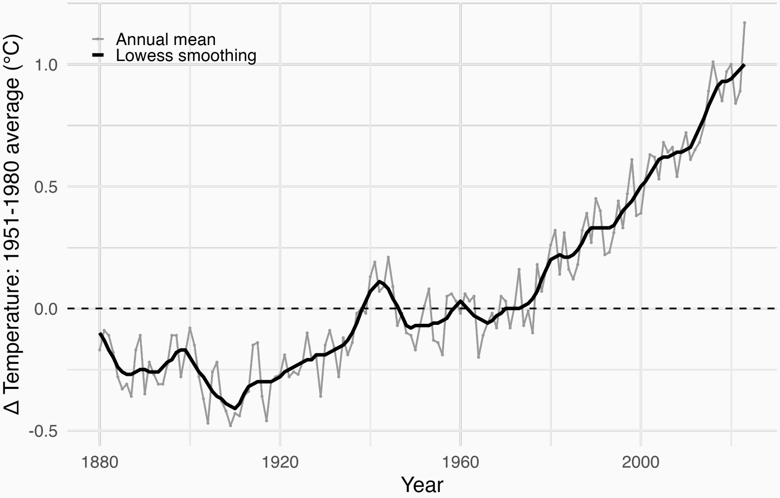
It's getting hot in here...



Source: climate.nasa.gov

So take off...and migrate

History suggests that human migration is a ubiquitous response to environmental change

- 100k years ago out of Africa due to glacial changes (Timmermann & Friedrich, 2017)
- 400 years ago through Europe due to the Little Ice Age (Waldinger, 2022)
- Almost 100 years ago in the United States due to the Dust Bowl (Hornbeck, 2012)

The Intergovernmental Panel on Climate Change (IPCC) has documented that an average of 21.5 million people have been displaced due to weather-related events *annually* since 2008

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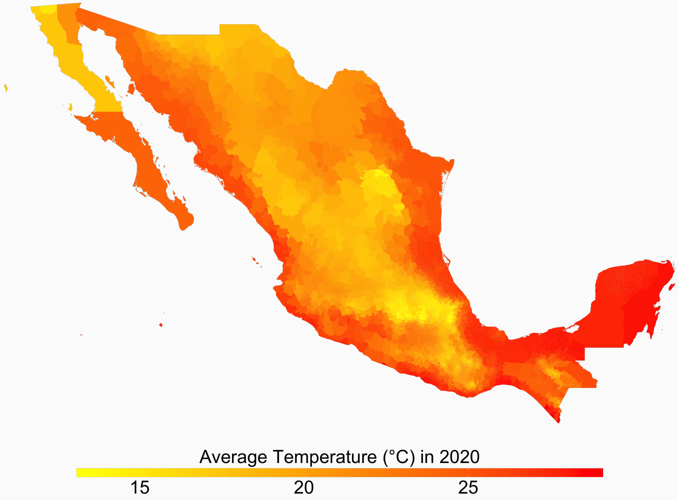
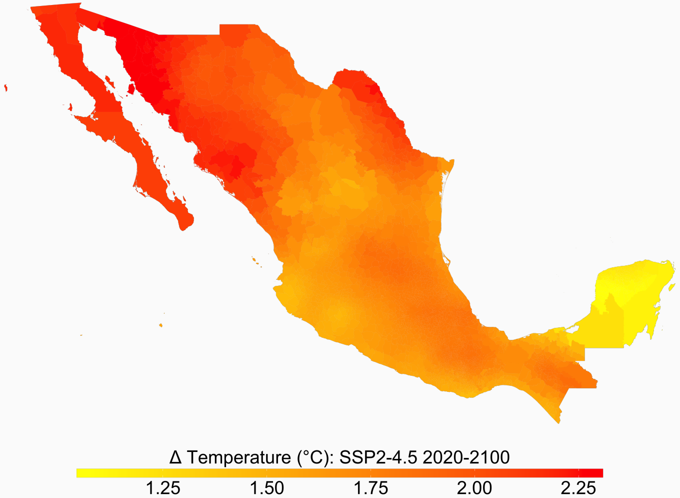
Mexico is a large country with wide variation in local climates



The rate of warming varies strongly throughout Mexico



This paper

Questions:

1. How effectively will migration limit the damages of *future* changes to the climate?
    - How large are the costs associated with migration as adaptation to climate change?
2. How sensitive are the reduced climate damages from migration to relaxing the assumption that everyone fully understands the climate system?
    - Naivety $\Rightarrow$ *lower* rates of climate-induced migration
3. How can policy be designed to help close the resulting "adaptation gap?"

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Empirical approach

I combine a dynamic lifecycle model of domestic migration with a non-stationary and spatially heterogeneous model of the climate

- Estimation uses a rich panel of life histories from the Mexican Migration Project
- I estimate masses of the fully-rational and the naive surrounding the climate system

Counterfactual simulations use the estimated model and full-count census data to:

- Calculate welfare under different climate scenarios, with & without the ability to migrate
- Compare welfare across different policy options

The structure allows for rich counterfactuals

I combine the estimated model with full-count Census data to simulate individual decisions, across the remainder of their lifetime, for the entire male population of Mexico

I identify the value of migration in reducing damages from climate change:

- Comparisons of decisions and welfare under business-as-usual warming (climate change with current policies, BAU) to a limited warming scenario (same as 1950-1979)
- With and without the ability to move
- For both the fully-informed and the climate-naive
- While explicitly accounting for the costs associated with migration

I compare potential policy options by studying moving subsidies that:

- Must be taken in a given period (static)
- Can be taken once at the time of an individual's choosing (dynamic)

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Dynamics are needed to study migration and climate change

- Migration is a decision with dynamic consequences
  - Past work has highlighted large costs associated with migration
- Weather shocks $\neq$ Climate change
  - Panel models relating weather to migration identify the effect of an unexpected shock
  - Dynamic forms of adaptation are based on longer run expectations
- Allowing for forward-looking expectations of future climate is important
  - Assuming that everyone does not understand the climate system would lead to underestimates of migration rates and overestimates of expected climate damages

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Accounting for adaptation is important when calculating climate damages

Accounting for the costs of adaptation is important

- A move to an arbitrary location at an arbitrary time generates welfare costs of $100k
- Being forced to move in response to a disaster could be very costly!

Domestic migration is an important tool for limiting climate damages

- New workers today: $\mathbb{E}$[lifetime climate damages] are 28% lower because of migration
  - 17–19-year-olds in 2020
- Children born today: $\mathbb{E}$[lifetime climate damages] are 33% lower because of migration
  - 0–2-year-olds in 2020

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Correct information is valuable when dynamically adapting to climate change

The climate-naive stand to face 2% more damages ($\sim \$1,100$) from climate change

- Naivety $\Rightarrow$ a reduced migration propensity rather than mistakes during a move (3x)
- This reduced propensity is 2.5x more costly than mistakes made during a move

Migration subsidies can serve as a nudge to the climate naive

- Dynamically-available subsidies reduce the gap b/w the belief types by 19%
- Statically-available subsidies reduce the gap b/w the belief types by 8%

Static policies induce dynamically suboptimal moves

- The dynamic value added is present in many common policies: provisions of the IRA and first-time homeowners tax credits are examples

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Literature

- What are the damages of climate change?
  - Reduced form: Schlenker & Roberts (2009), Burke et al. (2015), Carleton et al. (2022)
  - Spatial: Rudik et al. (2022), Bilal & Rossi-Hansburg (2023), Cruz & Rossi-Hansburg (2023)
- What are the origins of the observed "adaptation gap?"
  - Carleton & Hsiang (2016), Zappalà (2024)
- What are the welfare effects of migration?
  - Reduced form: Deryugina et al. (2018), Nakamura et al. (2022), Sarvimäki et al. (2022)
  - Structural: Kennan & Walker (2011), Oswald (2019), Ransom (2022)
- I (will) provide code and assistance to implement my algorithm

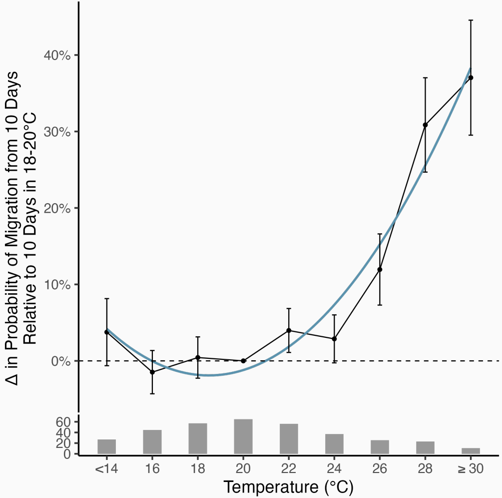
Data & Empirical Motivation

I use rich microdata

Data Source	Purpose	Years
Mexican Migration Project (MMP)	Estimation (11,194 Life-histories)	1950–2019
ENIGH, ENE surveys	Estimation (Income)	1984–2019
Linveh et al. (2015)	Estimation (Weather)	1930–1979
Daymet	Estimation (Weather)	1980–2019
NASA NEX-GDDP CMIP6	Estimation/Simulations (Weather)	2020–2100
Mexican full-count Census	Simulations	2020

MMP & Census Summary Statistics

There is a nonlinear relationship between migration and daily temperature



Conditional on expected wages, age, person, and state-year fixed effects

The structural model builds on important patterns in the data

- Shocks to mean temperature and extreme daily temperatures, across geography and personal experience, correlate with migration decisions Table
  - Extreme temperature shocks correlate with migration decisions when living both in and out of one's birth location Table
  - This relationship persists even when comparing the average number of degree days an individual faces in a given location in the years they migrate to the years they do not Table
- Individuals seem to be forward looking over temperature when deciding to migrate Table
- Individuals consider the weather of their destination when choosing whether and where to move Static Logit Table

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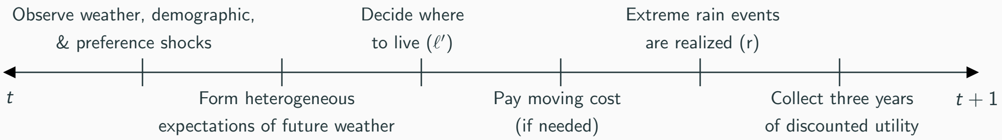
Model

Migration is modeled as a decision with dynamic consequences

- Individuals are modeled to make the decision of where to live in Mexico
  - This decision is made every three years
  - The first decision is made at 17 years old
  - Retirement occurs at 62 years old

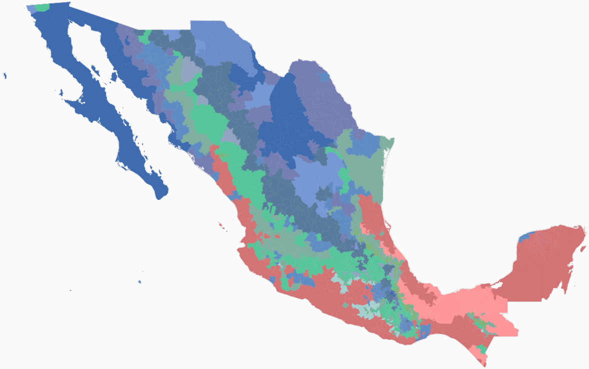
- I allow for four unobserved types of individuals
  - Those who are willing to move and those who are not
  - Fully-informed or naive in their expectations of the climate system



Individuals choose from a set of 27 locations in Mexico

The choice set is composed of:

- 14 Köppen climate zones
  - INEGI modified to account for local idiosyncrasies (García, 2004)
- Urban-Rural Classification
  - INEGI Metro zones



Individuals receive flow utility from living in a location

$$\bar{u}(\ell', \omega, r; \theta) = \theta_1 \mathsf{inc}(\ell', \omega, r) + \theta_2 DD26(\ell', \omega) + \theta_3 DD26(\ell', \omega)^2 + \theta_4 DD14(\ell', \omega) + \theta_5 DD14(\ell', \omega)^2 + \theta_6 \mathbb{1}\{\ell' = \nu^\ell\} + \theta_7 \mathbb{1}\{\ell' \in \mathcal{U}\}$$

- Expected income, *inc*, is a function of individual and location-specific characteristics
- $DD26$: Annual degree days above 26°C $\left(\sum_{d=1}^{365} \mathbb{1}\{\overline{\text{temp}}_d \geq 26\}(\overline{\text{temp}}_d - 26)\right)$
- $DD14$: Annual degree days below 14°C $\left(\sum_{d=1}^{365} \mathbb{1}\{\overline{\text{temp}}_d \leq 14\}(14 - \overline{\text{temp}}_d)\right)$
- $\mathbb{1}\{\ell' = \nu^\ell\}$: Is ℓ' their location of birth?
- $\mathbb{1}\{\ell' \in \mathcal{U}\}$: Is ℓ' an urban location?

Wages are a flexible function of individual and environmental variables

$$
\begin{aligned}
\text{inc}(\ell', \omega, r) = & \sum_a \sum_e \beta_{a,e} + \beta_{ag} ag(\omega) \\
& + \sum_{c=1}^{3} \left[\beta_c^{GDD,C} GDD(\omega) + \beta_c^{GDD2,C} GDD(\omega)^2 + \beta_c^{D,C} D(r) + \beta_c^{I,C} I(r) \right] \\
& + \sum_{ag=0}^{1} \left[\beta_{ag}^{GDD,Ag} GDD(\omega) + \beta_{ag}^{GDD2,Ag} GDD(\omega)^2 + \beta_{ag}^{D,Ag} D(r) + \beta_{ag}^{I,Ag} I(r) \right] \\
& + \xi_{\ell'} + \eta_y(\omega)
\end{aligned}
$$

- GDD: Maíz growing degree days $\left(\sum_{d=1}^{365} \mathbb{1}\{8 \leq \overline{\text{temp}}_d \leq 32\}(\overline{\text{temp}}_d - 8) + \mathbb{1}\{\overline{\text{temp}}_d > 32\} 24 \right)$
- D: Drought realization
- I: Flood realization

Wage Equation Estimates

If individuals move, they have to pay an upfront cost

$$\bar{c}(\ell, \ell', \omega; \theta, \tau) = \gamma_1(\tau) + \gamma_2 d(\ell, \ell') + \gamma_3 \mathbb{1}\{k_\omega \geq 1\} + \gamma_4 \text{age}_\omega$$

- $\gamma_1(\tau)$: $\gamma_1(\text{mover}) \in \mathbb{R}, \gamma_1(\text{stayer}) \approx \infty$
- $d(\ell, \ell')$: Distance between the largest city in ℓ and ℓ'
- k_ω: Individual's number of children
- age_ω: How old is the individual?

The problem can be written as a finite-horizon Bellman

At time $t < T$, individual i, of unobserved type τ, living in ℓ with state ω chooses between locations $k \in \{1, \cdots, K\}$, after forming expectations for extreme rain (R), faces a Bellman:

$$V_t(\ell, \omega; \theta, \tau) = \max_k \{ \underbrace{\mathbb{E}_R[u(\ell, k, \omega, r; \theta, \tau)] + \varepsilon_{tk}}_{\substack{\text{Expected flow utility} \\ \text{from moving to } k}} + \delta^3 \underbrace{\mathbb{E}_{\Omega, \varepsilon|\tau}[V_{t+1}(k, \omega'; \theta, \tau)|\omega]}_{\substack{\text{Expected continuation} \\ \text{value from choice } k}} \},$$

At time T, this individual's value function is instead:

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$\varepsilon_{i,t} \sim$ Type-1 Extreme Value

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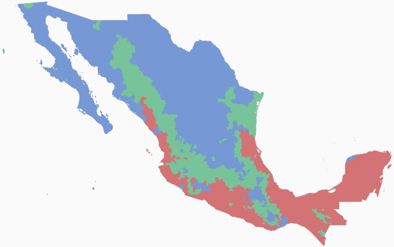
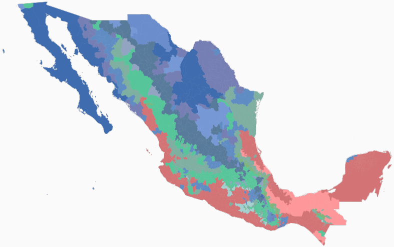
Köppen climates are nested in space



(a) Level-One Köppen Climate Zones



(b) Level-Two Köppen Climate Zones

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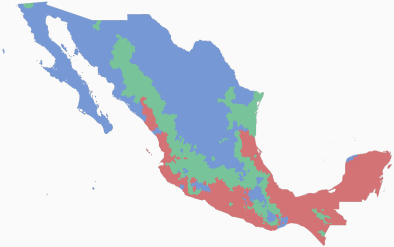
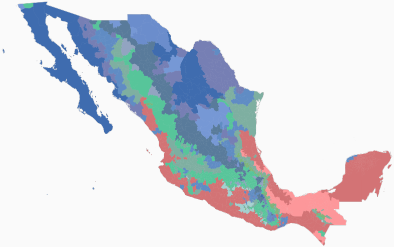


(c) Level-One Köppen Climate Zones



(d) Level-Two Köppen Climate Zones

The climate is a high-dimensional system

The climate affects economic outcomes nonlinearly, but the curse of dimensionality is real...

I modify the techniques used by moment-based approximate equilibrium concepts to reduce the dimensionality problem arising from strategic interactions to instead combat the same problem arising from the high-dimensional nature of the climate system.

- Ifrach and Weintraub (2016); Gowrisankaran, Langer, and Zhang (2024)

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I use a set of first-stage estimates to reduce the number of weather variables I need to track, per-location, from 5 to 2

This allows me to use information from 135 distinct weather variables in the dynamic model

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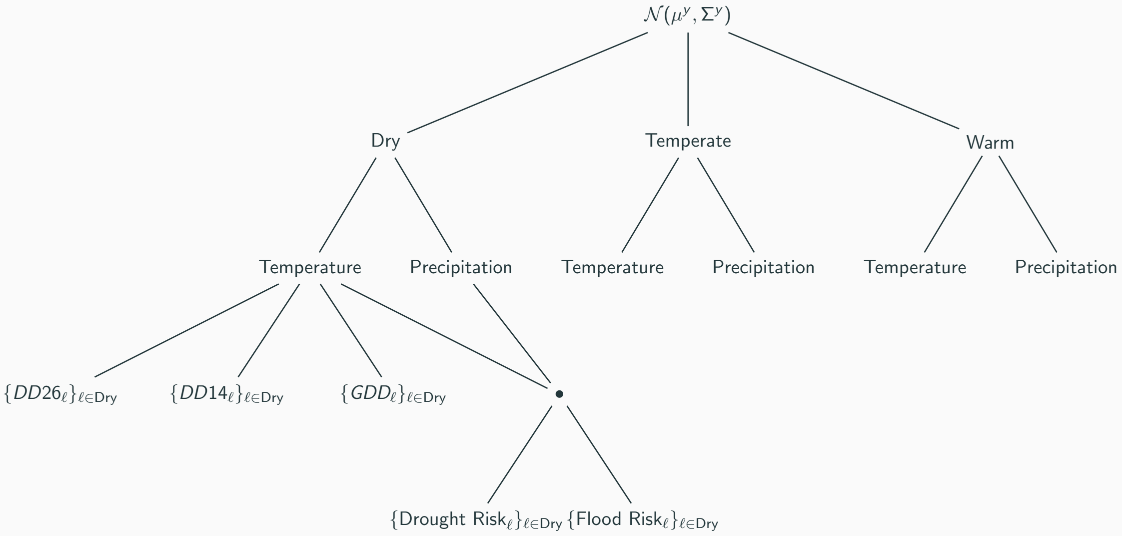
A summary of the climate model



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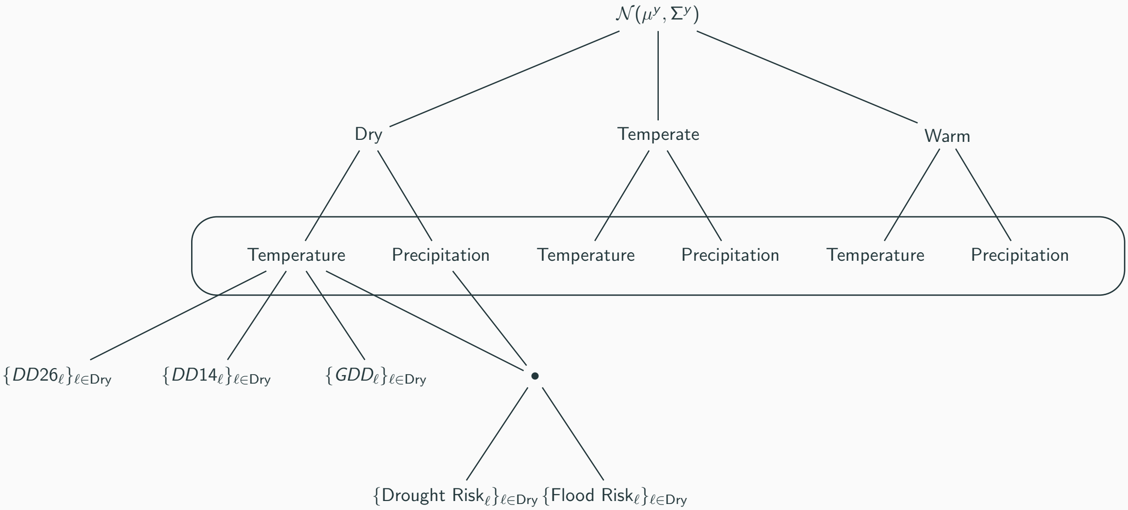

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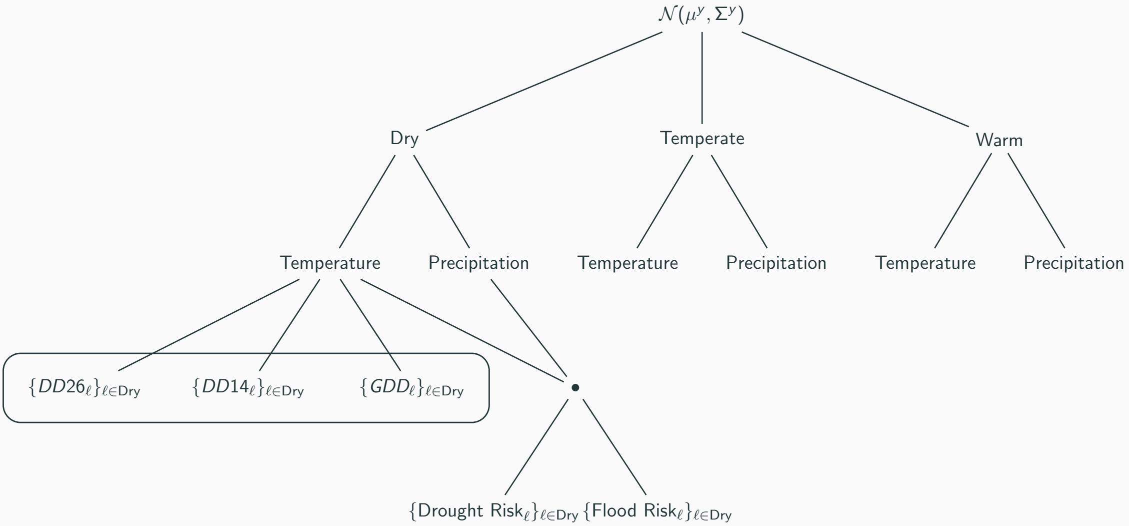

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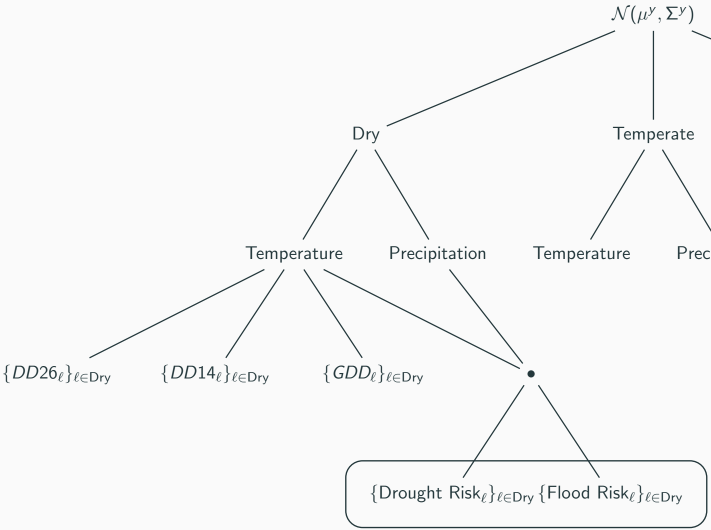


The climate varies spatially and temporally

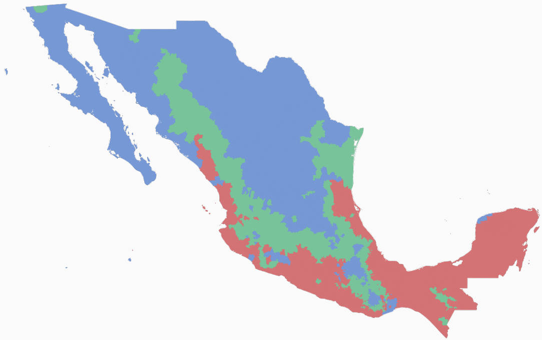
The climate evolves according to:

$$\begin{pmatrix}\text{temp}\\ \text{prec}\end{pmatrix} \sim \mathcal{N}(\mu^y, \Sigma^y),$$

Where:

$$\mu_w^y = \alpha_w^y + \alpha_{w1}^y \mu_w^{y-1} + \alpha_{w2}^y y,$$

And fully-informed individuals, in year y, use the last 30 years of weather to obtain $\hat{\alpha}^y$ & $\hat{\Sigma}^y$



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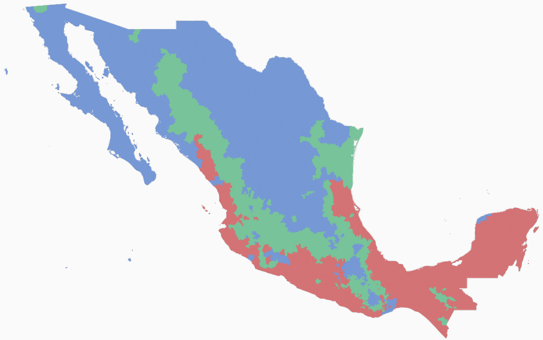

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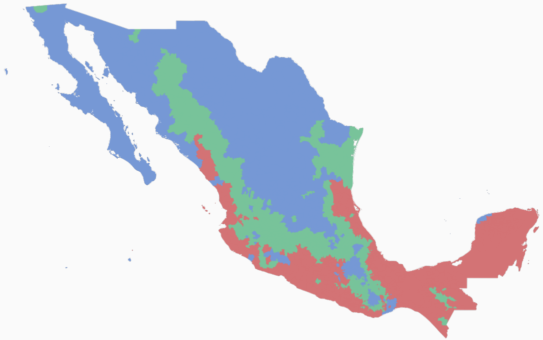


A model of heterogeneous climate expectations in Mexico

Fully-informed individuals use the average daily temperature to calculate the expected number of each measure of degree days in each location:

$$DD_\ell = \mathbb{1}\{\lambda_\ell^D + \lambda_{1\ell}^D \text{temp}_{C(\ell)} > 0\} \times \left[\lambda_\ell^D + \lambda_{1\ell}^D \text{temp}_{C(\ell)}\right], \tag{1}$$

They use realized agricultural-season precipitation (P) to calculate drought and flood risk:

$$\text{prob}(R_\ell) = \Phi\left(\eta_\ell^R + \eta_1^R \text{P}_{C(\ell)} + \eta_2^R \text{temp}_{C(\ell)}\right), \tag{2}$$

Individuals who form naive climate expectations are only assumed to observe the current years' weather and to assume that all future years will be the same

Climate Model Fit

Estimation & Identification

Identification of model primitives

Flow utility parameters: Identification comes from variation in the input of interest and i) where individuals choose to live across their menu of choices and ii) how they long they decide to live there

Moving cost parameters: Identification comes from comparisons of migration rates across variation in the input of interest

Mass of movers: Identification comes from comparisons of the first-time migration rate to the migration rate of individuals on their second and later moves

Mass of believers: Identification comes from information on where individuals choose to live coupled with variation in rates of warming across space and time

I estimate the primitives using a full solution maximum likelihood routine

Initial Step: Estimate distribution of state variable transitions, the wage equation, and the climate mappings

Inner Loop: Solve the Bellman using backward recursion across t to form model-induced choice probabilities

Outer Loop: Maximize log likelihood

The likelihood is a finite mixture

The log-likelihood is given by:

$$\Lambda(\theta, \pi) = \sum_i \log\left(\mathbb{E}_\tau[\mathcal{L}_i(\theta;\tau)]\right)$$
$$= \sum_i \log\left(\sum_\tau \pi_\tau \cdot \mathcal{L}_i(\theta;\tau)\right),$$

Where:

$$\mathcal{L}_i(\theta;\tau) = \prod_{t=1}^{T_i} \mathcal{L}_{it}(\theta;\tau) = \prod_{t=1}^{T_i} \frac{\exp(\overline{V}_t(\ell_{it}, \ell_{it+1}, \omega; \theta, \tau))}{\sum_{j\in\mathcal{C}} \exp(\overline{V}_t(\ell_{it}, j, \omega; \theta, \tau))},$$

And, π_τ is the probability of being of type τ $\left(\sum_{\tau=1}^{4} \pi_\tau = 1\right)$

Alternative-Specific Value Function

Results

Parameter estimates

Description	Parameter	Coefficient	Std. Error
Flow utility			
Income, measured in 2010 hourly pesos	θ_1	0.006	(0.0007)
Degree days above 26°C	θ_2	0.034	(0.005)
Degree days above 26°C squared	θ_3	-0.015	(0.002)
Degree days below 14°C	θ_4	0.020	(0.002)
Degree days below 14°C squared	θ_5	-0.003	(0.0003)
Living in location of birth	θ_6	0.183	(0.002)
Living in an urban location	θ_7	-0.041	(0.003)
Moving costs			
Fixed migration cost, for movers	γ_1	2.599	(0.073)
Distance of move	γ_2	0.140	(0.011)
Cost shifter: parenthood	γ_3	0.072	(0.022)
Cost shifter: age	γ_4	0.172	(0.006)
Unobserved heterogeneity			
Mass of movers	π_m	0.628	(0.013)
Mass of fully-informed expectations	π_b	0.673	(0.206)

Notes: Distance is measured in log kilometers. The likelihood contains 90,578 individual-year observations from 11,194 individuals. Asymptotic standard errors are calculated using the score of the likelihood.

Understanding magnitudes

- Individuals are indifferent between living in their location of birth and living away from this location with about twice the average annual income
- Negative preference for living in an urban location
  - Evidence of a compensating differential for living in urban centers (Rosen, 1986)
- Estimated average moving costs are very large ($\sim$ \$99k)
  - This is the average cost of a forced move in an arbitrary period to an arbitrary location
  - Kennan & Walker (2011) style calculations show that actual costs paid are on average negative ($\sim$ \$-50k) and positive for moves back home (\$29k)
  - Migration is an endogenous choice!

Understanding magnitudes

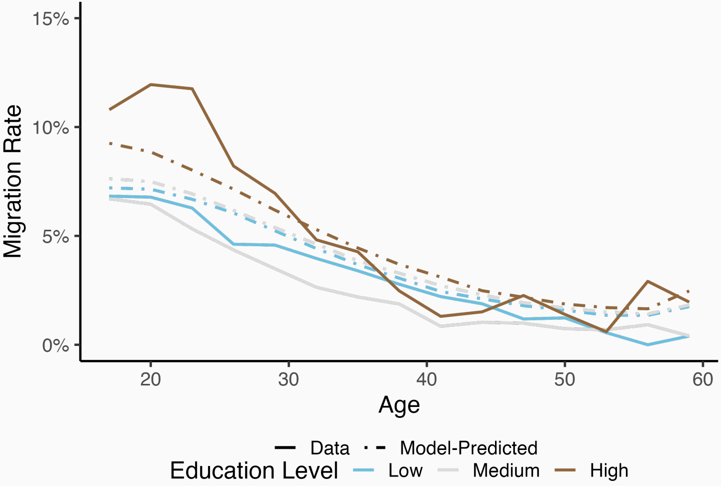
I estimate a bliss-point of 113 degree days above 26°C

- Historically, 16% of the population experienced heat beyond this level
- In 2050, 49% of the population would experience heat beyond this level, w/o migration

I estimate a bliss-point of 333 degree days below 14°C

- Historically, 9% of the population experienced cold beyond this level
- In 2050, 0.02% of the population would experience cold beyond this level, w/o migration

The model fits the data well across levels of education



The model fits the data well across sectors of employment

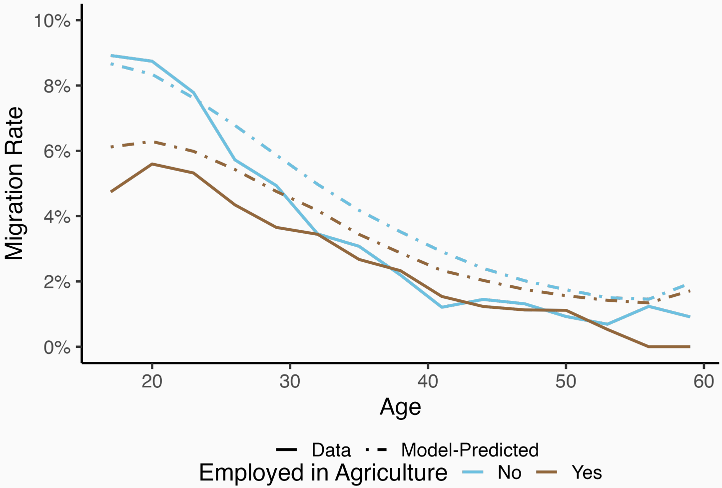


Table of moments

Simulations

I use the model to simulate choices under different environments

- I use the 2020 Mexican Census to obtain:
  - Number of individuals, by age, living in each municipality
  - Percent of individuals, by municipality, employed in agriculture
  - Distribution of education by municipality
- Simulate different climate scenarios with and without the ability to move
  - Use daily data from CMIP6 SSP2 4.5 scenario to simulate business-as-usual climate
  - Use historical data to simulate limited warming as a counterfactual scenario of the climate system centered around 1950-1979 averages
- Simulate the decisions of individuals under the different scenarios
  - Bring new young men into the model based on census counts for children
  - Retire people at 62 years old

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What is the lifetime value of migration?

The lifetime value of the ability to migrate, at year y, can be calculated as the average difference in welfare across counterfactual simulations, with and without the ability to migrate, amongst those who are 17–19-years-old in y. Mathematically,

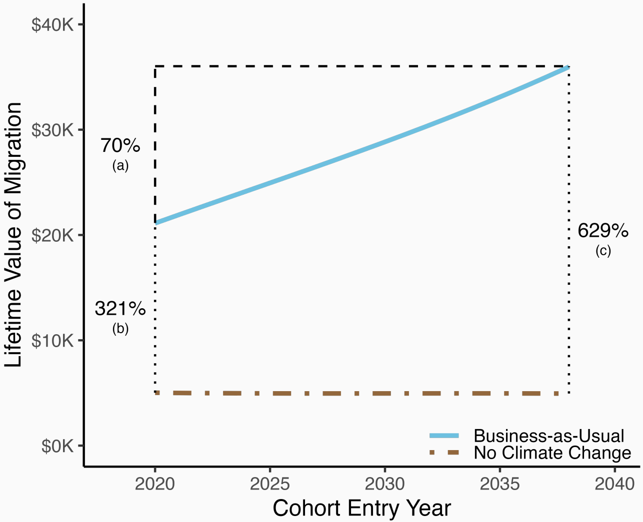
$$\frac{1}{n(y)} \sum_{i(y)} \left\{ \tilde{V}(\ell_i, \omega_i | s) - \tilde{V}(\ell_i, \omega_i | s, \gamma_1 = \infty) \right\}.$$

- $\tilde{V}(\cdot)$: Value function, scaled to 2024 dollars
- γ_1: Fixed moving cost
- i indexes individuals making their first migration decision in year y ($|i| = n_y$)

Translation from utils to dollars | Accounting for congestion effects on wages | Heterogeneity in the value of migration

Migration rates across time and heterogeneous beliefs | Recursive derivation of naive value function

Migration becomes more valuable over time with warming

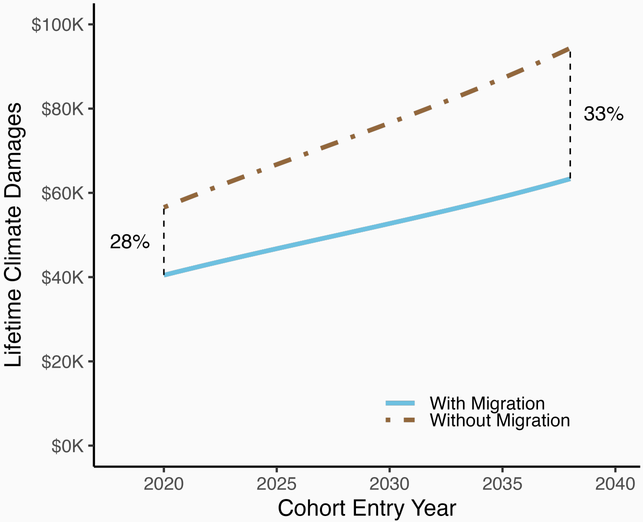


How effectively will migration limit climate damages?

Average expected lifetime climate damages can be calculated as the average difference in welfare across counterfactual simulations with and without climate change. Mathematically,

$$\frac{1}{n(y)} \sum_{i(y)} \left\{ \tilde{V}(\ell_i, \omega_i | \text{no cc}) - \tilde{V}(\ell_i, \omega_i | \text{BAU}) \right\}.$$

Migration reduces expected climate damages



Migration is progressive adaptation to regressive climate damages

	% ↓ in Damages from Migration	
Age in 2020:	17–19-years-old	<2-years-old
Average	28%	33%
Climate Figure		
Dry	27%	27%
Temperate	3%	1%
Warm	35%	40%
Agricultural Worker Figure		
Yes	32%	37%
No	28%	32%
Years of Education Figure		
0–5	32%	36%
6–11	30%	34%
12+	28%	32%

Notes: These are the average results of 100 simulations of the model. Damages are measured in lifetime values. Climate damages are in 2024 dollars, and represent the average difference in lifetime welfare for a 17-year-old in 2020. The percentage decrease in damages from migration is the average difference in climate damages from a world without migration to one with migration.

Incomplete information on the climate system makes migration less valuable

	% ↓ in Climate Damages from Info	
Age in 2020:	17–19-years-old	<2-years-old
Average	2.2%	1.2%
Climate		
Dry	0.4%	0.6%
Temperate	1.3%	2.2%
Warm	3.2%	1.2%
Agricultural Worker		
Yes	2.9%	1.0%
No	2.1%	1.3%
Years of Education		
0–5	2.7%	1.1%
6–11	2.5%	1.2%
12+	2.1%	1.3%

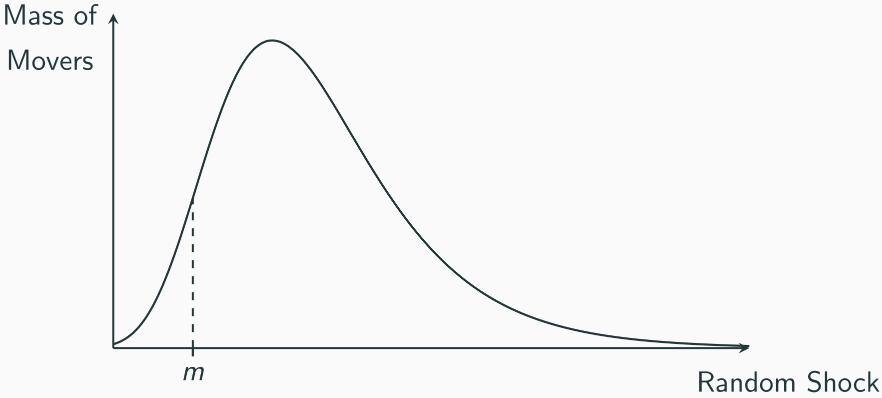
Notes: These are the average results of 100 simulations of the model. Values are for 17-19 year olds, measured in 2024 dollars. The percent decrease in climate damages represents that for the climate-naive individuals from becoming fully-informed.

Common policy tools can reduce the size of this internality

	Value of Climate Information in 2020		
	Dollar Value	% ↓ from \$1,100 Dynamic Subsidy	% ↓ from \$1,100 Static Subsidy
Average	1,099	18.7%	7.8%
Climate			
Dry	544	29.7%	12.8%
Temperate	298	49.0%	21.4%
Warm	4,300	10.4%	4.1%
Agricultural Worker			
Yes	2,019	13.7%	5.3%
No	976	20.2%	8.6%
Years of Education			
0–5	1,700	13.7%	6.0%
6–11	1,313	18.8%	7.0%
12+	987	19.2%	8.5%

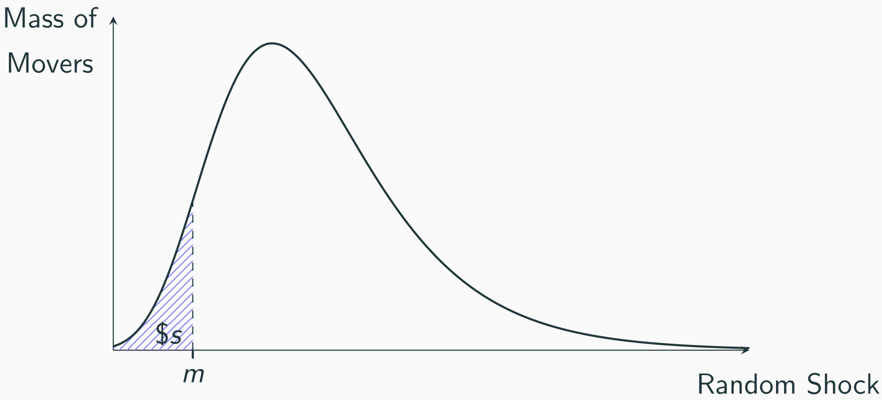
Notes: These are the average results of 100 simulations of the model. The value of climate information refers to the difference in average lifetime welfare between the population of fully-informed and climate-naive individuals, in 2020. The decrease in the value of climate information from a dynamic and static subsidy refers to the decrease of the dollar value of climate information from a one-time $1,100 subsidy to be used at the first time an individual moves and a take-it-or-leave-it offer, both in 2020.

Intuition for the differences between dynamic and static policies



Notes: m is the cutoff for inframarginal movers, s is the size of the subsidy, w is the size of the option value for future moving opportunities with a subsidy of s.

Intuition for the differences between dynamic and static policies



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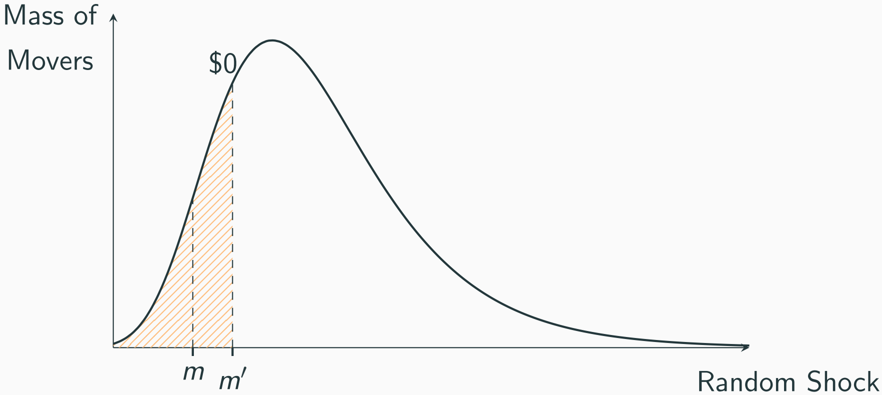

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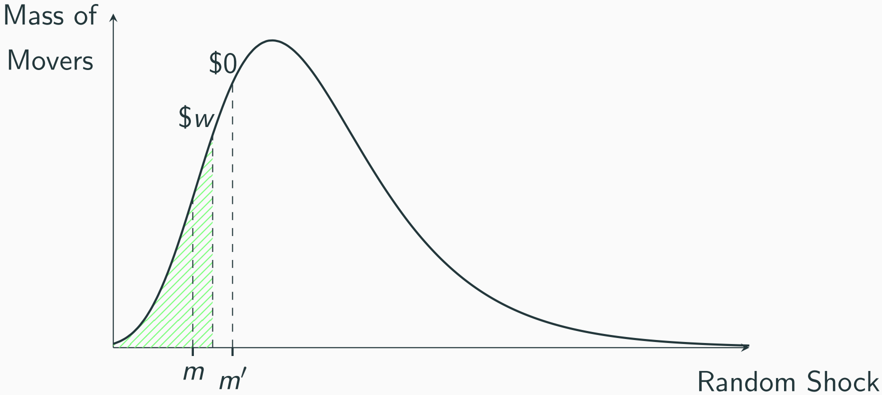

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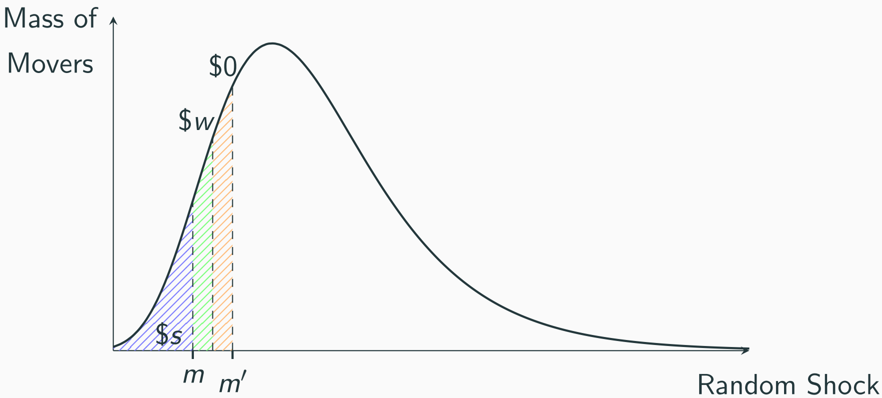

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Conclusion

Summary of findings

- The spatial heterogeneity in climate damages makes migration a highly valuable mechanism of adaptation, even within national borders
    - Accounting for adaptation when estimating climate damages is important ($\downarrow$ 28%)
    - Accounting for the costs of adaptation when estimating climate damages is important
    - Damages could be even lower if the population understood the climate system ($\downarrow$ 2%)
- Policy can play a role in helping individuals adapt to climate change
    - Migration subsidies nudge the climate-naive into behaving more similarly to the fully-informed
    - Dynamic policies are over twice as valuable as static policies
- Future work on the topic could study:
    - The role of endogenous liquidity constraints ($\uparrow$ migration costs and $\uparrow$ climate damages)

Thank You

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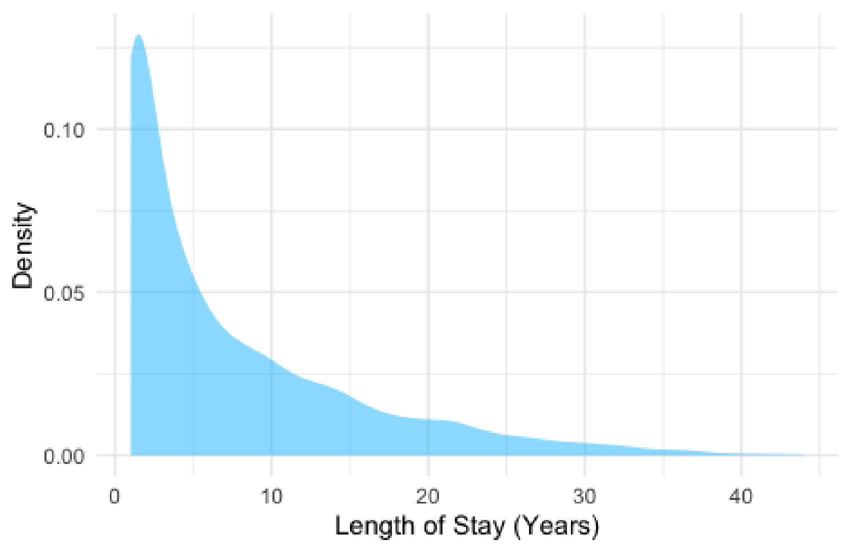
Appendix

Data: MMP

- Annual survey (since 1982) of individuals living in Mexico
- 3-5 locations are chosen each year - Not a nationally representative sample
  - Previous work has found that the MMP sample has, on average, a higher level of education, and a large oversampling of men
- Use de-censored version of life history files to construct a panel of the location of residence for $\sim$ 12k people

Back

Length of Stay



Estimation - Inner Loop

1. **State Space Partitioning:**
   - Divide the individual-specific state space into n chunks.
   - Assign each of the n compute nodes its own chunk.
2. **Utility Calculation:**
   - u is linear in parameters.
   - Compute a high-dimensional tensor product of utility inputs and the vector of structural parameters.

Back

Estimation - Inner Loop

3. **Value Function at T:**
    - For each location in state space, integrate out state transitions in time $T+1$.
    - Solve for $\overline{V}_T$.
4. **Backward Induction:**
    - Use $\{\overline{V}_T(\omega)\}$ and 2. to calculate $\overline{V}_{T-1}$ at each point in state space.
    - Repeat until $t=1$.

Back

	Dependent Variable: $\mathbb{1}\{\text{Migrate}\}$			
	(1)	(2)	(3)	(4)
Average Temperature	0.00143***	0.00142***	0.0045***	0.0106***
	(0.00031)	(0.00033)	(0.0010)	(0.0014)
Cooling Degree Days (26)	0.0129***	0.0130***	0.00589***	0.0149***
	(0.0017)	(0.0017)	(0.00095)	(0.0024)
Heating Degree Days (14)	0.00303***	0.00318***	0.0075***	0.0083***
	(0.00059)	(0.00059)	(0.0011)	(0.0016)
Agricultural Worker	-0.0052***			
	(0.0006)			
Education	0.00084***			
	(0.00010)			
Children	-0.01365***			
	(0.00089)			
Num.Obs.	260472	260472	260472	260472
R2	0.052	0.050	0.168	0.201
FE: Year-State	X	X		X
FE: Person			X	X

Back

	Dependent Variable: $\mathbb{1}\{\text{Migrate}\}$			
	(1)	(2)	(3)	(4)
Cooling Degree Days (26)	0.0113***	0.00479***	0.0180***	0.0043***
	(0.0014)	(0.00085)	(0.0022)	(0.0017)
Heating Degree Days (14)	0.00189***	0.0028***	-0.000027	-0.0012
	(0.00039)	(0.0010)	(0.001404)	(0.0013)
Cooling Degree Days: Away From Birth Loc	0.0071***	0.0168***	0.0123***	
	(0.0021)	(0.0038)	(0.0037)	
Heating Degree Days: Away From Birth Loc	-0.00249***	-0.0024	-0.00029	
	(0.00065)	(0.0021)	(0.00227)	
Num.Obs.	260472	260472	260472	260472
R2	0.064	0.176	0.205	0.341
FE: Year-State	X		X	X
FE: Person		X	X	
FE: Person-Location				X

Back

	Dependent Variable: $\mathbb{1}\{\text{Migrate}\}$		
	(1)	(2)	(3)
Current Temperature	0.0097***	0.0052***	0.0011
	(0.0012)	(0.0012)	(0.0014)
Last Year's Temperature		0.0050***	0.0044***
		(0.0013)	(0.0013)
Next Year's Temperature			0.0052***
			(0.0012)
Num.Obs.	260472	260472	260472
R2	0.200	0.200	0.200
FE: Year-State	X	X	X
FE: Person	X	X	X

Back

Flow Utility		Moving Costs	
Income	0.061	Moving Intercept	2.89
	(0.008)		(0.161)
Cooling Degree Days (26)	0.071	Distance	0.139
	(0.051)		(0.027)
Cooling Degree Days^2	-0.074	Children	0.130
	(0.015)		(0.040)
Heating Degree Days (14)	0.137	Age	0.210
	(0.015)		(0.009)
Heating Degree Days^2	-0.023		
	(0.002)		
Urban Location	-0.345		
	(0.011)		
Birth Location	2.452		
	(0.41)		
Log-Likelihood: -25255.83			

Back

	Hourly Income
Ag worker	0.74
	(3.55)
Growing Degree Days	7.5***
	(2.8)
Growing Degree Days^2	-0.95**
	(0.44)
Drought	-0.38*
	(0.20)
Inundation	-0.036
	(0.310)
Ag worker × GDD	-3.0
	(2.8)
Ag worker × GDD^2	0.58
	(0.52)
Ag worker × Drought	0.38
	(0.25)
Ag worker × Inundation	-0.44*
	(0.24)
Temperate × GDD	-5.1
	(3.8)
Warm × GDD	-6.4
	(14.6)
Temperate × GDD^2	0.75
	(0.75)
Warm × GDD^2	0.87
	(2.17)
Temperate × Drought	0.77***
	(0.22)
Warm × Drought	0.66**
	(0.33)
Temperate × Inundation	-0.56*
	(0.32)
Warm × Inundation	-0.13
	(0.36)
Num.Obs.	3626618
R2	0.231
FE: Location, Year	X
Dep. Var. Mean	27.06

Back

Alternative-specific value function

$$
\begin{aligned}
\overline{V}_t(\ell, k, \omega; \theta, \tau) &= \mathbb{E}_R[u(\ell, k, \omega, r; \theta, \tau)] + \delta^3 \mathbb{E}_{\Omega, \varepsilon|\tau}[V_{t+1}(k, \omega'; \theta, \tau)|\omega] \\
&= \mathbb{E}_R[u(\ell, k, \omega, r; \theta, \tau)] + \delta^3 \int \max_j \{\overline{V}_{t+1}(k, j, \omega'; \theta, \tau) + \varepsilon_j\} dF_{\omega', \varepsilon|\omega, \tau} \\
&= \mathbb{E}_R[u(\ell, k, \omega, r; \theta, \tau)] + \delta^3 \int \log \left(\sum_{j \in \mathcal{C}} \exp(\overline{V}_{t+1}(k, j, \omega'; \theta, \tau)) \right) dF_{\omega'|\omega, \tau}
\end{aligned}
$$

Back

Mapping Utils to Dollars

Define some quantity u measured in utils.

1. $u_1 = \frac{u}{\theta_1}$ is measured in 2010 pesos per hour per year
   - θ_1 is measured in utils per 2010 peso per hour per year
2. $u_2 = u_1 \times \overline{\text{hours of work per year}}$ is measured in 2010 pesos
   - OECD gives that this value is 2,224 hours, for the average Mexican in 2010
3. $u_3 = \frac{u_2}{e_{2010}}$ is measured in 2010 dollars
   - e_{2010} is the exchange rate on January 1, 2010: 12.8096
4. $u_4 = u_3 \times \text{inflation rate}_{2010->2024}$ is measured in 2024 dollars
   - I use the CPI for all urban consumers: 1.45

Back

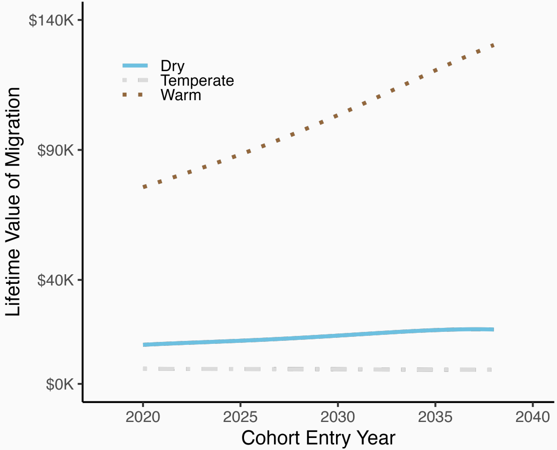
Equilibrium over population shares through wages

Migration is modelled in a partial equilibrium setting. I employ the following to understand how strong general equilibrium effects may be:

1. Simulate migration decisions with the estimated model and wage equation through 2038
2. Calculate the difference in population levels from 2023 to 2038 throughout Mexico
3. Assume that wages respond to this change in population
4. Resimulate behavior under the new wage regime

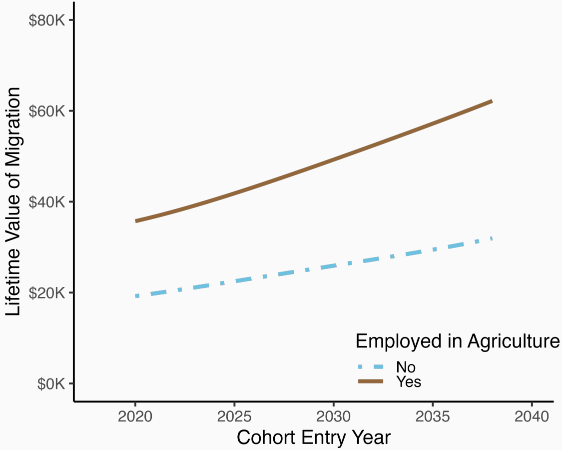
I iterate on this process until population counts converge across iterations. It takes 17 iterations to do so. Back

Heterogeneity in Values across Space



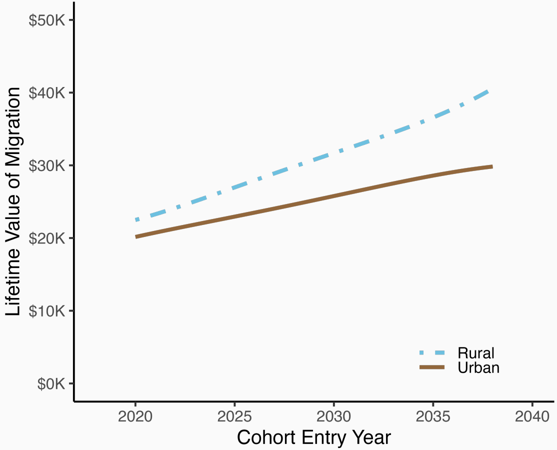
Back

Heterogeneity in Values across Sector of Employment



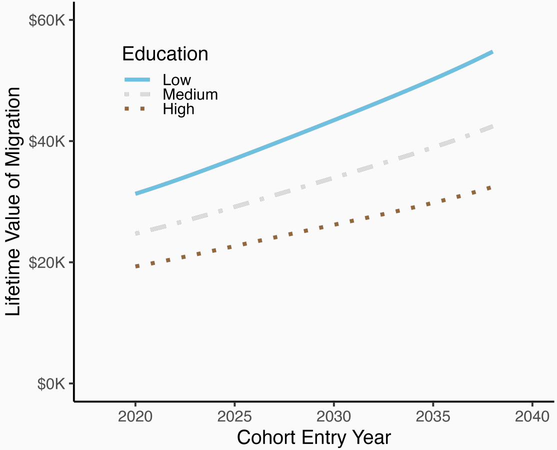
Back

Heterogeneity in Values across Urban-Rural



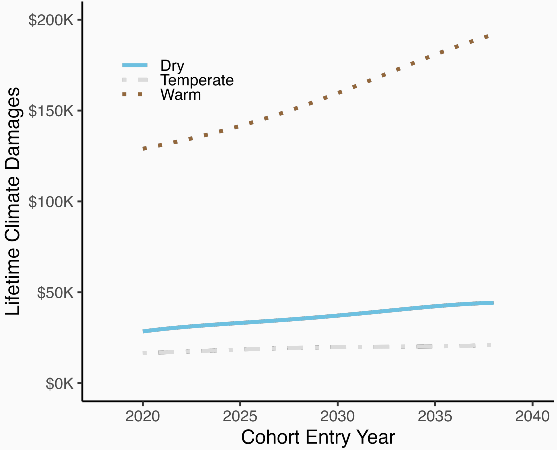
Back

Heterogeneity in Values across Levels of Education



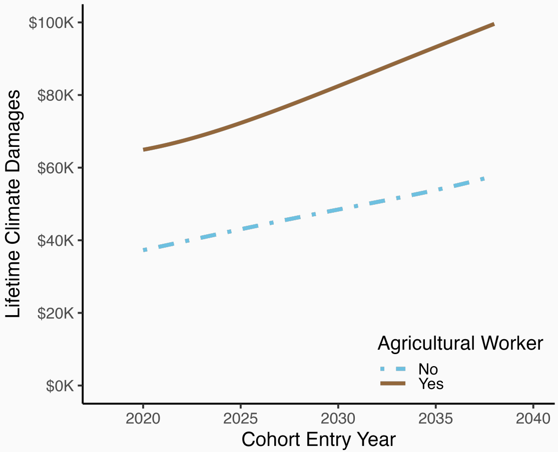
Back

Heterogeneity in Climate Damages across Space



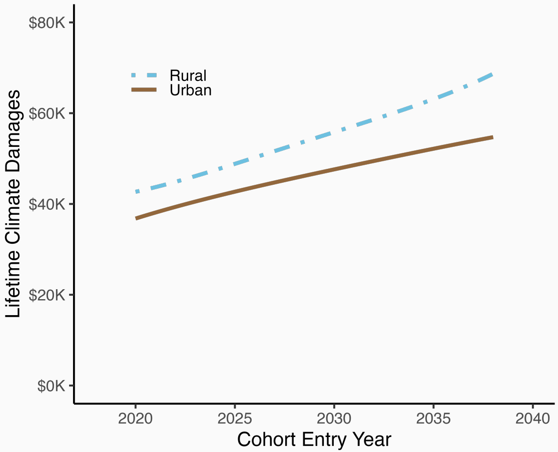
Back

Heterogeneity in Climate Damages across Sector of Employment



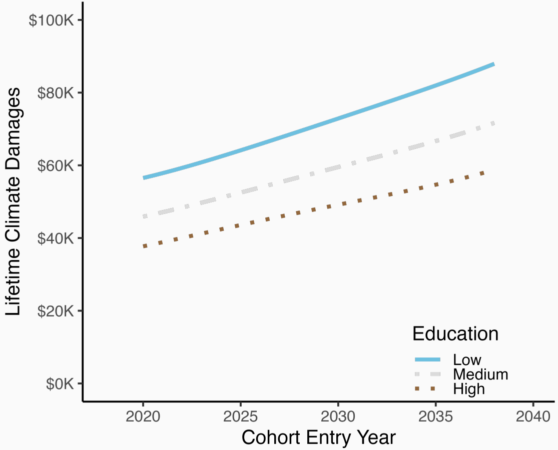
Back

Heterogeneity in Climate Damages across Urban-Rural



Back

Heterogeneity in Climate Damages across Levels of Education



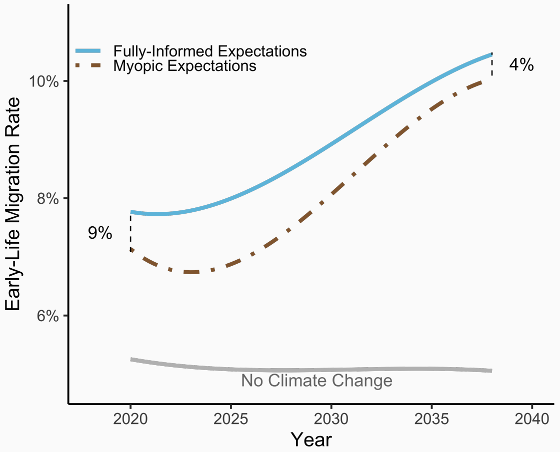
Back

Summary statistics

	Non-Migrants		Migrants		2020 Census	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Education	7.66	4.25	8.76	4.96	9.03	3.63
Agricultural Worker	0.32	0.47	0.22	0.41	0.31	0.46
Children	0.95	0.21	0.93	0.26	-	-
Age at Birth of First Child	23.83	4.90	24.37	4.90	-	-
Number of Moves	-	-	2.16	1.84	-	-
Age at First Move	-	-	22.69	6.30	-	-
Move to Urban Location	-	-	0.32	0.46	-	-
$\mathbb{1}\{\text{Stay} > 1 \text{ Year}\}$	-	-	0.74	0.44	-	-
Born in Dry Climate	0.28	-	0.26	-	0.24	-
Born in Temperate Climate	0.41	-	0.48	-	0.59	-
Born in Warm Climate	0.32	-	0.26	-	0.17	-
Born in Urban Location	0.25	-	0.24	-	0.41	-
Number of Individuals	8406		2788			

Back

Migration rates are increasing in warming



Back

Climate Model Fit

- The location-specific mapping from primary climates to growing degree days has an adjusted-R^2 of 0.985
  - If we remove all location-specific intercepts, the adjusted R^2 is 0.640 (this only looks at within-location variation in GDD explainable from variation in the primary climate's mean temperature)
- The location-specific mapping from primary climate temperature to degree days above 26°C has a McFadden pseudo-R^2 of 0.240
- The location-specific mapping from primary climate temperature to degree days below 14°C has a McFadden pseudo-R^2 of 0.240
- The model for the likelihood of drought has a McFadden pseudo-R^2 of 0.041
- The model for the likelihood of flood has a McFadden pseudo-R^2 of 0.101

Back

The model fits the data well

	Migration Rate	
	Model	Data
Overall	5.4%	4.7%
Children		
Yes	5.2%	3.4%
No	5.4%	7.2%
Agricultural Worker		
Yes	4.5%	3.5%
No	5.8%	5.3%
Years of Education		
0-5	5.0%	4.2%
6-11	5.3%	3.8%
12+	6.1%	7.5%

Notes: For each category, I calculate the average migration rate predicted by 100 model simulations of the life trajectories of the individual-year observations used in estimation.

Back

Migration as adaptation to climate change is progressive

	% ↑ in the value of the ability to move, from BAU warming	
	New workers today	Children born today
Climate Figure		
Dry	128%	314%
Temperate	12%	11%
Warm	1020%	2092%
Agricultural Worker Figure		
Yes	471%	987%
No	201%	469%
Years of Education Figure		
0–5	379%	832%
6–11	280%	641%
12+	205%	480%

Notes: Shown are the percentage change in the average 2020 lifetime value of migration, of business-as-usual warming compared to limited warming, across different demographic and spatial groups. BAU represents business-as-usual: the CMIP6 SSP2 4.5 scenario.

Back

Derivation of naive value function

$$
\begin{aligned}
\overline{V}_t^{nt}(\ell,\ell',\omega) &= u(\ell,\ell',\omega) + \delta^3 \mathbb{E}\left[V_{t+1}^{nt}(\ell',\omega')|\omega\right] \\
&= u(\ell,\ell',\omega) + \delta^3 \iint \left\{\overline{V}_{t+1}^{nt}(\ell',j,\omega') + \mathbb{E}\left[\varepsilon_j | d^n = j\right]\right\} dG^n(j|\ell',\omega')dF(\omega'|\omega) \\
&= u(\ell,\ell',\omega) + \delta^3 \iint \Bigg\{\overline{V}_{t+1}^{nt}(\ell',j,\omega') + \gamma \\
&\qquad + \log\left(\sum_{k=1}^{27} \exp\left(\overline{V}_{t+1}^{n}(\ell',k,\omega') - \overline{V}_{t+1}^{n}(\ell',j,\omega')\right)\right) \Bigg\} dG^n(j|\ell',\omega')dF(\omega'|\omega)
\end{aligned}
$$

Back