Human Capital Production in a Spatial Economy:

A Quantitative Assessment of the Decentralized U.S. Education System

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Motivation

- A nation's human capital = sum(human capital of sub-regions)
  $\Rightarrow$ shaped by education and labor mobility
- U.S. has a unique decentralized education system (Goldin and Katz 2008)
  - States set and finance education policies
- Interstate migration makes state education spills over into other states
  - Education policy of Oklahoma has GE effects

This paper

- How one state's efficiency of HC production propagates to the others?
- How these spillovers contribute to the national economy?

Propose and quantify **a dynamic spatial-GE framework** where

- Migration $\rightarrow$ expected returns to human capital $\rightarrow$ HC choices
- HC choice $\rightarrow$ migration propensity $\rightarrow$ HC allocation over spaces

\+ GE feedback to individual decisions

and evaluate

- the impact of a federal education grant on the state and national economies
- and an optimal strategy for its implementation

Model: Overview

- Dynamic spatial migration model with hetero. states (Artuc et al. 2010, Caliendo et al. 2019)
- Hetero. OLG household: human capital accumulation (Hsieh et al. 2019)
- Key margin: **interplay** of migration & human capital accumulation

$\longrightarrow$ Each bilateral link of migration embodies different amounts of HC

$\Longrightarrow$ Quantifies how state education quality/policy propagates

* Computationally intensive; focus on U.S. states

Key Findings

- Quantification: “A House Divided Cannot Stand.”
  - Skill production efficiency varies across states: P90/P10 = 1.23
  - High efficiency states export HC to low eff. ones
  - The U.S. GDP would decline by 7% ($ 700 bill.), absent migration

  $\Rightarrow$ Strong complementarity between migration and the decentralized system

- Counterfactual: the federal role in education
  - A federal education grant to states (Race to the Top) increased the U.S GDP by 0.2%
    - The gain $21.5 bill = 5x of the cost $4.1 bill
    - The grant-winning states and neighbors benefits the most
    - Alternative grant allocation could increase the national GDP gain

Literature and Contribution

Human Capital Production in General Equilibrium

- Erosa et al. (2010), Manuelli & Seshadri (2014), Hsieh et al. (2019), Ferriere et al. (2021), Xiang & Yeaple (2023)

\+ HC decision internalizes the possibility of future migration

Quantitative Spatial General Equilibrium Models

- Artuc et al. (2010), Caliendo et al. (2019), Bryan & Morten (2019), Eckert & Kleinberg (2021), Hsiao (2023)

\+ Worker heterogeneity and endogenous skill acquisition dynamics

School Finance (Reform)

- Fernandez & Rogerson (1998), Gordon (2004), Coen-Pirani (2015), Biasi (2023), Handel & Hanushek (2023)

\+ Spatial dynamics $\rightarrow$ propagation of education policies; RTT cost-benefit analysis

Economic Impacts of Local Education Quality

- Card & Krueger (1992), Chetty et al. (2014), Jackson et al. (2016), Altonji and Mansfield (2018)

Model

Model Components

A collection of closed states that workers move across borders

+ State-specific: Amenity, TFP, **skill production efficiency** (“education quality”)
  - Exogenous and time-invariant

+ Production: one sector, non-tradable final good
  - Inputs: two types of HC (**c**ollege and **n**on-college workers)

+ Finitely-lived Households = Education and Working stages
  - Education Stage: Skill investment and degree choice $\Rightarrow$ **fixed** thereafter (Hsieh et al. 2019)
  - Working Stage: Work and migrate, subject to moving cost (Artuc et al. 2010)
  - Parents pay for skill investment of children

Skill Production

- Individual **skill** = $f($innate **ability**, acquired **knowledge**$)$
- Innate ability $\varepsilon \sim \mathcal{LN}(0, {\sigma_\varepsilon}^2)$
- Acquired knowledge $H = h^{k_B} \times e^\eta$
  - e: skill investment
  - h^{kB}: **skill-production efficiency** of state of birth k_B
  - $\eta \in (0, 1)$: returns to the investment

$\Rightarrow$ Individual worker's skill = $H\varepsilon$

Degree Choice

- State labor market is segmented by degree = $\{$College, Non-college$\}$
- College jobs pay higher wages
- College workers pay lower moving costs
- College is not free:
  - fixed utility cost χ
  - idiosyncratic utility cost $z \sim$ Logistic(0, σ_z^2)

$\Rightarrow$ High-skill individuals select into college

Human Capital, Worker Type, and Income

Human Capital = Skill & Degree

$$\Downarrow$$

Worker type $\mathbf{s} \equiv (k_B, \varepsilon, e, o)$

born in state k_B with ability ε, spent e on skill, and chose degree o

$$\Downarrow$$

Labor income $I^k(\mathbf{s}) = \underbrace{w_o^k}_{\text{Degree}} \underbrace{H(\mathbf{s})\varepsilon}_{\text{Skill}}$, given state

Households: Overview

	Adult	Work, Consume, Relocate
Working Stage (3 periods)		

Households: Overview

Working Stage (3 periods)

Adult Work, Consume, Relocate

↓

Parent Work, Consume, Relocate

Households: Overview

Child

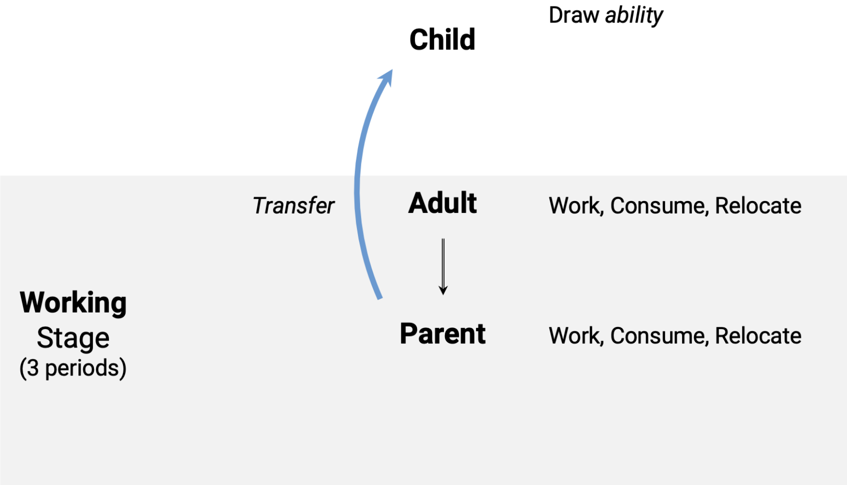
Working Stage (3 periods)

Working Stage (3 periods)	**Adult**	Work, Consume, Relocate
	↓	
	Parent	Work, Consume, Relocate

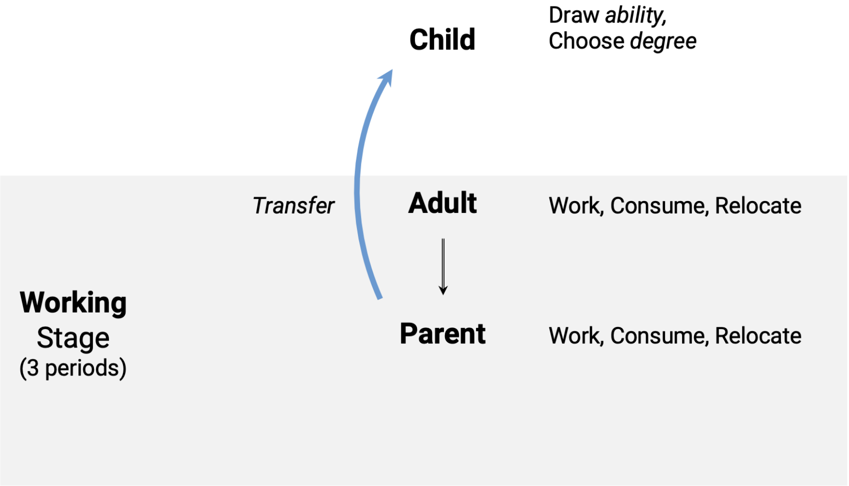
Households: Overview

	Child	Draw *ability*
	Adult	Work, Consume, Relocate
	↓	
Working Stage (3 periods)	**Parent**	Work, Consume, Relocate

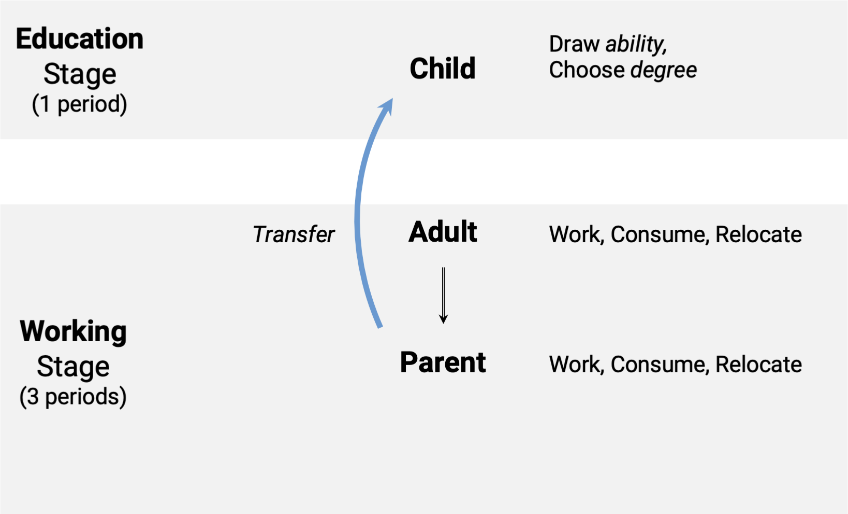
Households: Overview



Households: Overview



Households: Overview



Households: Overview

Education Stage (1 period)

Child — Draw *ability*, Choose *degree*, Relocate

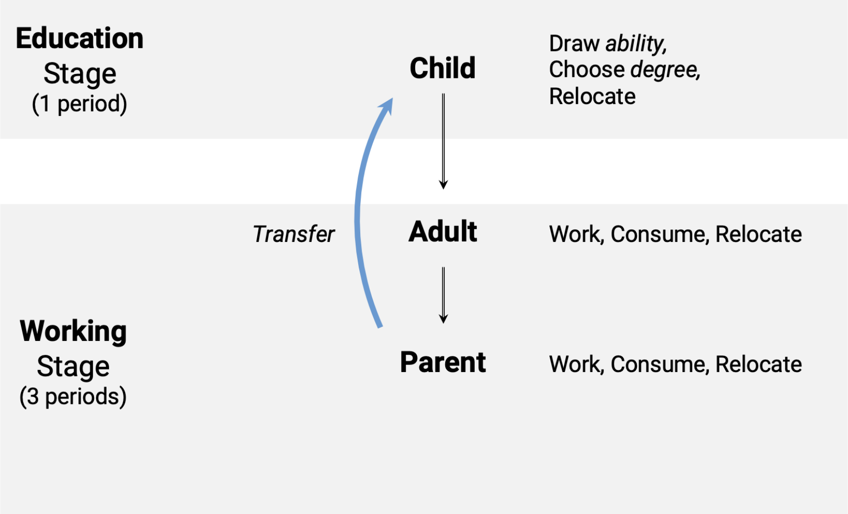
Working Stage (3 periods)

Transfer

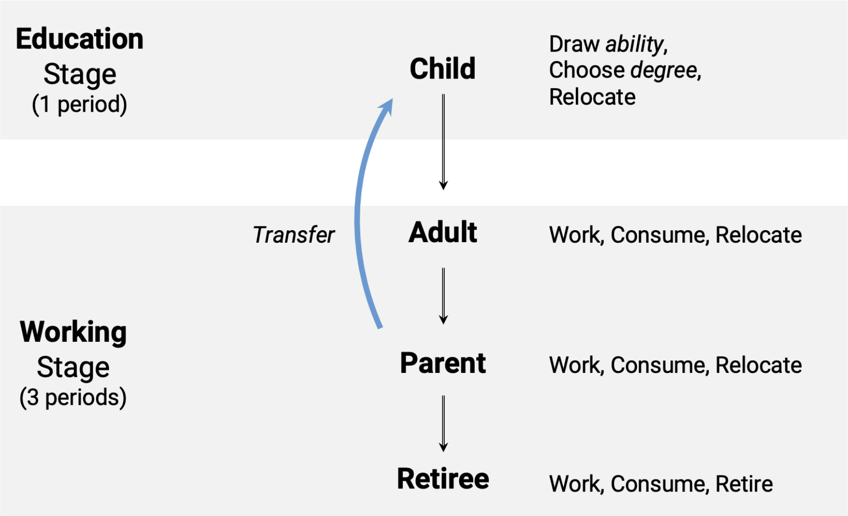
Adult — Work, Consume, Relocate

Parent — Work, Consume, Relocate

Households: Overview



Households: Overview



Producer's Problem

$$Y^k = \Theta^k \left[A_c^k (L_c^{kD})^{\frac{\sigma-1}{\sigma}} + A_n^k (L_n^{kD})^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{1}$$

+ L_c^{kD} and L_n^{kD} denote **c**ollege and **n**on-college HC demanded in state k
+ Θ^k denotes the state TFP
+ A_o^k denotes education-specific technological parameters, $A_c^k + A_n^k = 1$.

Aggregation Market Clearing Equilibrium

Decision Rules

- Skill Acquisition: individuals invest more / go to college if
  - draw a higher innate ability
  - born in a higher skill production efficiency state
  - have higher-income parents
  - can enjoy marginal returns to human capital via migration
- Migration: individuals are moving because of
  - high-paying jobs (for own consumption)
  - better skill production efficiency (for children)
  - idiosyncratic taste shocks

  and more likely to move with higher HC (skill, degree)

Visual Illustration

Quantification: U.S. States

Quantification Procedure

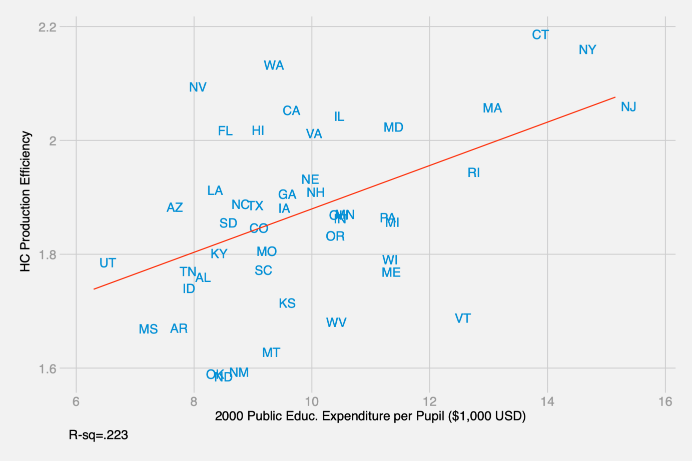
1. Set the preference and production parameters externally Details
2. Estimate moving costs and the migration elasticity PPML est.
   - Outside of the main calibration, using wages and cross-state migration flows
3. Calibrate the region fundamentals and human capital related parameters Details
   - **Key**: state skill production efficiency **h**
   - Identification: per capita skill demand & market clearing

Calibration

- Data Data Overview Migration Data
  - Wages by degree and states, migration flows (Census, ACS, CPS)
  - State GDP (BEA)
- Setup
  - Calibrate the model to the 2000 U.S. economy
  - 47 U.S. States, excluding Alaska, Delaware, Wyoming, and D.C. (Hanushek et al. 2017)
- Fit and Validation
  - The model perfectly matches the target moments
  - Calibrated state fundamentals are consistent to the existing literature
  - Model-predicted migration rates are close to the observed ones

TFP and Migration Rates

h is correlated with public education spending



OLS Regression

Human Capital Flow and State Gross Output

- Current HC stock of state k = native stayers + (inflow - outflow)

$$\text{Adjusted Net Inflow}^k = \frac{\text{inflow - outflow (eff. labor)}}{\text{k-born population (headcount)}}$$

- *ANI* is an **absolute** measure: the magnitude of HC flows implied by migration flows
  - An indicator of state-level brain gain or drain
  - Likely to decrease in h, but Θ and a may compensate

$\Rightarrow$ $ANI \uparrow \implies$ **Gross** output $Y \uparrow$

Human Capital Flow and State per capita Output

$$\text{State per capita income} = \text{wage} \times \underbrace{[\text{ HCpc of native stayer + in-migrants}]}_{\text{weighted by emp share}}$$

$$\text{Relative HC per capita}^k = \frac{\text{HCpc of in-migrants}}{\text{HCpc of native stayers}} - 1$$

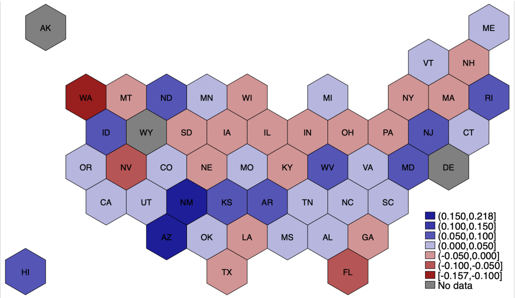
- *RHCPC* is a **relative** measure: headcounts / magnitudes are irrelevant
  - Value-added contribution of in-migrants to state output, compared to the native stayers
  - Decreasing in h

$\Rightarrow$ $RHCPC \uparrow \implies$ **per capita** output $y \uparrow$

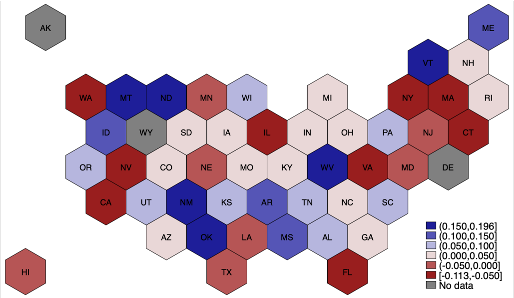
Formal Definitions

Results: Human Capital Flows (Non College)

(a) Adjusted Net Inflow



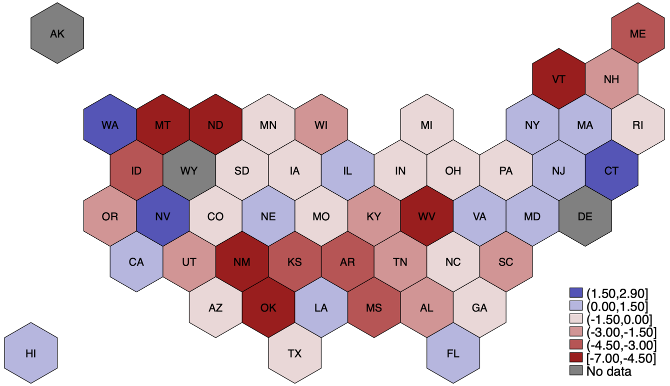
(b) Relative HC per capita



- Oklahoma: Low h, $\Theta \rightarrow ANI \uparrow$, $RHCPC \uparrow\uparrow$
- Connecticut: High h, $\Theta \rightarrow ANI \uparrow$, $RHCPC \downarrow\downarrow$

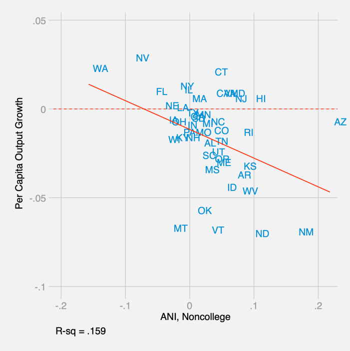
“A House Divided”: shutting down migration

- The U.S. output: drops by 6.9% ($700 bill. in 2000)
- State-level responses are heterogeneous

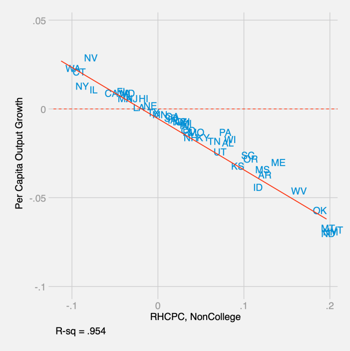


A House Divided: HC Flows and Output per capita (Non College)

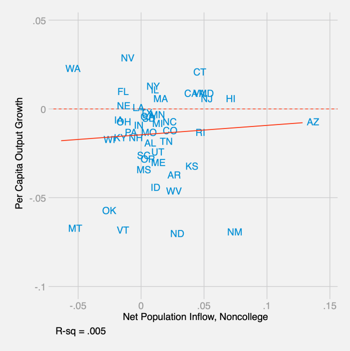
(a) Adjusted Net Inflow



(b) Relative HC per capita



(c) Net Population Inflow



- High ANI, RHCPC $\Rightarrow$ Higher gains in output per capita
- Net population inflow is not a good predictor

College

Policy Simulation

Policy: Race To the Top (RTT)

- U.S. DoE competitive grant to states, upon voluntary participation
- $4.12 billion to 18 states + D.C. (2010-2011)
- The grant amount varies across states, from $18 mil. (CO) to $700 mil. (NY)

$\Longrightarrow$ What is the impact of the grant on the states, and the national economy?

Simulation Procedure

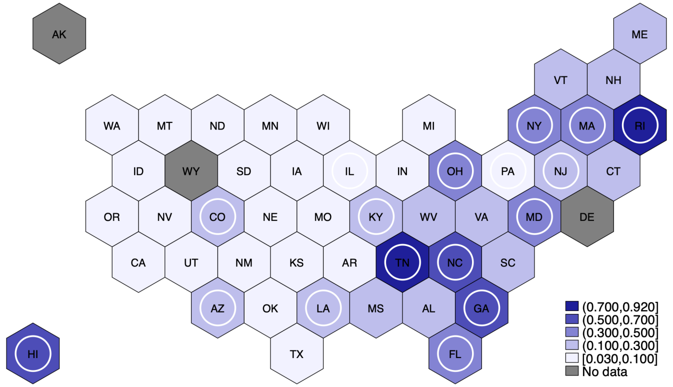
1. Regress h on **public expenditure per pupil** and take the OLS coefficient $\hat{b}$
2. Convert the RTT funding amounts into per pupil scale, Δ^k
3. Obtain a counterfactual skill production efficiency $h^k_{Sim} = h^k + \hat{b}\Delta^k$

Simulation: Mimicking the RTT

	\$ Mill.	\$ per pupil	% growth	Δh
Arizona	25	28.5	0.38	0.001
Colorado	18	24.8	0.28	0.001
Florida	700	287.5	3.46	0.011
Georgia	400	276.8	2.97	0.011
Hawaii	75	406.8	4.58	0.015
Illinois	43	21.0	0.20	0.001
Kentucky	17	25.5	0.31	0.001
Louisiana	17	22.9	0.28	0.001
Maryland	250	293.1	2.63	0.011
Massachusetts	250	256.4	2.00	0.010
New Jersey	38	28.9	0.19	0.001
New York	700	242.9	1.68	0.009
North Carolina	400	309.2	3.62	0.012
Ohio	400	218.0	2.14	0.008
Pennsylvania	41	22.6	0.20	0.001
Rhode Island	75	476.7	3.80	0.018
Tennessee	500	550.0	7.18	0.021
Delaware	100	872.0	7.23	0.033
District of Columbia	75	1088.1	6.71	0.041

Results: per capita Output Changes (%)

- U.S. GDP: 0.22% ↑
- The Eastern U.S. mostly benefits from RTT



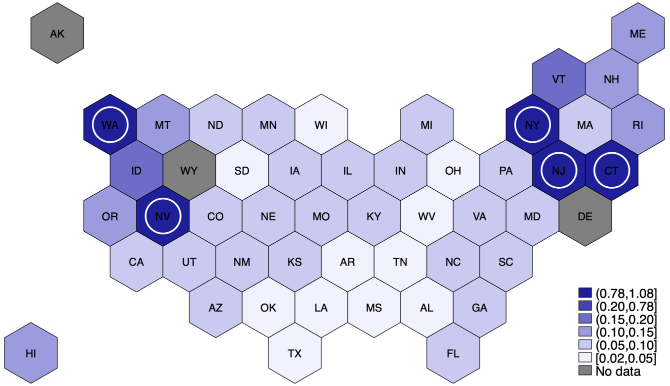
Simulation: Alternative Implementations

	States	\$ Per Pupil	Δh
Top 5	New Jersey, Nevada, Washington, New York, Connecticut	647.0	0.025

Bottom 5 Results

Results: per capita Output Changes (%), Subsidize the Top 5

- U.S. GDP: 0.27% ↑
- The 5 states: 0.8%-1.1% ↑, increasing in TFP Θ



Summary

- New dynamic spatial model to quantify human capital flows
  - Endogenizes human capital accumulation and migration jointly
  - Incorporates and quantifies GE spatial linkages
- Quantify the skill production efficiency and interstate HC flows
  - Skill production efficiency varies across states: P90/P10 = 1.23
  - Human capital mostly flows from high to low efficiency states
- Results suggests:
  - The U.S. GDP would decline by 7% ($ 700 bill.), absent migration
  - Race to the Top increased the U.S GDP by 0.2% ($21 bill.)
- Future study
  - Declining interstate migration $\rightarrow$ federalism in education?
  - Applicable to other large economies (e.g. EU) or international migration

Thank you!

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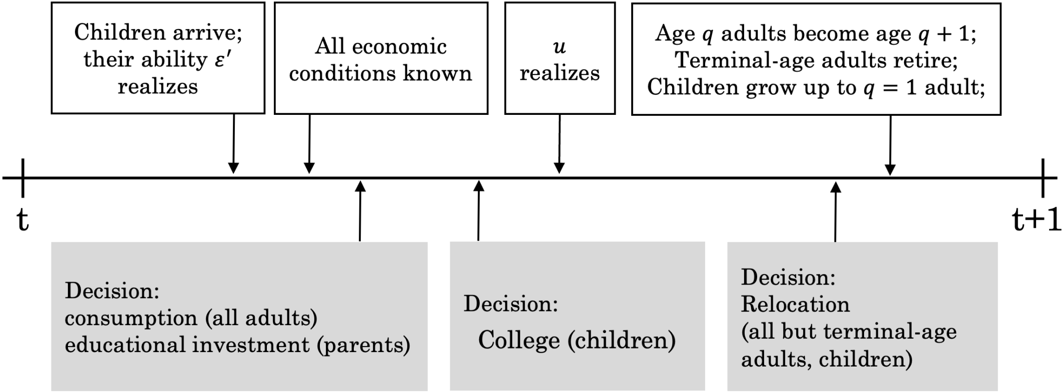
Appendix

Households: Within-Period



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Households' Problem

Value of an **adult** worker $\mathbf{s}$ at age q working in state k

$$v^q(k;\mathbf{s}) = u(c) + a^k + \max_{k' \in \mathcal{K}} \left\{ u^{k'} - \tau^{k,k'} + \beta \mathbb{E} v^{q+1}(k';\mathbf{s}) \right\}$$
$$\text{s.t.} \quad c = I^k(\mathbf{s})/P^k$$

Problem: choosing where to live tomorrow

- Utility function $u(c)$: CRRA
- Regional amenity a^k
- Preference shock $u^k \sim^{iid} T1EV(-\gamma\nu, \nu)$
- Moving costs $\tau^{k,k'} \geq 0$ is in terms of utility

Households' Problem

Type-I EV distribution delivers the expected value of a worker at age q in state k:

$$V^q(k;\mathbf{s}) = u\left(I^k(\mathbf{s})/P^k\right) + a^k + \nu \log\left[\sum_{k'} \exp\left(\beta V^{q+1}(k',\mathbf{s}) - \tau^{k,k'}\right)^{\frac{1}{\nu}}\right]$$

where $V^q(k,\mathbf{s}) \equiv \mathbb{E}v^q(k;\mathbf{s})$ (expectation taken over u).

The probability of moving from k to k' for worker $\mathbf{s}$:

$$m^q(k,k';\mathbf{s}) = \frac{\exp\left[\beta V^{q+1}(k';\mathbf{s}) - \tau^{k,k'}\right]^{\frac{1}{\nu}}}{\sum_{k'\in\mathcal{K}} \exp\left[\beta V^{q+1}(k';\mathbf{s}) - \tau^{k,k'}\right]^{\frac{1}{\nu}}} \tag{2}$$

Gradient: Geography and Education Gradient: Selection and Sorting

Households' Problem

End-period value of a **child** at age $q = 0$ in state $k = k_P = k_B$: choose where to live tomorrow

$$V^{0+}(k_P, \varepsilon, e; o) = \nu \log \left[\sum_{k'} \exp \left(\beta V^1(k', \mathbf{s}) - \tau^{k_p, k'} \right)^{\frac{1}{\nu}} \right]$$

Beginning-period value of a **child** in k_p with (ε, e): choose whether go to college

$$V^{0-}(k_P, \varepsilon; e) = \max_{o \in \{c,n\}} \left\{ V^{0+}(k_P, \varepsilon; e, n), V^{0+}(k_P, \varepsilon; e, c) - z - \chi \right\}$$

- Children have no own consumption
- Parents finance skill investment e

Households' Problem

Value of a **parent** at age $q = q_P$ in state k :

$$V^{q_P}(k, \varepsilon'; \mathbf{s}) = \max_{c, e'} u(c) + a^k + \alpha V^{0-}(k, \varepsilon'; e') + \nu \log \left[\sum_{k'} \exp \left(\beta V^{q_P+1}(k', \mathbf{s}) - \tau^{k,k'} \right)^{\frac{1}{\nu}} \right]$$

$$s.t. \qquad c + e' = I^k(\mathbf{s}) / P^k$$

- α: the degree of altruism
- The $c - e'$ decision before relocation $\rightarrow$ departs from ACM (2010), CDP (2019), etc.
- Investment decision **after** observing ε', given parental income

retirees Within-period Timeline

Households: pre-parents and retirees

- Dynastic framework with two stages: children (education) and **adult (working)**

  Value of a worker at age $q = q_P - 1$ in state k who **becomes a parent tomorrow**

$$V^{q_P-1}(k;\mathbf{s}) = u(c) + \nu \log\left[\sum_{k'} \exp\left(\beta \mathbb{E}_{\varepsilon'} V^{q_P}(k',\varepsilon';\mathbf{s}) - \tau^{k,k'}\right)^{\frac{1}{\nu}}\right]$$

  - $V^{q_P}(\cdot)$ involves education quality h^k

  Value of a **retiring worker** at age $q = q_R$

$$V^{q_R}(k;\mathbf{s}) = u(I^k(\mathbf{s})/P^k)$$

  - A simple hand-to-mouth problem without relocation decision

back

Migration Probs: Qualitative Predictions

- Migration cost (geography)
  Consider a parent-age individual in A with $\mathbf{s}$ and her migration probability to B, $m^{q_P}(A, B; \mathbf{s})$. The first derivative of m^{q_P} is:

$$\frac{\partial m^{q_P}(A, B; \mathbf{s})}{\partial \tau} = -\frac{1}{\nu} m^{q_P}(A, A; \mathbf{s}) m^{q_P}(A, B; \mathbf{s}) < 0$$

- HC productivity (education motive)
  Take a pre-parental individual $(A, \mathbf{s})$ and consider $m^0(A, B; \mathbf{s})$ again.

$$\frac{\partial m^{q_P-1}(A, B; \mathbf{s})}{\partial h_c^B} = \underbrace{m^{q_P-1}(A, A; \mathbf{s}) m^{q_P-1}(A, B; \mathbf{s})}_{>0} \left[\frac{\beta}{\nu} \underbrace{\mathbb{E}_{\varepsilon'} V^{q_P}_{\varepsilon'}(B; \mathbf{s})}_{\geq 0} \right]$$

$$V^{q_P}_{h_c^B} = \alpha V^{0-}_{h_c^B} \geq 0$$

where the equality holds if a child will be specialized in n Back

Migration Probs: Qualitative Predictions

- Selection: move from A to B

$$\frac{\partial m^{q_P}(A,B;\mathbf{s})}{\partial H} = \underbrace{m^{q_P}(A,A;\mathbf{s})m^{q_P}(A,B;\mathbf{s})}_{>0}\left[\frac{\beta}{\nu}\underbrace{\left(V_H^{q_R}(B;\mathbf{s}) - V_H^{q_R}(A;\mathbf{s})\right)}_{\text{(*), ambiguous}}\right]$$

  - (*) > 0 with $\rho > 0$
- Sorting: move from A to B or C; same as above

$$\frac{\partial}{\partial H}\log\left[\frac{m^{q_R}(A,B;\mathbf{s})}{m^{q_R}(A,C;\mathbf{s})}\right] = \frac{\beta}{\nu}\left[\underbrace{V_H^{q_R}(B;\mathbf{s}) - V_H^{q_R}(C;\mathbf{s})}_{(*)}\right]$$

- HC gradient of geography (derivative w.r.t. H and τ): same logic applies

Back

HC Aggregation

- For a measure $\mu^q(k; \mathbf{s})$, the state labor supply = agg. individual HC:

$$L_o^{kS}(q) = \int_{\mathbf{s}} (h_o^{k_B} e^{\eta}) \varepsilon_o d\mu^q$$
$$L_o^{kS} = \sum_{q \geq 1} L_o^{kS}(q)$$

- Law of motion: aggregate evolution of the labor force

$$\mu^{q+1}(k', \mathbf{s}) = \sum_k m^q(k, k'; \mathbf{s}) \mu^q(k, \mathbf{s}) \qquad 0 \leq q \leq q_R - 1$$

- Steady state: gross migration flows are positive but net flows are zero

Market Clearing

- State Labor Market Clearing

$$L_o^{kS} = L_o^{kD} \qquad \forall_{o,k}$$

- State Goods Market Clearing

$$Y^k = C^k + E^k$$

where

$$C^k = \sum_q \Big[\int_{\mathbf{s}} c^q(\cdot) d\mu^q\Big], \qquad E^k = \int_{\varepsilon'} \int_{\mathbf{s}} e'(\cdot) d\mu^{q_P}$$

- State Price Index

$$P^k = \frac{1}{\Theta^k}\left[(A_c^k)^\sigma (w_c^k)^{1-\sigma} + (A_n^k)^\sigma (w_n^k)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

Equilibrium

Equilibrium

The analysis is focused on steady states. Back

Definition (Stationary Equilibrium)

Given the fundamentals Γ, a stationary equilibrium of the model consists of prices $\{w_o^k, P^k\}$, value functions and policy functions for workers $\{V^q(k;\mathbf{s})\}, c(k;\mathbf{s}), e'(k;\mathbf{s}), o(k,e,\varepsilon), m^q(k;\mathbf{s})$, policies for firms $\{L_o^{kD}\}$, and a stationary measure $\mu^q(k;\mathbf{s})$ that solves the dynamic problem of individuals and the corresponding laws of motion for labor, sub-static subproblem for production, and market clearing conditions.

Unpacking Decision Rules: A Tale of Two Regions

Consider two regions *Rural* and *Urban*, where

- **Identical** skill production efficiency h
- **College job** pays more than non-college job in both
- **Urban** pays more than Rural for each type of job
- **Rural college** pays more than Urban non-college

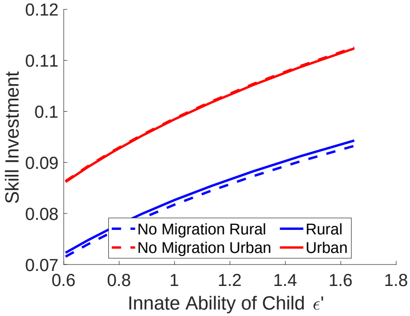
Check the decision rules to see

$$\text{Skill} \begin{array}{c}\text{Formation} \\ \text{Heterogeneity}\end{array} \Longleftrightarrow \text{Migration}$$

Unpacking Decision Rules: Skill Investment

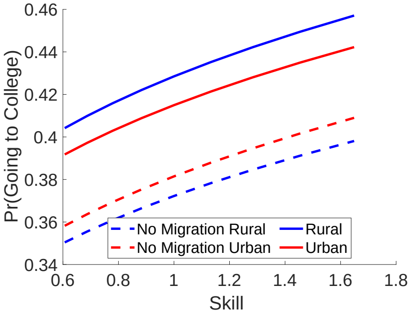
- Child ability $\uparrow \implies$ investment $\uparrow$ (given parental income)
- Migration averages returns to skill over spaces

$\Rightarrow$ Shifts the curves: Rural $\uparrow\uparrow$, Urban $\downarrow$



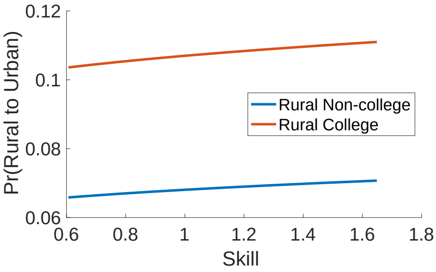
Unpacking Decision Rules: College Propensity

- Skill $\uparrow \Rightarrow$ Pr(College) $\uparrow$
- Migration $\rightarrow$ Value of College Degree $\uparrow$
  - Rural: access to higher w_c^U + lower moving cost
  - Urban: insure against w_n^R

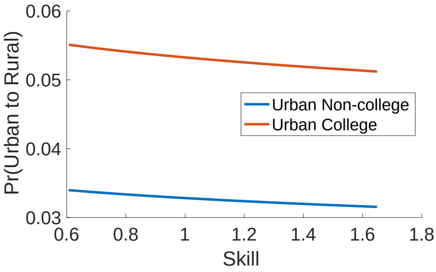


Unpacking Decision Rules: Migration Propensity and Human Capital

(a) Pr(Rural to Urban)



(b) Pr(Urban to Rural)



- Selection: Skill $\uparrow \Rightarrow$ Pr(Migrate) $\uparrow$
- Sorting: Skill $\uparrow \Rightarrow$ Pr(Destination = Rural) $\downarrow$
- Lower moving cost (college) $\Rightarrow$ Pr(Migrate$|$College) $\uparrow\uparrow$

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Human Capital Flow Accounting Framework: Formal Definitions

- I formally propose the three measures as follows.

$$
\begin{aligned}
NI_o^k &= \sum_{s \neq k} L_o^k(s) - \sum_{d \neq k} L_o^d(k) \\
ANI_o^k &= (\widetilde{N}^k)^{-1} NI_o^k \\
RHCPC_o^k &= \frac{L_o^k(-k)/N_o^k(-k)}{L_o^k(k)/N_o^k(k)} - 1
\end{aligned}
$$

  - *NI* and *ANI* are **absolute** measures: the magnitude of migration flows (headcounts) matter
  - *RHCPC* is a **relative** measure: it compares HC per capita, regardless of headcounts

Derivation: RHCPC

Derivation: RHCPC

$$Y^k = \sum_o w_o^k \Big[\underbrace{L_o^k(k)}_{\text{k-born k-residents}} + \underbrace{L_o^k(-k)}_{\text{all migrants}} \Big]$$

$$y^k = \sum_o w_o^k \underbrace{\frac{N_o^k}{N^k}}_{\text{Emp shares by degree}} \Bigg[\underbrace{\frac{N_o^k(k)}{N_o^k} \frac{L_o^k(k)}{N_o^k(k)}}_{\text{k-born k-residents}} + \underbrace{\frac{N_o^k(-k)}{N_o^k} \frac{L_o^k(-k)}{N_o^k(-k)}}_{\text{all migrants}} \Bigg]$$

where

$$\frac{N_o^k(-k)}{N_o^{-k}} \frac{L_o^k(-k)}{N_o^k(-k)} \equiv \sum_{s \neq k} \frac{N_o^k(s)}{N_o^k} \frac{L_o^k(s)}{N_o^k(s)}$$

The per capita income is decomposed into the per capita HC by degree and origin, weighted by emp shares by degree and within-degree origin composition. Comparing the HC per capita, we obtain: Back

$$RHCPC_o^k = \frac{L_o^k(-k)/N_o^k(-k)}{L_o^k(k)/N_o^k(k)} - 1$$

Quantification Step 1: Set Parameters Externally

- Production
  - CES elasticity of substitution $\sigma = 1.5$ (Cantore et al. 2017)
- Human capital
  - Elasticity of HC investment $\eta = 0.103$ (Hsieh et al. 2019)
- Preference
  - CRRA utility, risk aversion ρ = 0.9 (Chetty 2006: [0.15, 2.2] median = 0.71, mean = 0.9)
  - Subjective discount factor $\beta = 0.9 \to$ annual = 0.98
  - Altruism $\alpha = 0.5$ (Del Boca et al. 2019)

+ Time: period = 5 years, $q_R = 3$, $q_P = 2$.
  - Individuals live through $1 + 3$ periods; relocate up to 3 times

Quantification Step 2: Two-Stage PPML Estimation

- Stage 1: Estimate $\tau_o^{k,k'}/\nu$, recasting the migration propensity (1)

$$\text{NumMigrants}_t^{k,k'}(o) = \exp\left[\underbrace{\text{origin}_t^k + \text{destin}_t^{k'}}_{\text{Fixed effects}} - \frac{\tau_o^{k,k'}}{\nu}\right] + \text{error}_t^{k,k'}(o)$$

- Stage 2: Estimate $1/\nu$, recasting the working adult's problem

$$\kappa_t^k(o) = \underbrace{\text{time}_t(o) + \text{region}^k(o)}_{\text{Fixed effects}} + \frac{\beta}{\nu} u\left[\frac{I_{t+1}^k(o)}{P_{t+1}^k}\right] + \text{error}_t^k(o)$$

  - $\kappa_t^k(o)$: function of origin_t^k, destin_t^k, and $\text{population}_{t+1}^k$

PPML Results

Table: Moving Costs

	Mean	SD	Min	Max
Non-College	7.234	1.744	3.081	12.139
College	6.450	1.304	3.307	10.712

Table: Migration Elasticity

	(1) All	(2) Non College	(3) College
$1/\nu$	0.617*** (0.142)	0.546*** (0.188)	0.643*** (0.141)
N	1880	940	940

Quantification Step 3: Calibration

Solve for region fundamentals $\{h^k, \Theta^k, a^k, A_o^k\}$, college cost parameters $\{\chi, \sigma_z\}$, and skill dispersion σ_ε such that match

- state-level moments:
  - output per capita y
  - wages by degree w_o
  - population share N
- national moment:
  - share of college graduates
- clear all labor markets

Identification

Data

- Regional GDP (BEA)
  - Drop the capital portion assuming the Cobb-Douglas (capital share = 0.38)
  - Stata-level capital stock data is from El-Shagi and Yamarik (2019)
- Wages by degree and state: CPS-ASEC, ACS, and Decennial Census
- Interstate migration flows: CPS-ASEC, ACS, Decennial Census
- National % college graduates: ACS

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Migration Data

Table: Three Samples of 5-year Migration Flows

	Simulated All-year Sample	Simulated 5-year Sample	Alternating Sample
Source	CPS-ASEC	CPS-ASEC	CPS-ASEC and Census
Simulation	Yes, fully	Yes, partially	No
Raw Data Frequency	Annual	Demi-decennial	Demi-decennial
Availablity	1985-2010 (26 periods)	1985-2010 (6 periods)	1985-2000 (4 periods)

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Migration Data: Simulated Samples

- Construct 5-year flows from 1-year flows for better data availability (Eckert and Kleinberg 2021)

- Accounting identity of migration flows

$$N_{t+1}^{k'} = \mathbf{M}_{t-1,t}^{kk'} N_t^k$$

- Forward iteration of **M** yields a simulated 5-year transition matrix

$$N_t^{k'} = \mathbf{M}_{t-5,t}^{kk'} N_{t-5}^k \approx \left[\prod_{d=1}^{5} \mathbf{M}_{t,t-d}^{kk'} \right] N_{t-5}^k$$

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Calibration: Identifying the Key Parameters

All parameters are jointly identified. All things equal,

- Higher w and $y \Rightarrow$ higher Θ
- Higher $N \Rightarrow$ higher a
- $h \Rightarrow$ the per capita labor supply L/N
- $A_o \Rightarrow$ the relative labor demand L_c/L_n
- χ and $\sigma_z \Rightarrow$ the national share of college education

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Model Validation: h and public spending

$$h^k = a + b\text{Expenditure}^k + \text{error}^k$$

	Level		Log	
	(1) 1990	(2) 2000	(3) 1990	(4) 2000
Expenditure Per Pupil	0.031*** (0.006)	0.038*** (0.010)	0.387*** (0.072)	0.378*** (0.101)
R-squared	0.329	0.224	0.331	0.214

Robust standard errors in parentheses. $*p < 0.1, **p < 0.05, ***p < 0.01$.

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Model Validation: TFP and Migration Rates

- TFP: Compare the calibrated Θ and the estimates from Herkenhoff et al. (2018)

	1980	1990	2000	2014
Rank Corr.	0.280	0.703	0.743	0.580
	(0.060)	(0.000)	(0.000)	(0.000)

Spearman rank correlation coefficients. P-values in parentheses.

- Migration Rates: Compare the model and the empirical rates

	Model	Data (CPS)
Mig. Rate (Non-College)	0.085	0.071
Mig. Rate (College)	0.135	0.122

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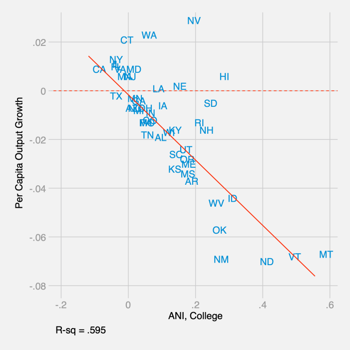
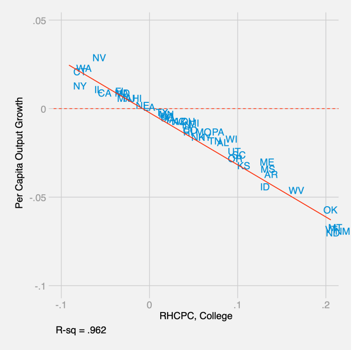
A House Divided: Output per capita and HC Flows (College)

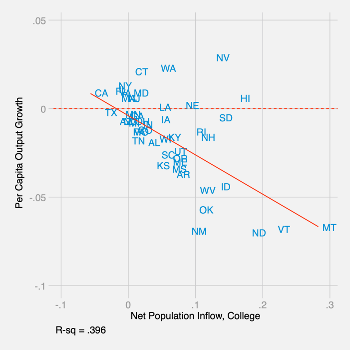
(a) ANI



(b) RHCPC



(c) Net Population Inflow



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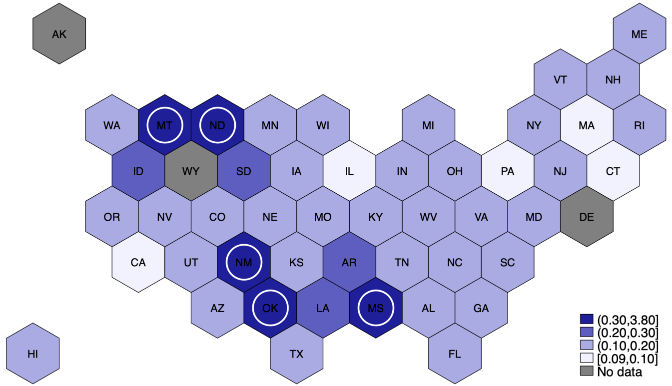
Results: Subsidize the Bottom 5

- U.S. GDP: 0.13% $\uparrow$
- The 5 states: 3.25%-3.8% $\uparrow$, increasing in TFP Θ



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