Lecture 6: Economic Geography and Trade

Economics 552

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Allen and Arkolakis

- Enormous degree of spatial inequality of economic activity
  - McLeod County, MN: 26 persons/km^2 and payroll \$13.5k per capita.
  - Mercer County, NJ: 591 persons/km^2 and payroll \$20.8k per capita.
- Why?
  - Local characteristics (climate, natural resources, institutions, etc.).
  - Geographic location.
- How important is geographic location?
- Much recent advancement in theory of economic geography.
- But the stylized nature of geography in these models make it difficult to take them directly to the data.

Geography

- Compact set S of locations inhabited by $\bar{L}$ workers.
- Location $i \in S$ is endowed with:
  - Differentiated variety (Armington assumption).
  - Productivity $\bar{A}(i)$.
  - Amenity $\bar{u}(i)$.
- For all $i, j \in S$, let the iceberg bilateral trade cost be $T(i, j)$.

- Terminology
  - $\bar{A}$ and $\bar{u}$ are the **local characteristics**.
  - T determines **geographic location**.
  - Together, $\bar{A}$, $\bar{u}$, and T comprise the **geography** of S.

- A geography is **regular** if $\bar{A}$, $\bar{u}$ and T are continuous and bounded above and below by strictly positive numbers.

Workers

- Endowed with identical CES preferences over differentiated varieties with elasticity of substitution $\sigma > 1$.
- Can choose to live/work in any location $i \in S$.
- Receive wage $w(i)$ for their inelastically supplied unit of labor.
- Welfare in location i is:

$$W(i) = \left(\int_{s \in S} q(s, i)^{\frac{\sigma - 1}{\sigma}} ds \right)^{\frac{\sigma}{\sigma - 1}} u(i)$$

where $q(s, i)$ is the per capita quantity consumed in location i of the good produced in location s and $u(i)$ is the local amenity.

Production

- Labor is the only factor of production, $L(i)$ is the density of workers.
- Productivity of worker in location i is $A(i)$.
- Perfect competition implies price of good from i is $\frac{w(i)}{A(i)} T(i,j)$ in location j.
- Functions w and L comprise the **distribution of economic activity**.

Productivity and Amenity Spillovers

- Productivity is potentially subject to externalities:

$$A(i) = \bar{A}(i) L(i)^{\alpha}$$

- Amenities are potentially subject to externalities:

$$u(i) = \bar{u}(i) L(i)^{\beta}$$

- Isomorphisms:
  - Monopolistic competition with free entry: $\alpha = \frac{1}{\sigma - 1}$.
  - Cobb-Douglas preferences over non-tradable sector: $\beta = -\frac{1-\gamma}{\gamma}$.
  - Heterogeneous (extreme-value) worker preferences: $\beta = -\frac{1}{\theta}$.

Equilibrium

- A **spatial equilibrium** is a distribution of economic activity such that:
- Markets clear: for all $i \in S$:

$$w(i)\, L(i) = \int_S X(i,s)\, ds,$$

  where $X(i,j)$ is the value of trade flows from $i \in S$ to $j \in S$.
- Welfare is equalized**:** there exists $W \in \mathbb{R}_{++}$ such that for all $i \in S$, $W(i) \leq W$, with the equality strict if $L(i) > 0$.
- The aggregate labor market clears, i.e. $\int_S L(s)\, ds = \bar{L}$.
- Characterization
  - A spatial equilibrium is **regular** if L and w are strictly positive and continuous.
  - A spatial equilibrium is **point-wise locally stable** if $\frac{dW(i)}{dL(i)} < 0$ for all $i \in S$.

Equilibrium without Spillovers

- Suppose $\alpha = \beta = 0$ so that $A(i) = \bar{A}(i)$ and $u(i) = \bar{u}(i)$. Then from welfare equalization:

$$w(i)^{1-\sigma} = W^{1-\sigma} \int_S T(s,i)^{1-\sigma} u(i)^{\sigma-1} A(s)^{\sigma-1} w(s)^{1-\sigma} ds$$

and from balanced trade

$$L(i) w(i)^{\sigma} = W^{1-\sigma} \int_S T(i,s)^{1-\sigma} A(i)^{\sigma-1} u(s)^{\sigma-1} L(s) w(s)^{\sigma} ds$$

Theorem

For any regular geography with exogenous productivity and amenities:

1. *There exists a unique equilibrium.*
2. *The equilibrium is regular and point-wise locally stable.*
3. *Equilibrium can be determined using an iterative procedure.*

Equilibrium with Spillovers

Can rewrite balanced trade and utility equalization as:

$$L(i)^{1-\alpha(\sigma-1)} w(i)^{\sigma} = W^{1-\sigma} \int_S T(i,s)^{1-\sigma} \bar{A}(i)^{\sigma-1} \bar{u}(s)^{\sigma-1} L(s)^{1+\beta(\sigma-1)} w(s)^{\sigma} ds$$
$$w(i)^{1-\sigma} L(i)^{\beta(1-\sigma)} = W^{1-\sigma} \int_S T(s,i)^{1-\sigma} \bar{A}(s)^{\sigma-1} \bar{u}(i)^{\sigma-1} w(s)^{1-\sigma} L(s)^{\alpha(\sigma-1)} ds$$

If $T(i,s) = T(s,i)$ for all $i, s \in S$ then the solution can be written as:

$$A(i)^{\sigma-1} w(i)^{1-\sigma} = \phi L(i) w(i)^{\sigma} u(i)^{\sigma-1}$$
$$L(i)^{\tilde{\sigma}\gamma_1} = K_1(i) W^{1-\sigma} \int_S T(s,i)^{1-\sigma} K_2(s) \left(L(s)^{\tilde{\sigma}\gamma_1}\right)^{\frac{\gamma_2}{\gamma_1}} ds,$$

where $K_1(i)$ and $K_2(i)$ are functions of $\bar{A}(i)$ and $\bar{u}(i)$, γ_1, γ_2, and $\tilde{\sigma}$ are functions of α, β, and σ.

Equilibrium with Spillovers

Theorem

Consider any regular geography with endogenous productivity and amenities with T symmetric. Define $\gamma_1 \equiv 1 - \alpha(\sigma - 1) - \beta\sigma$ and $\gamma_2 \equiv 1 + \alpha\sigma + (\sigma - 1)\beta$. If $\gamma_1 \neq 0$, then:

1. *There exists a regular equilibrium.*
2. *If $\gamma_1 < 0$, no regular equilibria are point-wise locally stable.*
3. *If $\gamma_1 > 0$, all equilibria are regular and point-wise locally stable.*
4. *If $\frac{\gamma_2}{\gamma_1} \in [-1, 1]$, the equilibrium is unique.*
5. *If $\frac{\gamma_2}{\gamma_1} \in (-1, 1]$, the equilibrium can be determined using an iterative procedure.*

Equilibrium Distribution of Labor

- When trade costs are symmetric, equilibrium distribution of labor can be written as a log-linear function of the underlying geography:

$$\gamma_1 \ln L(i) = C_L + (\sigma - 1) \ln \bar{A}(i) + \sigma \ln \bar{u}(i) + (1 - 2\sigma) \ln P(i)$$

- Implications:
  - When equilibrium is point-wise locally stable, population is increasing in $\bar{A}$ and $\bar{u}$.
  - Price index is a sufficient statistic for geographic location.
  - Conditional on price index, productivity and amenity spillovers only affect elasticity of $L(i)$ to geography.

Trade Costs

- Suppose S is a compact surface (e.g. a line, plane, or sphere).
- Let $\tau : S \rightarrow R_+$ be a continuous function, where $\tau(i)$ is the instantaneous trade cost of traveling over location $i \in S$.
- Define the **geographic trade cost** $T(i,j) = f(t(i,j))$, $f' > 0$, $f(0) = 1$ to be the total iceberg trade cost incurred traveling along the least cost route from i to j, i.e.

$$t(i,j) = \min_{\gamma \in \Gamma(i,j)} \int_0^1 \tau(\gamma(t)) \left|\left| \frac{d\gamma(t)}{dt} \right|\right| dt$$

where $\gamma : [0,1] \rightarrow S$ is a path and $\Gamma(i,j) \equiv \{\gamma \in C^1 | \gamma(0) = i, \gamma(1) = j\}$ is the set of all paths.
- $f(t) = \exp(t)$ natural choice since $\prod_0^1 (1 + \tau(x)\, dx) = \exp\left(\int_0^1 \tau(x)\, dx\right)$, but can show T satisfied triangle inequality $\iff$ f is log subadditive.

Optimal Path

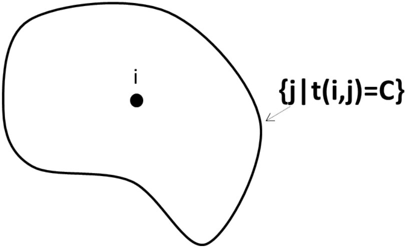
- Previous equation appears in a number of branches of physics. A necessary condition for its solution is the following *eikonal* equation:

$$||\nabla t\,(i,j)\,|| = \tau\,(j)$$

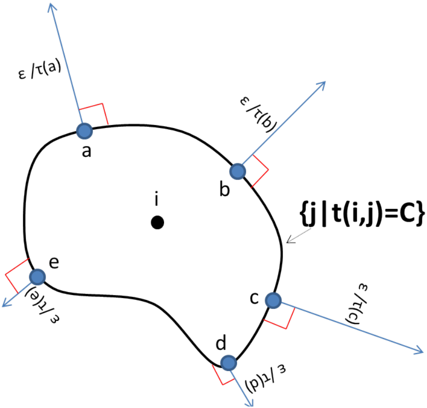
  where the gradient is taken with respect to j.

- Simple geometric interpretation: the trade cost contour expands outward in the direction orthogonal to the contour at a rate inversely proportional to the instantaneous trade cost.

Optimal Path



Optimal Path



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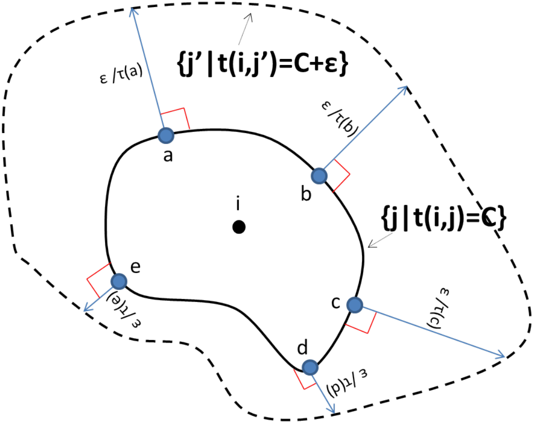

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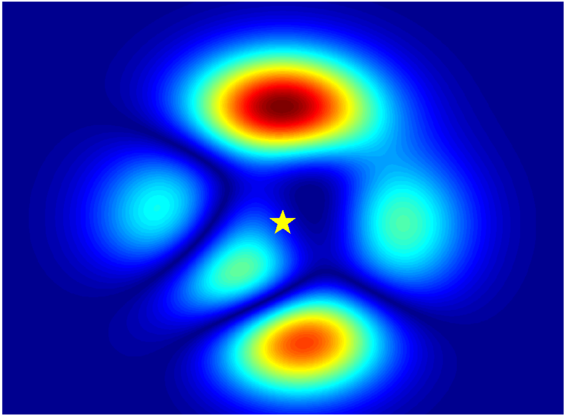

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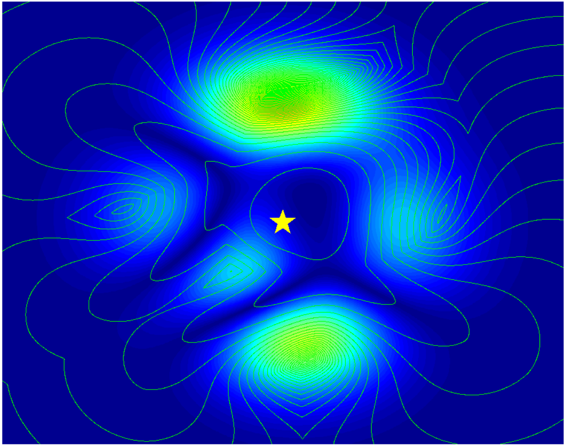

Estimating Trade Costs

- Goal: Find trade costs that best rationalize the bilateral trade flows observed in 2007 Commodity Flow Survey (CFS).
- Three step process:
  - Using **Fast Marching Method** (which operationalizes the Eikonal equation) and observed **transportation network**, calculate the (normalized) distance between every CFS area for each major mode of travel (road, rail, air, and water).
  - Using a **discrete choice** framework and observed **mode-specific bilateral trade shares**, estimate the relative cost of each mode of travel.
  - Using a **gravity** model and observed **total bilateral trade flows**, pin down normalization (and incorporate non-geographic trade costs).

Estimating Trade Costs

- For any $i, j \in S$, suppose $\exists$ traders $t \in T$ choosing mode $m \in \{1, ..., M\}$ of transit where cost is:

$$\exp\left(\tau_m d_m(i,j) + f_m + \nu_{tm}\right)$$

- Then mode-specific bilateral trade shares are:

$$\pi_m(i,j) = \frac{\exp\left(-a_m d_m(i,j) - b_m\right)}{\sum_k \left(\exp\left(-a_k d_k(i,j) - b_k\right)\right)},$$

where $a_m \equiv \theta \tau_m$ and $b_m \equiv \theta f_m$.

- Combined with model, yields gravity equation:

$$\ln X_{ij} = \frac{\sigma - 1}{\theta} \ln \sum_m \left(\exp\left(-a_m d_{mij} - b_m\right)\right) + (1-\sigma)\beta' \ln \mathbf{C}_{ij} + \delta_i + \delta_j$$

- Estimate a_m and b_m using bilateral trade shares, θ using gravity equation.
- Note:
  - No mode switching and assume $f_{road} = 0$ to pin down scale.

Estimating A and u

- Can identify a topography of productivities A and amenities u consistent with the estimated T and observed distribution of economic activity (w and L)
- See Theorem 3 in the paper
- Intuition: consider locations a and b with identical bilateral trade costs, i.e. for all $s \in S$, $T(a,s) = T(b,s)$. Then:
  - Utility equalization implies $\frac{u(b)}{u(a)} = \frac{w(a)}{w(b)}$.
  - Balanced trade implies $\frac{A(a)}{A(b)} = \left(\frac{L(a)w(a)^{\sigma}}{L(b)w(b)^{\sigma}}\right)^{\frac{1}{\sigma-1}}$.
- Note: $\bar{A}$ and $\bar{u}$ cannot be identified without knowledge of α and β.

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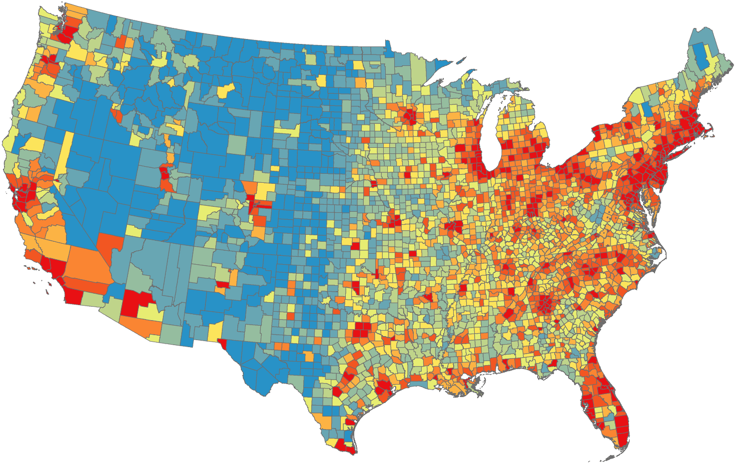
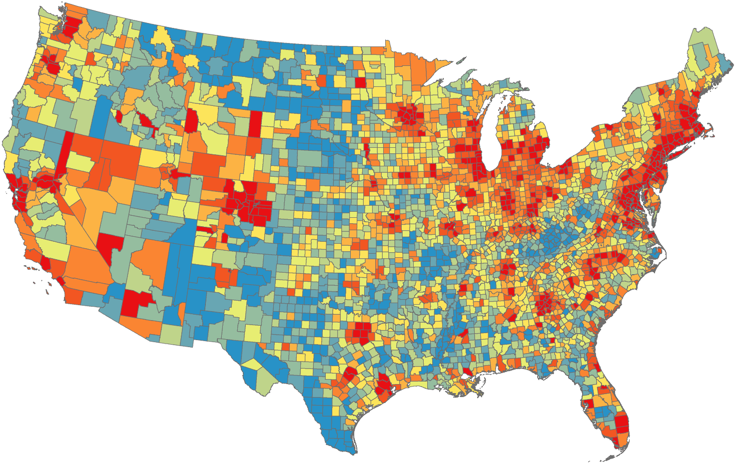
Observed L

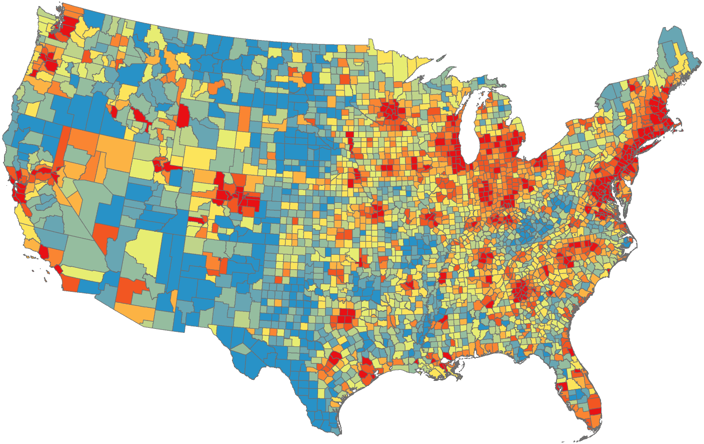


Observed w



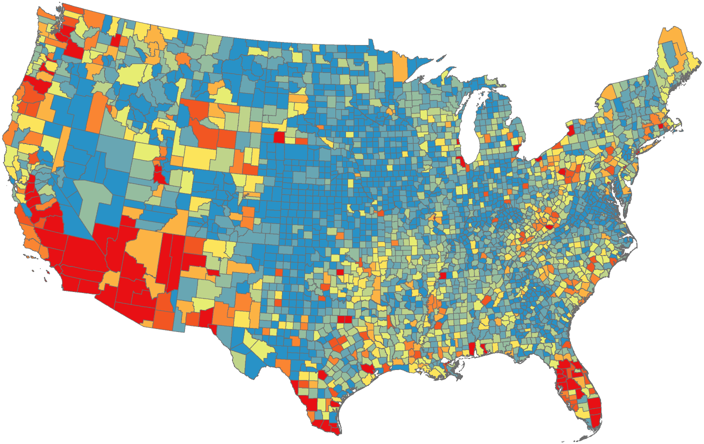
Exogenous A

- $\alpha = 0.1$

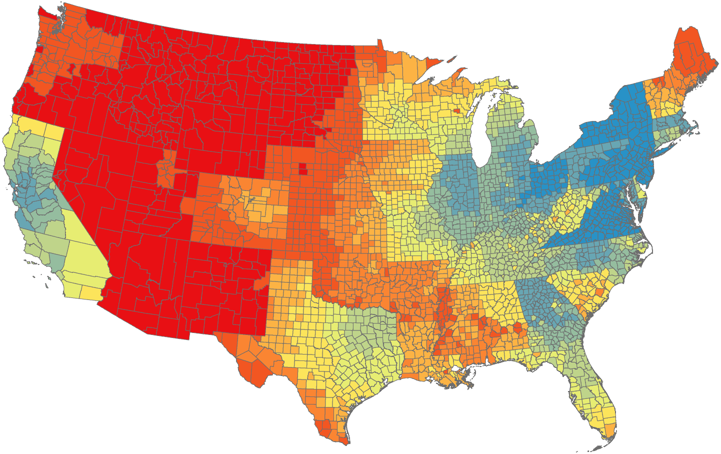


Exogenous u

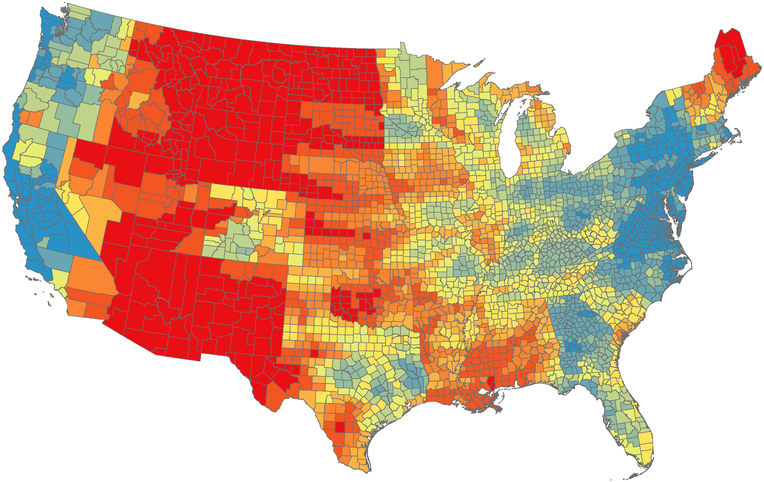
- $\beta = -0.3$



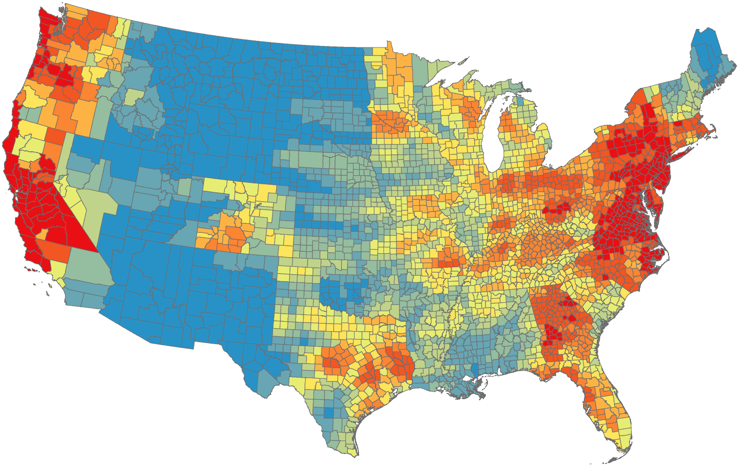
Estimated P



Removing the Interstate Highway System: P



Removing the Interstate Highway System: L



Removing the Interstate Highway System: Costs and Benefits

- Estimated annual cost of the IHS: $\approx$ \$100 billion
- Annualized cost of construction: $\approx$ \$30 billion (\$560 billion @5%/year) (CBO, 1982)
- Maintenance: $\approx$ \$70 billion (FHA, 2008)
- Estimated annual gain of the IHS: $\approx \$150 - 200$ billion
- Welfare gain of IHS: $1.1 - 1.4\%$.
- Given homothetic preferences and holding prices fixed, can multiply welfare gain by U.S. GDP.
- Suggests gains from IHS substantially greater than costs.

Conclusion

- Theoretical contributions
  - Unified GE framework combining gravity, labor mobility, flexible spillovers.
  - Microfoundation of trade costs as "geographic trade costs" .
  - Combine those two and develop appropriate tools to determine equilibrium economic activity on any surface with (nearly) any geography.
- Empirical contributions
  - Calculate bilateral trade costs based on observable geographical features and trade flows.
  - Disentangle productivities and amenities.
  - Quantify the importance of geographic location.
  - Perform counterfactual analysis based on changes in geography.

Caliendo, Parro, Sarte and R-H

- Fluctuations in aggregate economic activity are the result of a wide variety of disaggregated TFP changes
  - Sectoral: process or product innovations
  - Regional: natural disasters or changes in local regulations
  - Sectoral *and* regional: large corporate bankruptcy or bailout
- What are the mechanisms through which these changes affect the aggregate economy? What is their quantitative importance?
  - Input-output, trade and migration linkages
  - Differences in regional and sectoral TFP, local factors, and geography
- We model and calibrate these mechanisms for all 50 U.S. states and 26 traded and non-traded industries
- Aggregate real GDP elasticity to local productivity changes varies substantially:
  - 1.6 in NY, 1.3 in CA, but only 0.89 in FL and 0.34 in WI

Heterogeneity across U.S. states

- Differences in GDP and employment go beyond geographic size
  ▸ GDP by regions ▸ Regional employment
- GDP and Employment levels vary over time differentially across regions
  ▸ GDP change 2002 - 2007 ▸ Employment change 2002 - 2007
- Why?
  Local characteristics are essential to the answer
  - *Differences in TFP changes*
    Heterogeneity in changes in regional measured TFP
    ▸ Regional TFP ▸ Regional TFP contrib.
    Distribution of sectors across regions is far from uniform
    ▸ Petroleum ▸ Wood ▸ Concentration
    ... and changes in sectoral TFP varies widely across sectors
    ▸ Sectoral TFP ▸ Sectoral TFP contrib.
  - *Differences in local factors*
    ▸ Local Factors
  - *Differences in access to products from other regions*
    ▸ Regional Trade

Literature

- Literature has focused mainly on aggregate shocks as in Kydland and Prescott (1982) and the many papers that followed
  - When disaggregated, focus has been on sectors: Long and Plosser (1983), and Horvath (1998, 2000), Foerster, Sarte, and Watson (2012), Acemoglu, et al. (2012), Oberfield (2012)
    ... and sometimes firms: Jovanovic (1987), and Gabaix (2011)
  - Some papers have underscored labor mobility: Blanchard and Katz (1992), Fogli, Hill and Perri (2012), Hamilton and Owyang (2012)
- Recent literature on international trade uses static, multi-sector, multi-country quantitative models to assess the gains from trade
  - For example, Arkolakis, et al. (2012), Costinot, Donaldson, and Komunjer (2012), Caliendo and Parro (2012) and more
  - Paper relates to studies on internal trade and migration: Redding (2012), Allen and Arkolakis (2014), Fajgelbaum and Redding (2014)
- We adapt a multi-sector version of Eaton and Kortum (2002) to introduce labor mobility and local factors
  - Large scale quantitative exercise for 50 states and 26 industries

The Model

- The economy consists of N regions, J sectors, and two factors
  - Labor, L_n^j: mobile across regions and sectors
  - Land and structures, H_n: fixed across region but mobile across sectors
- The problem of an agent in region n is given by

$$v_n \equiv \max_{\left\{c_n^j\right\}_{j=1}^J} \prod_{j=1}^J \left(c_n^j\right)^{\alpha^j} \text{ with } \sum_{j=1}^J \alpha^j = 1$$

$$s.t. \sum_{j=1}^J P_n^j c_n^j = w_n + \frac{\sum_i \iota_i r_i H_i}{\sum_i L_i} + (1 - \iota_n) \frac{r_n H_n}{L_n} \equiv I_n.$$

- In equilibrium households are indifferent about living in any region so

$$v_n = \frac{I_n}{P_n} = U \text{ for all } n \in \{1, ..., N\}$$

where $P_n = \prod_{j=1}^J \left(P_n^j / \alpha^j\right)^{\alpha^j}$ is the ideal price index in region n

Model - Intermediate goods

- Representative firms in each region n and sector j produce a continuum of intermediate goods with *idiosyncratic* productivities z_n^j
  - Drawn independently across goods, sectors, and regions from a Fréchet distribution with shape parameter θ^j
  - Productivity of all firms is also determined by a deterministic productivity level T_n^j
- The production function of a variety with z_n^j and T_n^j is given by

$$q_n^j(z_n^j) = z_n^j \left[T_n^j h_n^j(z_n^j)^{\beta_n} l_n^j(z_n^j)^{(1-\beta_n)} \right]^{\gamma_n^j} \prod_{k=1}^{J} M_n^{jk}(z_n^j)^{\gamma_n^{jk}}$$

- Importantly, T_n^j affects value added and not gross output

Model - Intermediate good prices

- The cost of the input bundle needed to produce varieties in (n, j) is

$$x_n^j = B_n^j \left[r_n^{\beta_n} w_n^{1-\beta_n} \right]^{\gamma_n^j} \prod_{k=1}^{J} \left(P_n^k \right)^{\gamma_n^{jk}}$$

- The unit cost of a good of a variety with draw z_n^j in (n, j) is then given by

$$\frac{x_n^j}{z_n^j} \left(T_n^j \right)^{-\gamma_n^j}$$

and so its price under competition is given by

$$p_n^j \left(z^j \right) = \min_i \left\{ \frac{\kappa_{ni}^j x_i^j}{z_i^j} \left(T_i^j \right)^{-\gamma_i^j} \right\},$$

where $\kappa_{ni}^j \geq 1$ are "iceberg" bilateral trade cost

Model - Final goods

- The production of final goods is given by

$$Q_n^j = \left[\int \tilde{q}_n^j (z^j)^{1-1/\eta_n^j} \phi^j \left(z^j \right) dz^j \right]^{\eta_n^j / \left(\eta_n^j - 1 \right)},$$

  where $z^j = (z_1^j, z_2^j, ... z_N^j)$ denotes the vector of productivity draws for a given variety received by the different n regions

- The resulting price index in sector j and region n, given our distributional assumptions, is given by

$$P_n^j = \xi_n^j \left[\sum_{i=1}^{N} \left[x_i^j \kappa_{ni}^j \right]^{-\theta^j} \left(T_i^j \right)^{\theta^j \gamma_i^j} \right]^{-1/\theta^j},$$

  where ξ_n^j is a constant

Migration

- Labor market clearing

$$\sum_n \sum_{j=1}^{J} \int_0^{\infty} l_n^j(z) \phi_n^j(z)\, dz = \sum_n L_n = L$$

... plus firm optimization

$$w_n L_n = \frac{1-\beta_n}{\beta_n} r_n H_n$$

- Implies that

$$L_n = \frac{H_n \left[\frac{\omega_n}{P_n U}\right]^{1/\beta_n}}{\sum_{i=1}^{N} H_i \left[\frac{\omega_i}{P_i U}\right]^{1/\beta_i}} L$$

where $\omega_n \equiv (r_n/\beta_n)^{\beta_n} (w_n/(1-\beta_n))^{(1-\beta_n)}$

Regional trade

- Total expenditure on goods in industry j in region n

$$X_n^j = \sum_{k=1}^{J} \gamma_n^{kj} \sum_i \pi_{in}^k X_i^k + \alpha^j I_n L_n,$$

where π_{in}^k denote the share of region i's total expenditures on sector k's intermediate goods purchased from region n

- Then, as in Eaton and Kortum (2002),

$$\pi_{ni}^j = \frac{X_{ni}^j}{X_n^j} = \frac{\left[x_i^j \kappa_{ni}^j\right]^{-\theta^j} \left(T_i^j\right)^{\theta^j \gamma_i^j}}{\sum_{i'=1}^{N} \left[x_{i'}^j \kappa_{ni'}^j\right]^{-\theta^j} \left(T_{i'}^j\right)^{\theta^j \gamma_{i'}^j}}$$

- Trade surplus/deficit in n is given by $L_n \frac{\sum_i \iota_i r_i H_i}{\sum_i L_i} - \iota_n r_n H_n$

Changes in measured TFP

- Using firm optimization and aggregating over all produced intermediate goods, total gross output in (n, j) is given by

$$\frac{Y_n^j}{P_n^j} = \frac{x_n^j}{P_n^j} \left[\left(H_n^j \right)^{\beta_n} \left(L_n^j \right)^{(1-\beta_n)} \right]^{\gamma_n^j} \prod_{k=1}^{J} \left(M_n^{jk} \right)^{\gamma_n^{jk}}$$

  - $Y_n^j / P_n^j = Q_n^j$ when j is a non-tradable good

- So the change in measured TFP as a result of $\hat{T}_n^j$ is

$$\ln \hat{A}_n^j = \ln \frac{\widehat{x}_n^j}{\hat{P}_n^j} = \ln \frac{\left(\hat{T}_n^j \right)^{\gamma_n^j}}{\left(\hat{\pi}_{nn}^j \right)^{1/\theta^j}}$$

- Aggregate measured TFP changes using gross output revenue shares
  - Leads to aggregate TFP measures similar to those of the OECD

Changes in real GDP

- The Cobb-Douglas production function in intermediates implies that

$$\begin{aligned}\ln \widehat{GDP}_n^j &= \ln \frac{\hat{w}_n \hat{L}_n^j}{\hat{P}_n^j} \\ &= \ln \hat{A}_n^j + \ln \hat{L}_n^j + \ln \left(\frac{\hat{w}_n}{\widehat{x}_n^j} \right)\end{aligned}$$

  - In the case without materials, the last term is simply

$$\ln \left(\hat{w}_n / \widehat{x}_n^j \right) = \beta_n \ln \left(\hat{w}_n / \widehat{r}_n \right) = \beta_n \ln 1 / \hat{L}_n$$

    ... otherwise, a function of all final-good price changes

- We aggregate real GDP changes using value added shares

Changes in Welfare

- Welfare changes are given by

$$\ln \hat{U}_n = \sum_{j=1}^{J} \alpha^j \left(\ln \hat{A}_n^j + \ln \left(\varpi_n \frac{\hat{w}_n}{\hat{x}_n^j} + (1 - \varpi_n) \frac{\hat{\chi}}{\hat{x}_n^j} \right) \right),$$

where $\varpi_n = \frac{(1-\beta_n \iota_n) w_n}{(1-\beta_n \iota_n) w_n + (1-\beta_n)\chi}$

  - Note that if $\iota_n = 0$ for all n, then $\chi = 0$ and $\varpi_n = 1$. In that case

$$\ln \hat{U}_n = \sum_{j=1}^{J} \alpha^j \left(\ln \hat{A}_n^j + \ln \frac{\hat{w}_n}{\hat{x}_n^j} \right).$$

- ACR (2012) emphasize the case with one sector, no factor mobility, and no trade deficits where

$$\ln \hat{U}_n = \ln \hat{A}_n$$

Counterfactuals

- We need to calibrate and compute the model to assess the aggregate effect of regional shocks
  - We only compute the model in changes as a result of $\hat{T}_n^j$, parallel to Dekle, Eaton and Kortum (2008)
  - System of $2N + 3JN + JN^2 = 69000$ equations and unknowns
- Some issues:
  - We estimate ι_n to match 2007 regional trade imbalances, S_n
    - ★ Not exact since $\iota_n \in [0, 1]$ iota iota-map
    - ★ So use counterfactual without unexplained deficits
  - No international trade: CFS provides data of expenditures on domestically produced goods

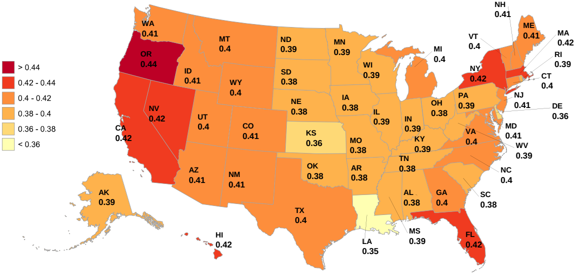
Data

- We need to find data for $I_n, L_n^j, S_n, \pi_{ni}^j$ as well as values for the parameters $\theta^j, \alpha^j, \beta_n, \iota_n, \gamma_n^{jk}$
  - L_n^j : BEA, with aggregate employment across all states summing to 137.3 million in 2007
  - I_n : Total value added in each state in 2007
  - π_{ni}^j and S_n : CFS with total trade equal to 5.2 trillion in 2007
  - θ^j : We use the numbers in Caliendo and Parro (2012)
  - α^j : Calculated as the aggregate share of consumption
  - β_n : Labor share by region adjusted by $\beta_n = (\bar{\beta}_n - .17)/.83$
    - ★ Share of equipment equal to .17 Greenwood, Hercowitz and Krusell (1997), which we group with materials
  - ι_n : From S_n using minimum least squares
  - γ_n^{jk} : Get γ_n^j from BEA value added shares and use national IO table to compute $\gamma_n^{jk} = (1 - \gamma_n^j)\gamma^{jk}$

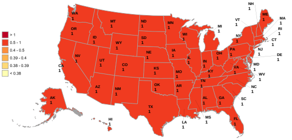
Aggregate and Local or Sectoral Elasticities

- We present all results using elasticities
  - All based on 10% changes ($\hat{T}_n^j = 1.1$)
    - ★ Matters due to non-linearities
  - Aggregate elasticities calculated by dividing by share of state/sector and the size of the shock
    - ★ So benchmark for aggregate TFP elasticity is 1 independent of the size of the state
  - Local/sectoral elasticities adjusted by the size of the shock only
    - ★ So benchmark for local TFP elasticity in the affected state/sector is 1 too

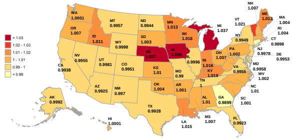
Aggregate TFP elasticity of a local productivity change



NRNS Model



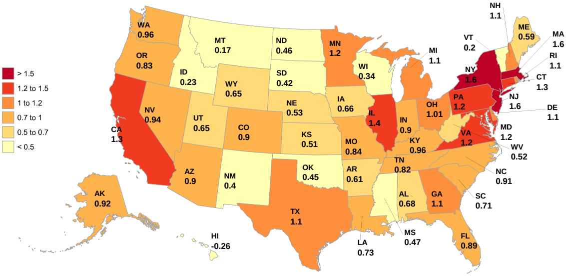
RNS Model



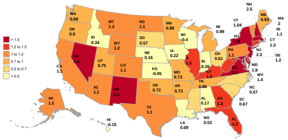
$$\ln \hat{A}_n^j = \ln \frac{\left(\hat{T}_n^j\right)^{\gamma_n^j}}{\left(\hat{\pi}_{nn}^j\right)^{1/\theta^j}}$$

Zoom

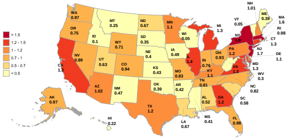
Aggregate GDP elasticity of a local productivity change



NRNS Model



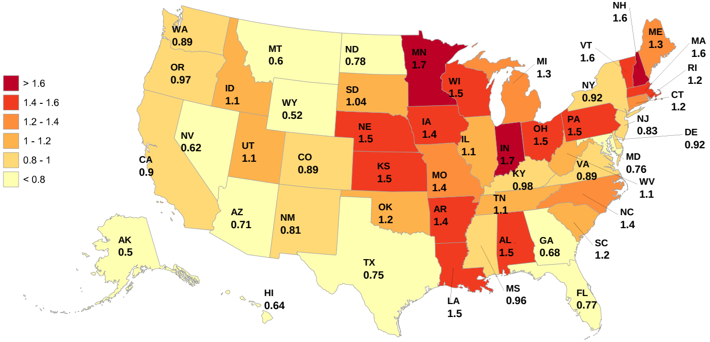
RNS Model



$$\ln \widehat{GDP}^j_n = \ln \hat{A}^j_n + \ln \hat{L}^j_n + \ln \left(\frac{\hat{w}_n}{\hat{x}^j_n} \right)$$

Local Factors | Zoom

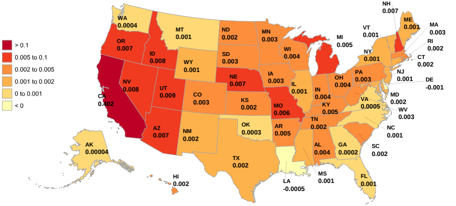
Welfare elasticity of a local productivity change



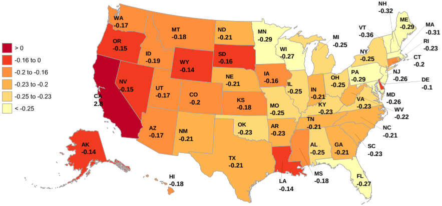
iota-map

Regional elasticity of a productivity change in California

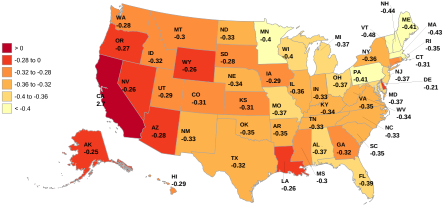
TFP elasticity



GDP elasticity

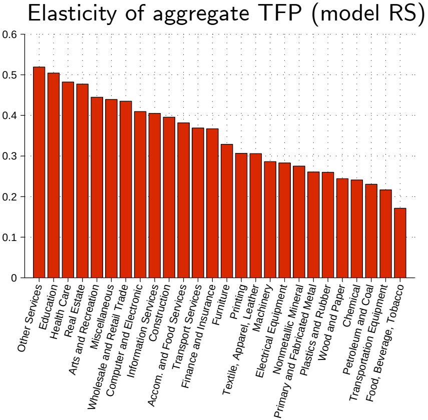


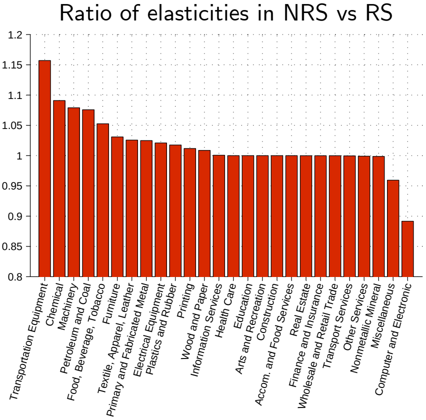
Employment elasticity



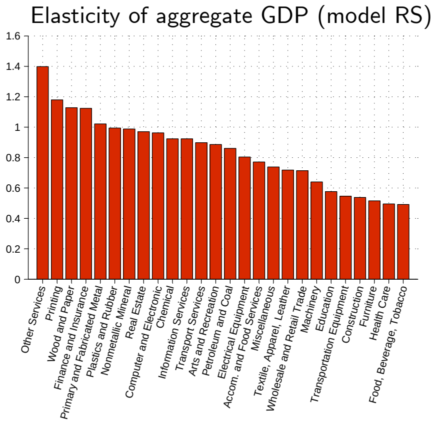
▸ Zoom ▸ Sectoral Comp.

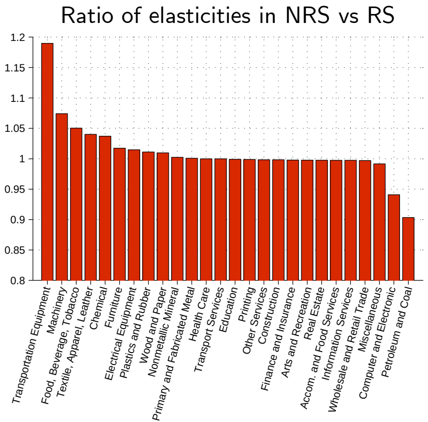
Aggregate TFP elasticities to a sectoral change



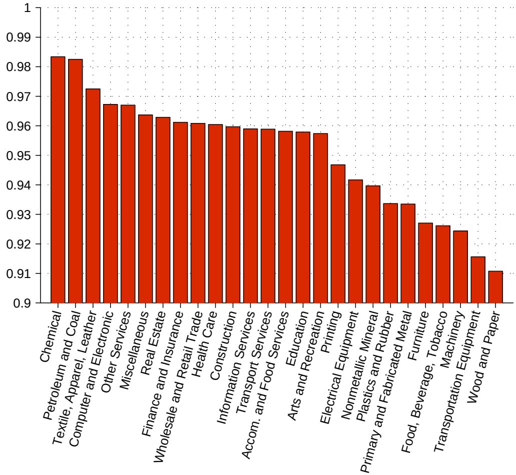


Aggregate GDP elasticities to a sectoral change





Welfare elasticity of a sectoral productivity change



▸ Concentration

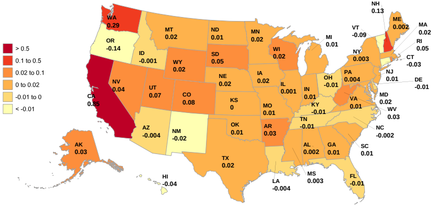
An Application

The Productivity Boom in Computers and Electronics in California

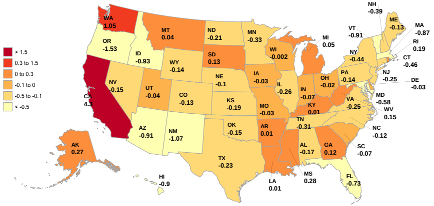
- California, home of prominent information and technology firms
  - Apple, Cisco Systems, Hewlett-Packard, Intel and others
- In 2007, California accounted for 24% of all employment in Computers and Electronics
  - Texas 8%, Massachusetts 6%, other states (37) less than 2%
- From 2002-2007 California experienced a productivity boom in Computers and Electronics
  - An average of 31% annual fundamental TFP increase in that sector, which corresponds to a 14.6% yearly increase in measured TFP
  - The largest across all states and regions in the U.S. during that period
- We evaluate how productivity boom in that sector and state propagated to all other sectors and states of the U.S. economy

Productivity Boom in Comp. & Elec. in California

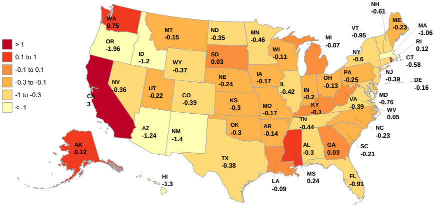
Regional TFP effects (percent)



Regional GDP effects (percent)



Regional Employment effects (percent)



Trade costs

- The exercises above suggest that trade is important in determining the effect of productivity changes
  - But how important are regional trade barriers?
  - What portion of trade barriers is explained by physical distance?
    - ★ Compute average miles per shipment for each region from CFS (996 for Indiana but 4154 for Hawaii)
  - What are the gains (TFP, GDP, welfare) from reducing distance versus other trade barriers?
- Following Head and Ries (2001) we can compute

$$\frac{\pi_{ni}^{j}\pi_{in}^{j}}{\pi_{ii}^{j}\pi_{nn}^{j}} = \left(\kappa_{ni}^{j}\kappa_{in}^{j}\right)^{-\theta^{j}}$$

- So given θ^{j}, and assuming symmetry, we can identify κ_{ni}^{j}

Counterfactuals

- Decompose trade barrier using

$$\log \kappa_{ni}^{j} = \delta^{j} \log d_{ni}^{j} / d_{ni}^{j\,\min} + \eta_{n} + \varepsilon_{ni}^{j}$$

- Then calculate counterfactuals:

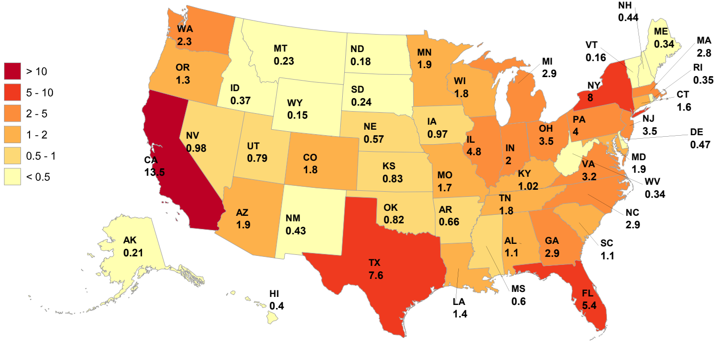
Effects of a reduction in trade cost across U.S. states		
	Distance	Other barriers
Aggregate TFP gains	50.98%	3.62%
Aggregate GDP gains	125.88%	10.54%
Aggregate Welfare gains	58.83%	10.10%

Conclusions

- Study the effects of disaggregated productivity changes in a model that recognizes explicitly the role of geographical factors
  - Calibrate for 50 U.S. states and 26 sectors
  - Ready to implement in other countries or regions
- Disaggregated productivity changes can have dramatically different aggregate quantitative implications
  - Elasticity of regional change on welfare varies from 1.7 in MN to 0.75 in TX and 0.5 in AK
  - Elasticity of sectoral productivity increases also varies from .98 in Chemicals to .92 in Transportation Equipment
    - ⋆ And very heterogenous regional impact
- For future work:
  - Mobility frictions
  - Local factor accumulation

Economic activity in the U.S.

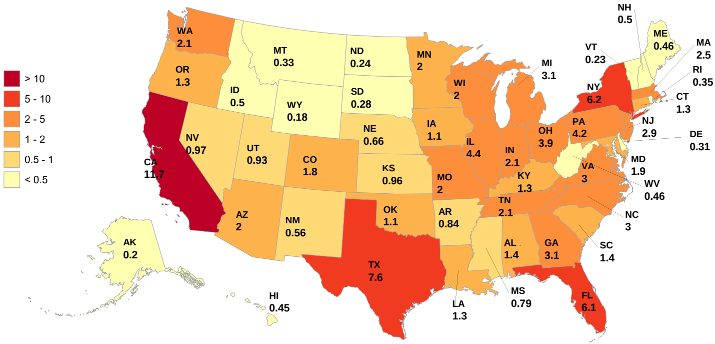
Share of GDP by region (%, 2007)



Back

Economic activity in the U.S.

Share of Employment by region (%, 2007)



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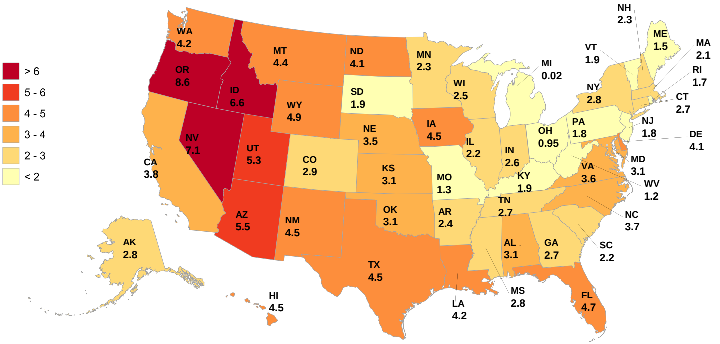
Economic activity in the U.S.

Change in GDP (%, 2002 to 2007)



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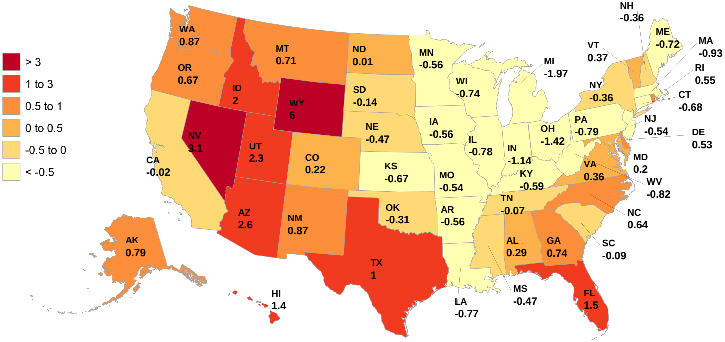
Economic activity in the U.S.

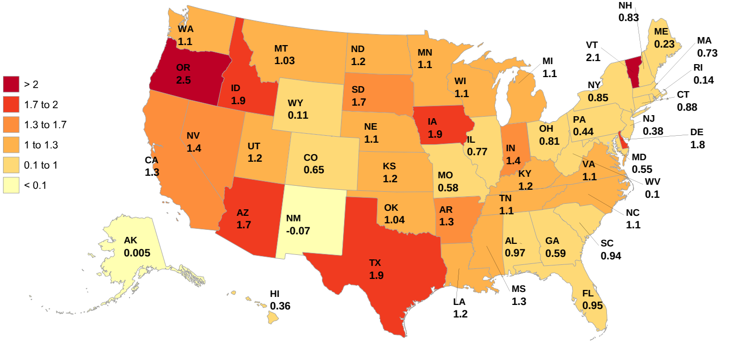
Change in Employment (%, 2002 to 2007)



▸ Back

Change in measured TFP by region

Annualized rate (2002-2007, %)



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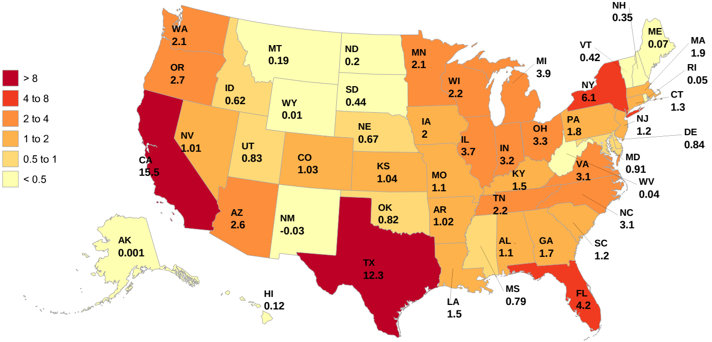
Regional contribution

Regional contribution to the change in aggregate measured TFP (%)



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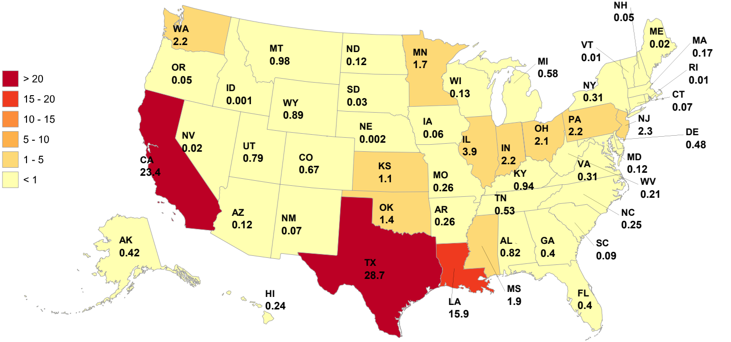
Economic activity in the U.S.

Petroleum and Coal concentration across regions (%, 2007)



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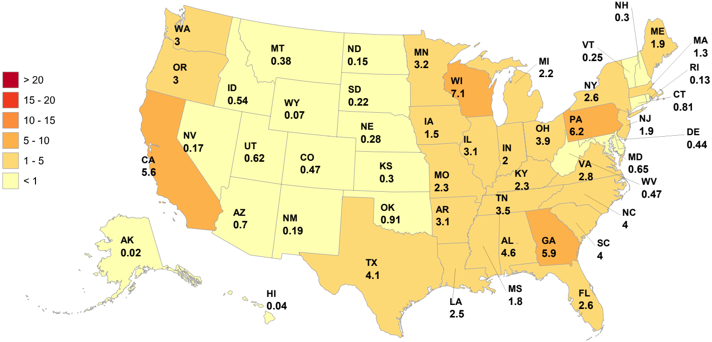
Economic activity in the U.S.

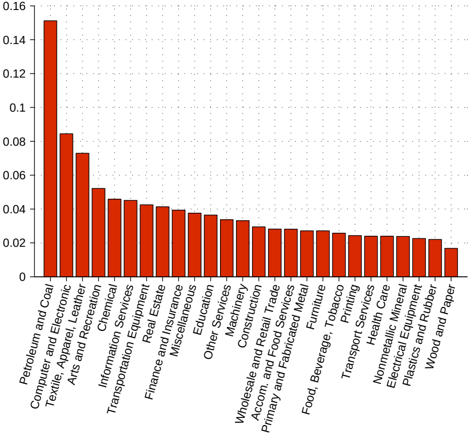
Wood and Paper concentration across regions (%, 2007)



▸ Back Intro

Regional concentration of economic activity across sectors

Herfindahl Index, 2007



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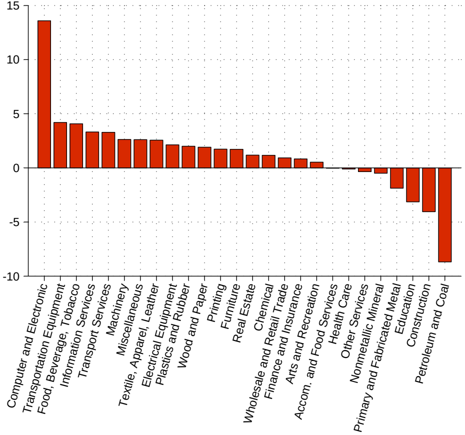
Change in sectoral measured TFP

Annualized rate (2002-2007, %)



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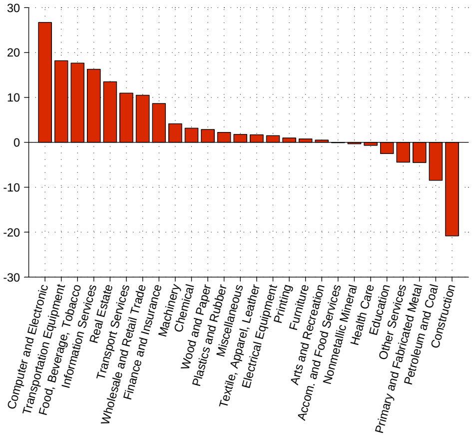
Sectoral contribution

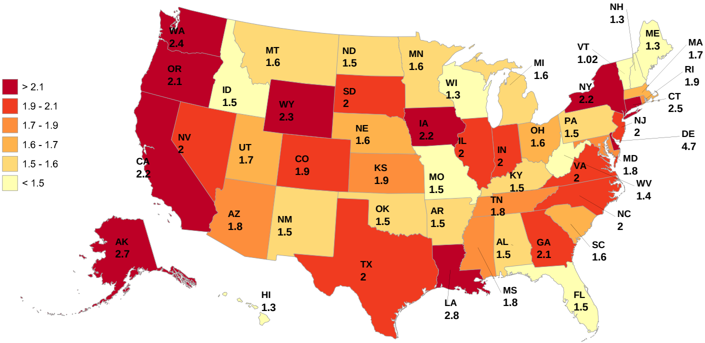
Sectoral contribution to the change in aggregate measured TFP (%)



Back Intro

Per capita returns from local factors

- Depicts $\frac{r_n H_n}{L_n}$ calculated using $GDP_n = w_n L_n + r_n H_n$



Back Intro | Counterfactuals GDP

Regional Trade

- Regional trade much more important than international trade

U.S. trade as a share of GDP (%, 2007)			
	Exports	Imports	Total
International trade	11.9	17.0	28.9
Inter-regional trade	33.4	33.4	66.8

Source: World Development indicators and CFS

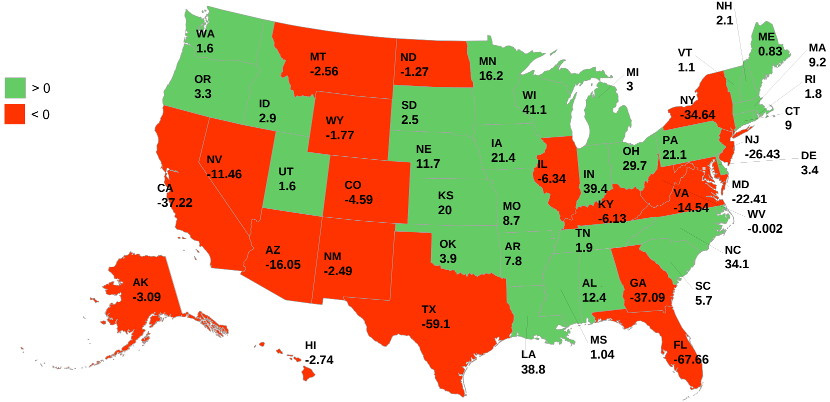
▸ Regional trade

- Still, calibrated trade costs are such that eliminating distance increases GDP by 125% and measured TFP by 50%
  - So geography of production determines prices and trade flows

▸ Back

Economic activity by regions

Net exports (exports - imports) across U.S. states (2007, U.S. dollars, billions)



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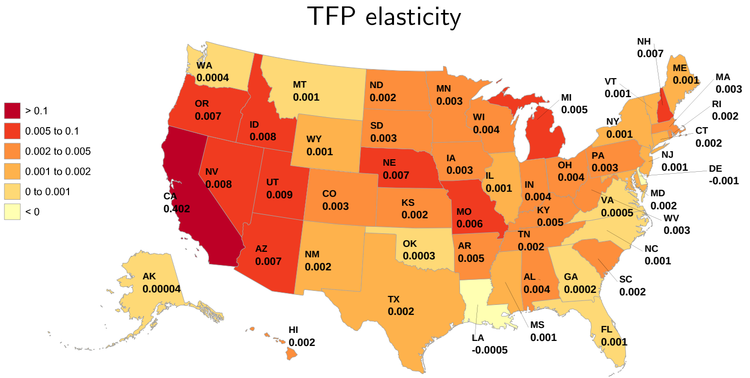
Regional elasticity of a productivity change in California



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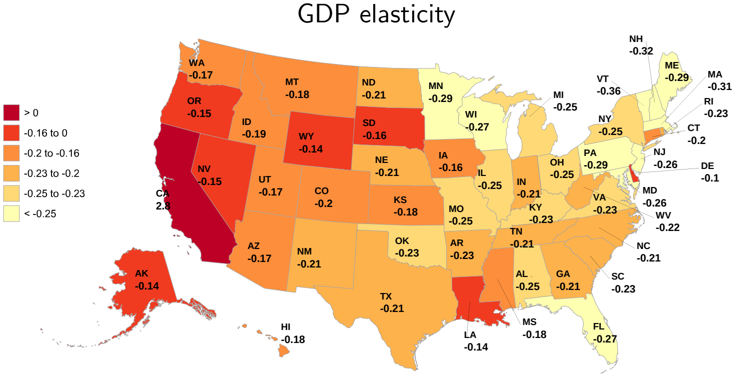
Regional elasticity of a productivity change in California



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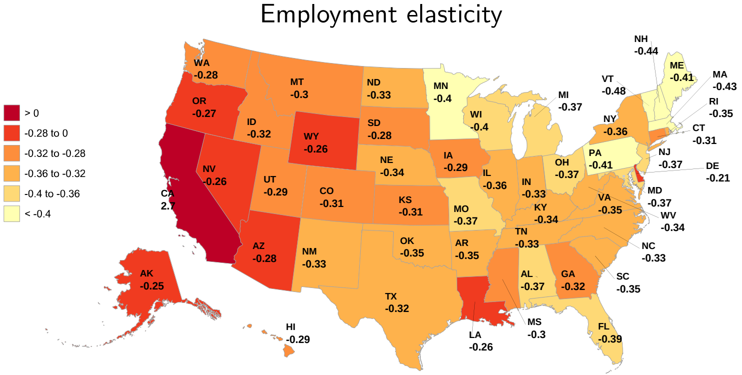
Regional elasticity of a productivity change in California



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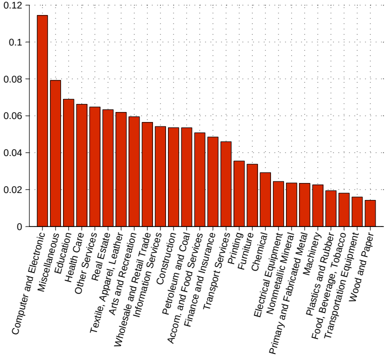
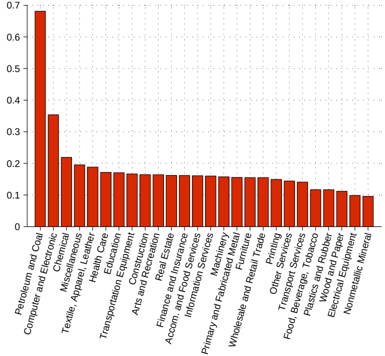
Sectoral elasticity of a productivity change in California

Elasticity of aggregate TFP



Elasticity of aggregate GDP



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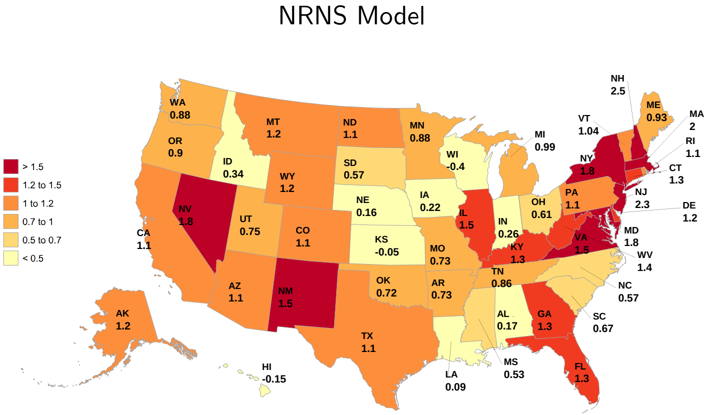
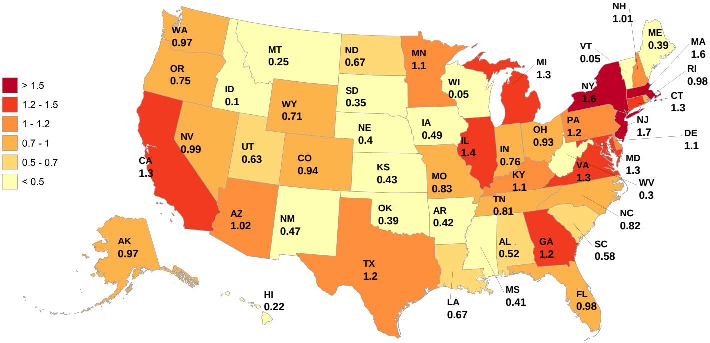
Aggregate elasticity of a local change: Real GDP



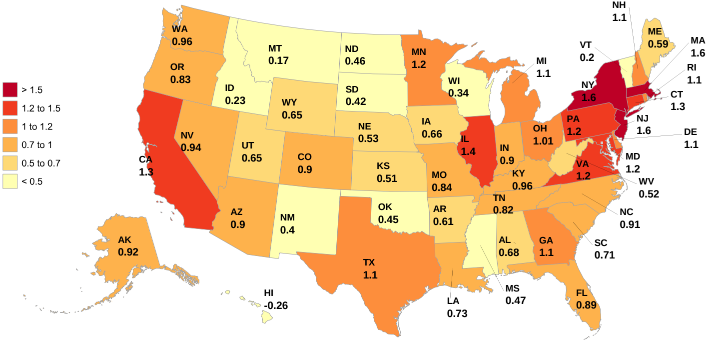
Aggregate elasticity of a local change: Real GDP

RNS Model



Aggregate elasticity of a local change: Real GDP

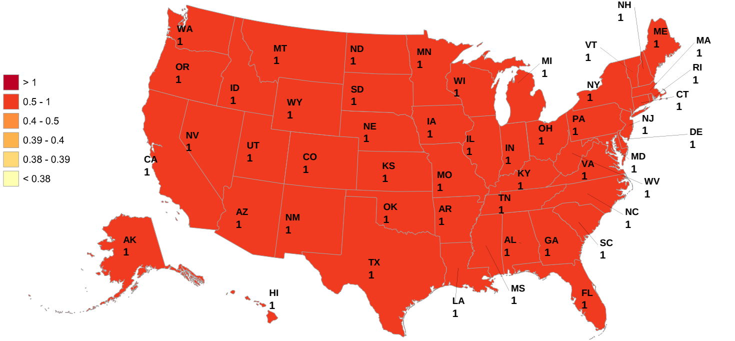
RS Model



Counterfactuals GDP

Aggregate elasticity of a local change: TFP

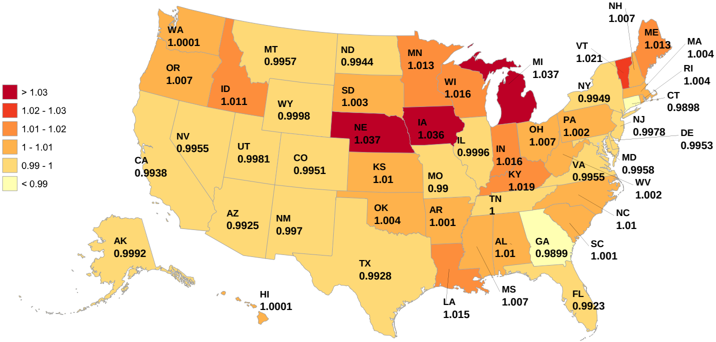
Model with no inter-regional trade and no inter-sectoral trade, NRNS
Then $\ln \hat{A}_n^j = \ln \hat{T}_n^j$



Aggregate elasticity of a local change: TFP

Model with inter-regional trade and no inter-sectoral trade, RNS

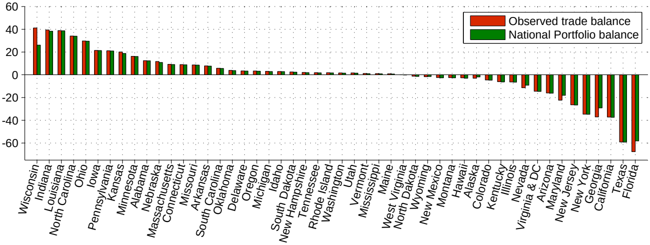
Then $\ln \hat{A}_n^j = \dfrac{\hat{T}_n^j}{\left(\hat{\pi}_{nn}^j\right)^{1/\theta^j}}$



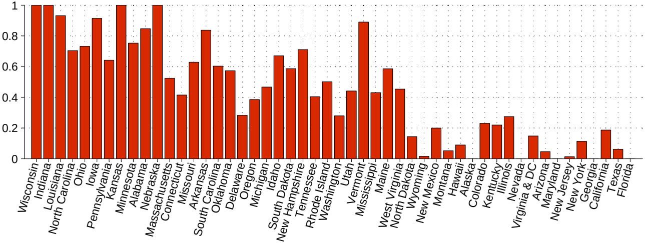
Back

Trade balances and contributions to the National Portfolio

Trade Balance: Model and data (2007 U.S. dollars, billions)



Local rents on structures contributed to the National Portfolio (ι_n)



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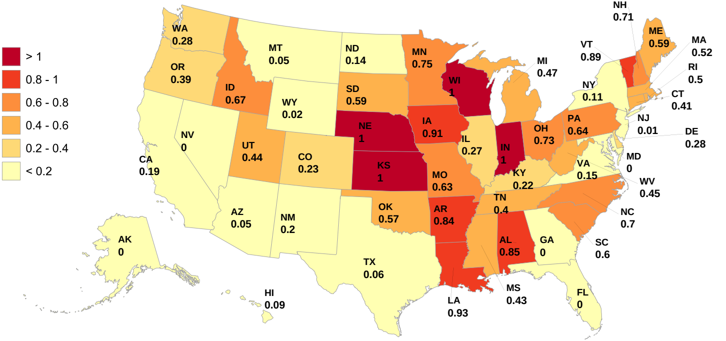
Contributions to the National Portfolio

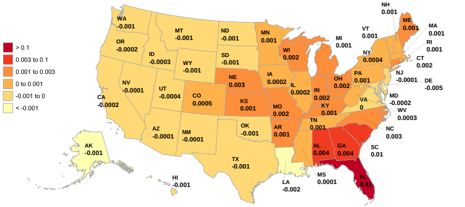
Local rents on structures contributed to the National Portfolio (ι_n)



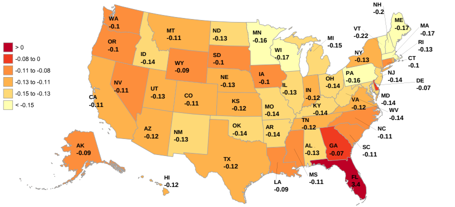
Back   Back to Welfare

Regional elasticity of a productivity change in Florida

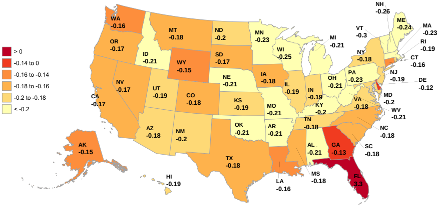
TFP elasticity



GDP elasticity



Employment elasticity



The Geography of Development, Desmet, Nagy and R-H

- Where a person lives determines his productivity, income and well-being
- But a person's location is neither a permanent characteristic nor a free choice
  - How do migratory restrictions shape the economy of the future?
  - How do they interact and affect the spatial distribution of productivity and amenities?
- We need a theory of development that explicitly takes into account
  - The geography of economic activity
  - The mobility restrictions and transport costs associated with it
- Theory can also be used to analyze specific spatial shocks.
  - Here: a 6-meter rise in the sea level (also 1-meter)

A Theory of the Geography of Development

- Each location is unique in terms of its
  - Amenities
  - Productivity
- Each location has firms that
  - Produce a variety of goods
  - Innovate
  - Trade subject to transport costs
- Static part of model
  - Allen and Arkolakis (2013) and Eaton and Kortum (2002)
  - Allow for migration restrictions
- Dynamic part of model
  - Desmet and Rossi-Hansberg (2014)
  - Land competition and technological diffusion

Bringing the Theory to the Data

- Discretize the world into 1° by 1° cells
- Use data on land, population, wages and trade costs to derive the spatial distribution of amenities relative to utility
- Literature has identified amenities in **static** models under **free mobility**
  - Using prices (Roback, 1982)
  - Using quantities (Behrens et al., Desmet and Rossi-Hansberg, 2013)
- This raises two issues
  - In a dynamic model parameters may change with development
  - Real world does not have free mobility

Changing Relation between Population Density and Income

- Correlation between population density and income today is -0.4
- Model predicts that this correlation should increase with income
  - Dynamic agglomeration economies greater in high-productivity places
  - Mobility
- Consistent with evidence from U.S. zip codes

Correlation between Population Density and Per Capita Income (logs)*

Year	$<$ 25th	25-50th	50th-75th	$>$75th	$<$ Median	$\geq$ Median
2000	-0.1001***	0.0495***	0.1499***	0.2248***	-0.0609***	0.3589***
2007-2011	-0.0930***	0.0175	0.0733***	0.2420***	-0.0781***	0.3234***

*Percentiles based on per capita income

- Also holds across zip codes within CBSAs

Mobility and Subjective Well-Being

- Model only identifies ratio of amenities to utility
  - Under free mobility Congo would have very attractive amenities
  - Once we take into account lower utility of Congo, this is no longer true
- We need additional data on utility: subjective well-being
- Subjective well-being
  - Evaluative measure of well-being on Cantril ladder
  - Correlates well with log of income (Kahneman and Deaton, 2010)
  - Use relationship in the data and in the model to transform subjective well-being into utility measure of model
  - Allows us to recover actual levels of amenities

Endowments and Preferences

- Economy occupies a two-dimensional surface S
  - Location is point $r \in S$
  - S is partitioned into C countries
- $\bar{L}$ agents each supplying one unit of labor
- An agent's period utility

$$u_t(r) = a_t(r)\left[\int_0^1 c_t^\omega(r)^\rho \, d\omega\right]^{\frac{1}{\rho}}$$

  where amenities take the form

$$a_t(r) = \overline{a}(r)\,\overline{L}_t(r)^{-\lambda}$$

- Agents earn income from work and from local ownership of land
- Migration restrictions modeled as keeping relative utilities across countries constant

Technology

- Production per unit of land of a firm producing good $\omega \in [0,1]$

$$q_t^{\omega}(r) = \phi_t^{\omega}(r)^{\gamma_1} z_t^{\omega}(r) L_t^{\omega}(r)^{\mu}$$

- $\phi_t^{\omega}(r)$ is an innovation requiring $\nu \phi_t^{\omega}(r)^{\xi}$ units of labor
- If $\gamma_1 < 1$, there are decreasing returns to local innovation
- $z_t^{\omega}(r)$ is the realization of a r.v. drawn from a Fréchet distribution

$$F(z,r) = e^{-T_t(r) z^{-\theta}}$$

where $T_t(r) = \tau_t(r) \bar{L}_t(r)^{\alpha}$ and

$$\tau_t(r) = \phi_{t-1}(r)^{\theta\gamma_1} \left[\int_S \eta_{t-1}(r,s) \tau_{t-1}(s)\, ds \right]^{1-\gamma_2} \tau_{t-1}(r)^{\gamma_2}$$

- If $\gamma_2 < 1$, we get global diffusion of technology

Productivity Draws and Competition

- Firms face perfect local competition and innovate
  - Productivity draws are i.i.d. across time and goods, but correlated across space (with perfect correlation as distance goes to zero)
  - Firm profits are linear in land, so for any small interval there is a continuum of firms that compete in prices
  - Firms bid for land up to point of making zero profits after covering investment in technology
- Dynamic profit maximization simplifies to sequence of static problems
  - Next period all potential entrants have access to same technology (Desmet and Rossi-Hansberg, 2014a)

$$\max_{L_t^\omega(r),\phi_t^\omega(r)} p_t^\omega(r,r)\,\phi_t^\omega(r)^{\gamma_1}\,z_t^\omega(r)\,L_t^\omega(r)^\mu - w_t(r)\,L_t^\omega(r) - w_t(r)\,\nu\phi_t^\omega(r)^\xi - R_t(r)$$

- **Lemma 1: In any $r \in S$, $L_t^\omega(r)$ and $\phi_t^\omega(r)$ are identical across goods ω**

Prices, Export Shares and Trade Balance

- Price of good produced at r and sold at r

$$p_t^{\omega}(r,r) = mc_t(r)/z_t^{\omega}(r)$$

  - From the point of view of the individual firm the input cost is given
  - Productivity draws affect prices without changing the input cost

- Probability that good produced in r is bought in s

$$\pi_t(s,r) = \frac{T_t(r)\left[mc_t(r)\varsigma(r,s)\right]^{-\theta}}{\int_S T_t(u)\left[mc_t(u)\varsigma(u,s)\right]^{-\theta} du} \text{ all } r,s \in S$$

- Trade balance location by location

$$w_t(r)H(r)\overline{L}_t(r) = \int_S \pi_t(s,r)w_t(s)H(s)\overline{L}_t(s)\,ds \text{ all } r \in S$$

Equilibrium: Definition, Existence and Uniqueness

- Standard definition of dynamic competitive equilibrium
- Equilibrium implies

$$\left[\frac{\bar{a}(r)}{\bar{u}(c)}\right]^{-\frac{\theta(1+\theta)}{1+2\theta}} \tau_t(r)^{-\frac{\theta}{1+2\theta}} H(r)^{\frac{\theta}{1+2\theta}} \bar{L}_t(r)^{\lambda\theta-\frac{\theta}{1+2\theta}\chi}$$

$$= \quad \left[\bar{u}_t^W\right]^{-\theta} \kappa_1 \sum_{d=1}^{C} \int_{S_d} \left[\frac{\bar{a}(s)}{\bar{u}(d)}\right]^{\frac{\theta^2}{1+2\theta}} \tau_t(s)^{\frac{1+\theta}{1+2\theta}} H(s)^{\frac{\theta}{1+2\theta}} \varsigma(r,s)^{-\theta} \bar{L}_t(s)^{1-\lambda\theta+\frac{1+\theta}{1+2\theta}\chi} ds$$

where $\chi = \left[\alpha - 1 + \left[\lambda + \frac{\gamma_1}{\xi} - [1-\mu]\right]\theta\right]$

- **Lemma 3: An equilibrium exists and is unique if**

$$\frac{\alpha}{\theta} + \frac{\gamma_1}{\xi} \leq \lambda + 1 - \mu$$

  - Lemma 7 show that iterative procedure converges to unique equilibrium

Balanced Growth Path

- In a balanced growth path (BGP) the spatial distribution of employment is constant and all locations grow at the same rate
- **Lemma 4: There exists a unique BGP if**

$$\frac{\alpha}{\theta}+\frac{\gamma_1}{\xi}+\frac{\gamma_1}{\left[1-\gamma_2\right]\xi}\leq\lambda+1-\mu$$

  - This condition is stronger than the condition for uniqueness and existence of the equilibrium

- In a BGP aggregate welfare and real consumption grow according to

$$\frac{\bar{u}^W_{t+1}}{\bar{u}^W_t}=\left[\frac{\int_0^1 c^{\omega}_{t+1}\left(r\right)^{\rho}d\omega}{\int_0^1 c^{\omega}_{t}\left(r\right)^{\rho}d\omega}\right]^{\frac{1}{\rho}}=\eta^{\frac{1-\gamma_2}{\theta}}\left[\frac{\gamma_1/\nu}{\gamma_1+\mu\xi}\right]^{\frac{\gamma_1}{\xi}}\left[\int_S\overline{L}\left(s\right)^{\frac{\theta\gamma_1}{\left[1-\gamma_2\right]\xi}}ds\right]^{\frac{1-\gamma_2}{\theta}}$$

  - Growth depends on population size and its distribution in space

Calibration: Summary

1. Preferences	
$\rho = 0.75$	Elasticity of substitution of 4 (Bernard et al., 2003)
$\lambda = 0.32$	Relation between amenities and population
$\psi = 1.8$	Deaton and Stone (2013), data on migration and subjective well-being
2. Technology	
$\alpha = 0.06$	Elasticity of productivity to density (Ciccone and Hall, 1996)
$\theta = 6.5$	Trade elasticity (Simonovska and Waugh, 2014)
$\mu = 0.8$	Labor or non-land share in production (Greenwood et al., 1997; Desmet and Rappaport, 2014)
$\gamma_1 = 0.319$	Relation between population distribution and growth
3. Evolution of productivity	
$\gamma_2 = 0.993$	Relation between population distribution and growth
$\xi = 125$	Desmet and Rossi-Hansberg (2014a)
$\nu = 0.2$	Initial world growth rate of real GDP of 2%
4. Trade Costs	
	Allen and Arkolakis (2014)

Calibration: Amenity and Technology Parameters

- Amenity parameter λ:

$$\log(a(r)) = E(\log(\bar{a}(r))) - \lambda \log \overline{L}(r) + \varepsilon(r)$$

  - Estimate using data on amenities and population for 192 U.S. MSAs
  - Instrument for $\bar{L}$ using productivity

- Technology parameters γ_1 and γ_2
  - Use cell level population data from G-Econ to estimate BGP relation

$$\log y_{t+1}(c) - \log y_t(c) = \alpha_1 + \alpha_2 \log \sum_{S_c} L_c(s)^{\alpha_3}$$

    where α_1, α_2 and α_3 are functions of γ_1 and γ_2
  - BGP relation is used as simplification
  - Technology parameters are consistent with 2% average growth rate in real GDP per capita today

Calibration: Trade Costs

- Similar to Allen and Arkolakis (2014)
- Discretize the world into 1° by 1° cells (64800 in total)
- To ship a good from location r to s, follow a continuous and once-differentiable path $g(r,s)$ that connects the two locations
- Cost of passing through location r is

$$\begin{aligned}\log\sigma(r) &= \beta_{rail}rail(r)+\beta_{no\_rail}\left[1-rail(r)\right]+\beta_{major\_road}major\_road(r)+\ldots \\ &\quad +\beta_{water}water(r)+\beta_{no\_water}\left[1-water(r)\right]\end{aligned}$$

- Use Fast Marching Algorithm to compute the minimum between r and s over all possible paths $g(r,s)$

$$\log\varsigma(r,s)=\inf_{g(r,s)}\int_{g(r,s)}\log\sigma(u)\,du$$

Simulation: Amenities and Productivity

- Use data on land, population and wages from G-Econ 4.0 to derive spatial distribution of $\overline{a}(r) / \overline{u}(c)$ and $\tau_0(r)$ by inverting the model
- Lemma 6 shows that this inversion yields a unique set of $\overline{a}(r) / \overline{u}(c)$ and $\tau_0(r)$
- Issue: does not separately identify $\overline{a}(r)$ and $\overline{u}(c)$
  - Not a problem if mobility restrictions kept unchanged
  - But if we change mobility restrictions, levels of $\overline{u}(c)$ change
  - Also important if we want estimate of $\overline{a}(r)$
    - ⋆ Otherwise Congo would be one of the most desirable places to live

Subjective Well-Being

- Data on subjective well-being from the Gallup World Poll
  - Cantril ladder from 0 to 10 ▸ Map subjective well-being
  - 0 is worst possible life and 10 is best possible life
  - Evidence shows linear relation between subjective well-being and the log of real income, within and across countries (Deaton and Stone, 2013)
- In model $u_i(r) = a(r) y_i(r)$, so transform subjective well-being into utility measure that is linear in the level of income
- Existing estimates of relation between subjective well-being and income
  - Deaton and Stone (2013) estimate $\tilde{u}_i(r) = \frac{1}{\psi} \ln y_i(r) + v(r) + \varepsilon_i$
  - Hence, relation between utility in model and subjective well-being is

$$u_i(r) = e^{\psi \tilde{u}_i(r)}$$

  - Deaton and Stone (2013) find $\psi = 1.8$
- Alternative methodology uses data on actual and desired migration

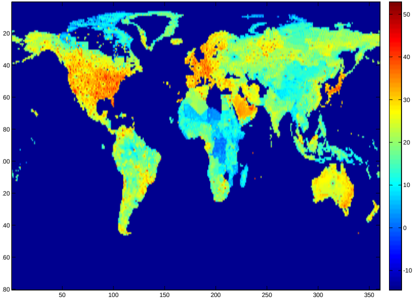
Counterfactual Migration

- Amenities then identified by $\overline{a}(r) = e^{1.8\tilde{u}(c)} \frac{\overline{a}(r)}{\overline{u}(c)}$
- Once we have values for $\bar{a}(r)$, simulate model forward using ratio of amenities to utility of

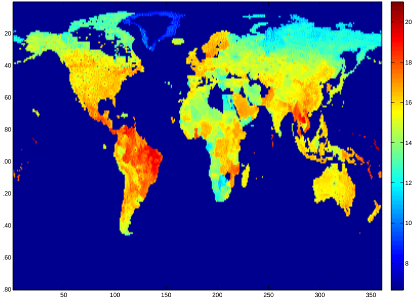
$$e^{\psi \tilde{u}(c)} \frac{\overline{a}(r)}{\overline{u}(c)} \quad \text{where } \psi \in [0, 1.8]$$

- Counterfactual migration scenarios
  - Keeping mobility restrictions unchanged ($\psi = 0$)
    - Keep values $\overline{a}(r) / \overline{u}(c)$ from the original inversion constant over time
  - Free mobility ($\psi = 1.8$)
    - Reshuffle population so that utility equalizes across space
    - Simulate model forward using the values $e^{1.8\tilde{u}(c)} \overline{a}(r) / \overline{u}(c)$
  - Partial mobility (ψ in between 0 and 1.8)
    - Keeps ranking of migration restrictions unchanged

Benchmark Calibration: Results from Inversion



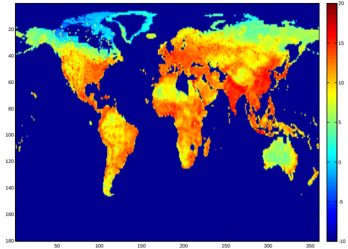
a. Fundamental Productivities: $\tau_0\left(r\right)$



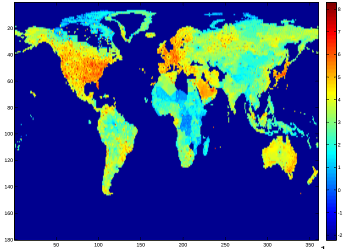
b. Fundamental Amenities: $\overline{a}\left(r\right)$

▸ Correlation amenities

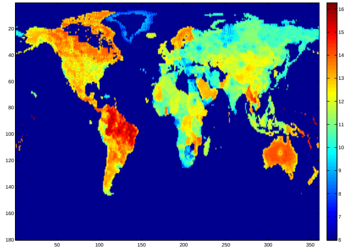
Benchmark Calibration: Period 1



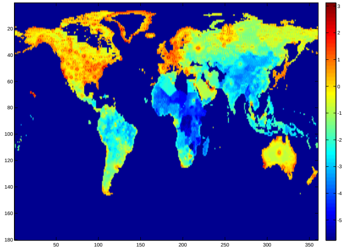
a. Population Density



b. Productivity: $\left[\tau_t(r)\,\overline{L}_t(r)^{\alpha}\right]^{\frac{1}{\theta}}$

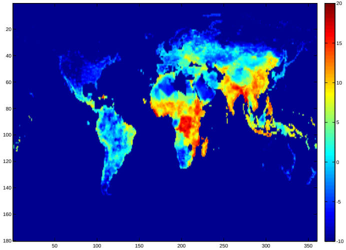


c. Amenities: $\overline{a}(r)\,\overline{L}_t(r)^{-\lambda}$

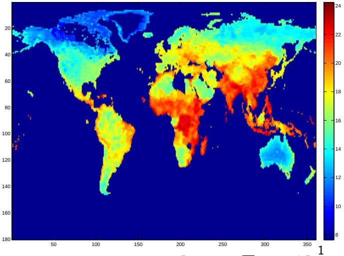


d. Real Income per Capita

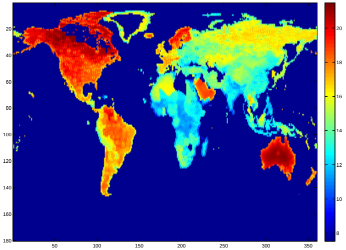
Keeping Migratory Restrictions Unchanged: Period 600



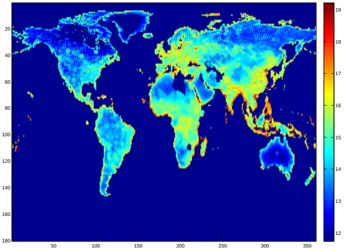
a. Population Density



b. Productivity: $\left[\tau_t(r)\,\overline{L}_t(r)^{\alpha}\right]^{\frac{1}{\theta}}$



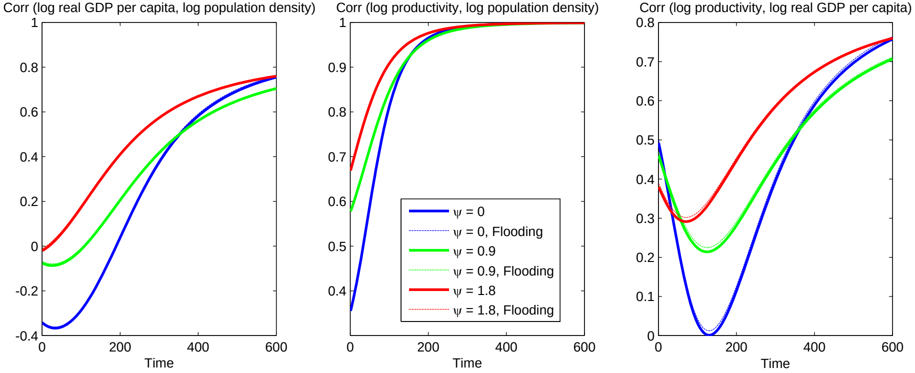
c. Amenities: $\overline{a}(r)\,\overline{L}_t(r)^{-\lambda}$



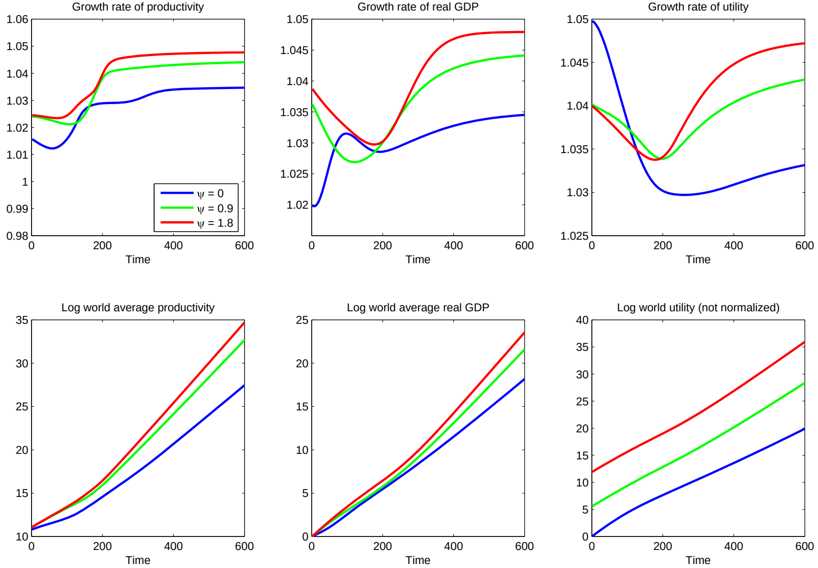
d. Real Income per Capita

Evolution of Population over Time

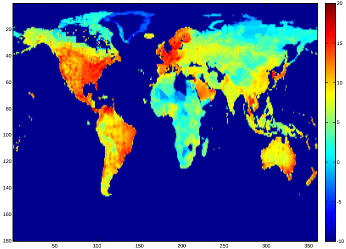
Correlations under Different Scenarios



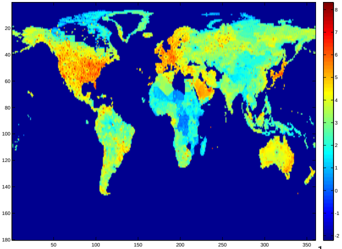
Growth Rates and Levels under Different Scenarios



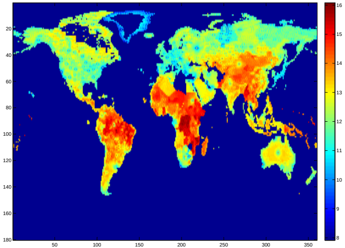
Free Mobility: Period 1



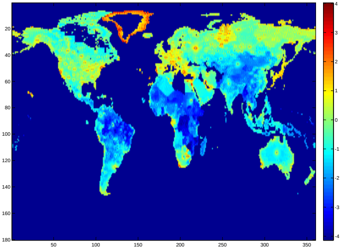
a. Population Density



b. Productivity: $\left[\tau_t\left(r\right)\overline{L}_t\left(r\right)^{\alpha}\right]^{\frac{1}{\theta}}$

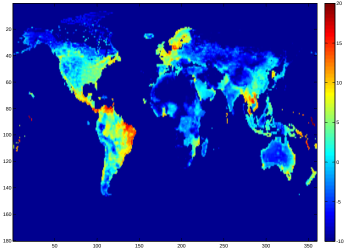


c. Amenities: $\overline{a}\left(r\right)\overline{L}_t\left(r\right)^{-\lambda}$

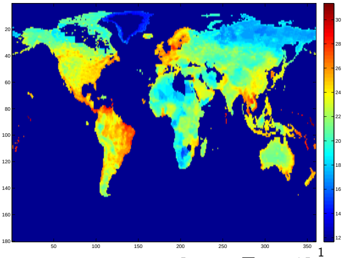


d. Real Income per Capita

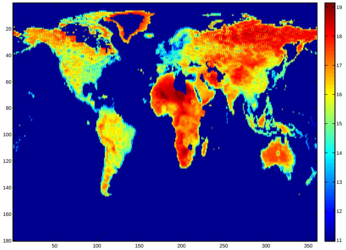
Free Mobility: Period 600



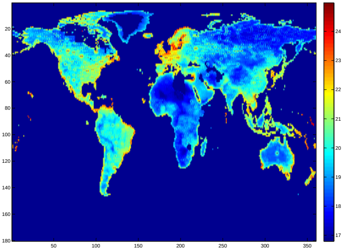
a. Population Density



b. Productivity: $\left[\tau_t(r)\,\overline{L}_t(r)^{\alpha}\right]^{\frac{1}{\theta}}$



c. Amenities: $\overline{a}(r)\,\overline{L}_t(r)^{-\lambda}$



d. Real Income per Capita

Evolution of Population over Time

Welfare and Migratory Restrictions

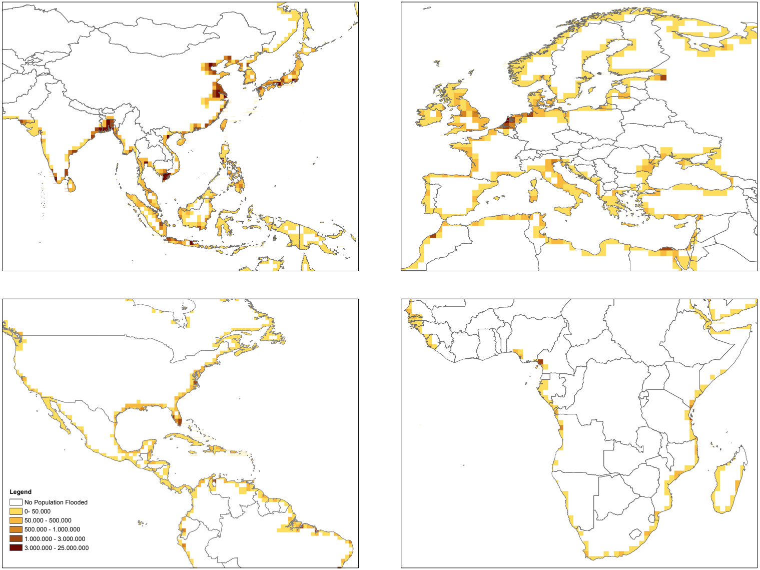
Mobility	Discounted Real Income*	Discounted Utility**	Migration Flows***
ψ	$\%\Delta$ w.r.t. $\psi = 0$	$\%\Delta$ w.r.t. $\psi = 0$	
0.0[a]	0%	0%	0.74%
0.3	3.5%	71%	24.5%
0.5	13.9%	131%	42.0%
0.9	39.8%	244%	65.0%
1.3	56.2%	298%	73.9%
1.8[b]	68.6%	312%	78.2%

We use $\beta = 0.95$. a: Observed Restrictions. b: Free Mobility. *: Normalized by world average for $t = 1$. **: Population-weighted average of cells' utility levels. ***: Share of world population moving to countries that grow between period 0 and 1 (immediately after the change in ψ).

Rise in Sea Levels

- The rise in sea level is a major consequence of global warming
  - Thermal expansion of the oceans
  - Melting of glaciers and depletion of ice sheets in Greenland and Antarctica
  - Next millennium expected rise by 7 meters
    - Likely increase by 0.5 to 1 meter by 2100 (IPCC)
- Disproportionate part of the world's population lives in coastal areas
- Existing literature
  - Accounting exercises based on current data (Dasgupta et al., 2007)
  - Studies accounting for changing conditions (Nicholls, 2004)
    - Lack of detail: all regions in a country behave in the same way
    - No analysis of how the world reacts to flooding
- Here: static and dynamic analysis of rise in sea level by 6 meters

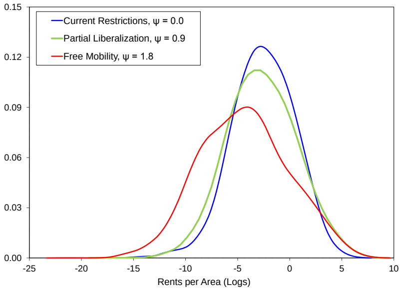
Population Flooded based on Today's Population



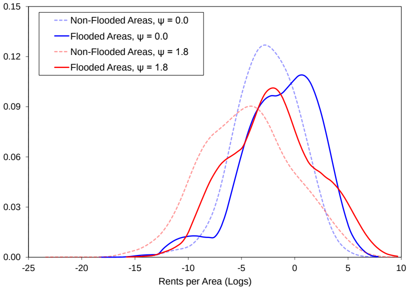
Static Effect of Flooding Depending on Date

	Period 1	Period 100	Period 500
A. Keeping mobility restrictions unchanged			
Percentage land flooded	1.0	1.0	1.0
Percentage population flooded	6.6	7.5	5.7
Percentage land rents lost	6.3	8.0	6.2
Percentage technology lost (land weighted)	2.4	2.5	2.6
Percentage technology lost (population weighted)	9.5	10.5	5.7
Percentage amenities lost (land weighted)	2.2	1.6	0.8
Percentage amenities lost (population weighted)	8.8	9.6	9.6
B. Free mobility			
Percentage land flooded	1.0	1.0	1.0
Percentage population flooded	11.2	14.9	81.4
Percentage land rents lost	8.4	13.7	89.1
Percentage technology lost (land weighted)	2.4	3.0	6.0
Percentage technology lost (population weighted)	11.6	19.4	97.4
Percentage amenities lost (land weighted)	1.2	0.9	0.5
Percentage amenities lost (population weighted)	11.9	18.0	80.9

Land Rent Distributions



a. Different Mobility Scenarios



b. Flooded vs. Non-Flooded Areas

Dynamic Effects of Flooding

Mobility ψ	Discounted Present Value of Real Income* Ratio (NF/F)	Welfare** Ratio (NF/F)
0.0^a	1.037	1.082
0.3	1.028	1.079
0.5	1.021	1.075
0.9	1.016	1.072
1.3	1.024	1.076
1.8^b	1.037	1.078

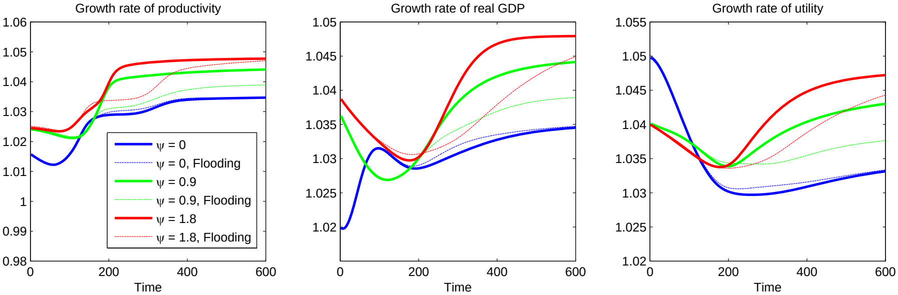
We use $\beta = 0.95$. a: Observed Restrictions. b: Free Mobility.
*: Normalized by world average GDP without flooding for $t = 1$.
**: Population-weighted average of cells' utility levels.

Sea level rise by 1 meter

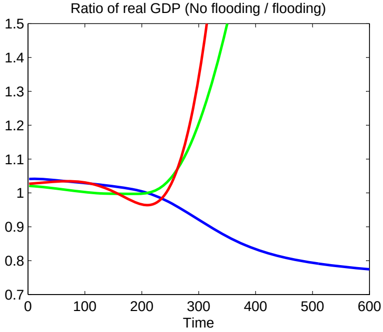
Dynamic Effects of Flooding

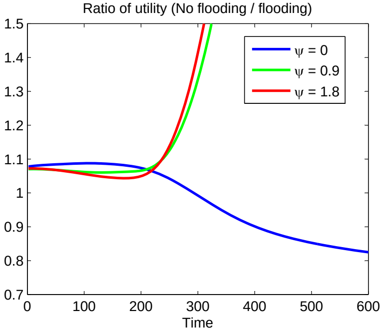
- Flooding reduces real income by 1.6% – 3.7%
- It reduces welfare by 7.2% – 8.2%
  - Loss in amenities due to flooding are large
- In PDV mobility has little effect on the welfare impact of flooding
  - We would expect mobility to mitigate negative effects (Desmet and Rossi-Hansberg, 2014b)
    - Mobility moves more people to coastal areas
    - People move to places that are individually, not socially, beneficial
    - Local migration argument does not work with more complex geography
  - Flooding affects the dynamic path significantly

Growth Rates under Different Scenarios



Dynamics of No Flooding vs Flooding



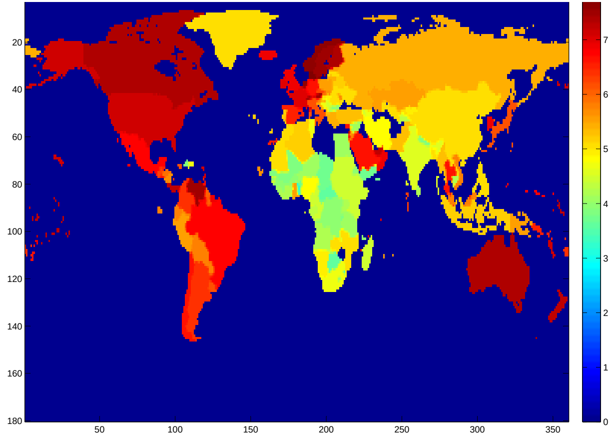


Conclusion

- Interaction between geography and economic development through trade, technology diffusion and migration
- Connect to real geography of the world at fine detail
- Relaxing migration restrictions can lead to very large welfare gains
- Level of migration restrictions will have important effect on which regions of the world will be the productivity leaders of the future
  - Correlation between density and productivity increases over time
- Coastal flooding will have important welfare effects
  - Mobility has little effect on the welfare effect of flooding

Map Subjective Well-Being

Subjective Well-being from the Gallup World Poll (Max = 10, Min = 0)



▸ Return

Correlation Amenities

	Correlations with Estimated Amenities (logs)				
	(1) All cells	(2) U.S.	(3) One cell per country	(4) Placebo of (1)	(5) Placebo of (3)
A. Water					
Water < 50 km	0.2198***	0.1286***	0.1232**	0.1064***	-0.1363**
B. Elevation					
Level	-0.4152***	-0.1493***	-0.2816***	-0.2793***	0.1283**
Standard deviation	-0.4599***	-0.2573***	-0.3099***	-0.3285***	0.1121*
C. Precipation					
Average	0.4176***	0.08643***	0.3851***	0.3185***	0.1830***
Maximum	0.4408***	0.1068***	0.3128***	0.4286***	0.3200***
Minimum	0.2035***	0.2136***	0.2108***	-0.0096	-0.1965**
Standard deviation	0.4160***	0.0212	0.2746***	0.4715***	0.4535***
D. Temperature					
Average	0.6241***	0.6928***	0.3087***	0.6914***	0.5692***
Maximum	0.5447***	0.7388***	0.1276***	0.6589***	0.4635***
Minimum	0.6128***	0.6060***	0.2931***	0.6565***	0.5389***
Standard deviation	-0.5587***	-0.3112***	-0.3313***	-0.5539***	-0.3679***
E. Vegetation					
Desert, ice or tundra	-0.3201***	-0.3993***	-0.1827***	-0.2440***	-0.1291*

- Correlations using all cells, U.S. cells, or one cell per country are similar (see (1), (2) and (3))
  - Also consistent with Albouy et al. (2014) and Morris & Ortalo-Magné (2007)
- Placebo correlations under free mobility are not (see (2), (4) and (5))

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Rise in Sea Level by 1 Meter

- We consider rise in sea levels that flood 0.4% of land
- On-impact flooding of population for sea level rise today
  - 1 meter: 1.6% (with restrictions) and 5.5% (free mobility)
  - 6 meters: 6.6% (with restrictions) and 11.2% (free mobility)
- Effects are smaller, but less than proportionally so

Dynamic Effects of Rise in Sea Level by 1 Meter

Mobility ψ	Discounted Present Value of Real Income* Ratio (NF/F)	Welfare** Ratio (NF/F)
0.0[a]	1.011	1.036
0.3	1.011	1.040
0.5	1.010	1.041
0.9	1.008	1.041
1.3	1.012	1.039
1.8[b]	1.014	1.034

We use $\beta = 0.95$. a: Observed Restrictions. b: Free Mobility.
*: Normalized by world average GDP without flooding for $t = 1$.
**: Population-weighted average of cells' utility levels.

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