2020 Lectures on Urban Economics

Lecture 8: Dynamics in Spatial Economics

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Dynamics in Spatial Economics

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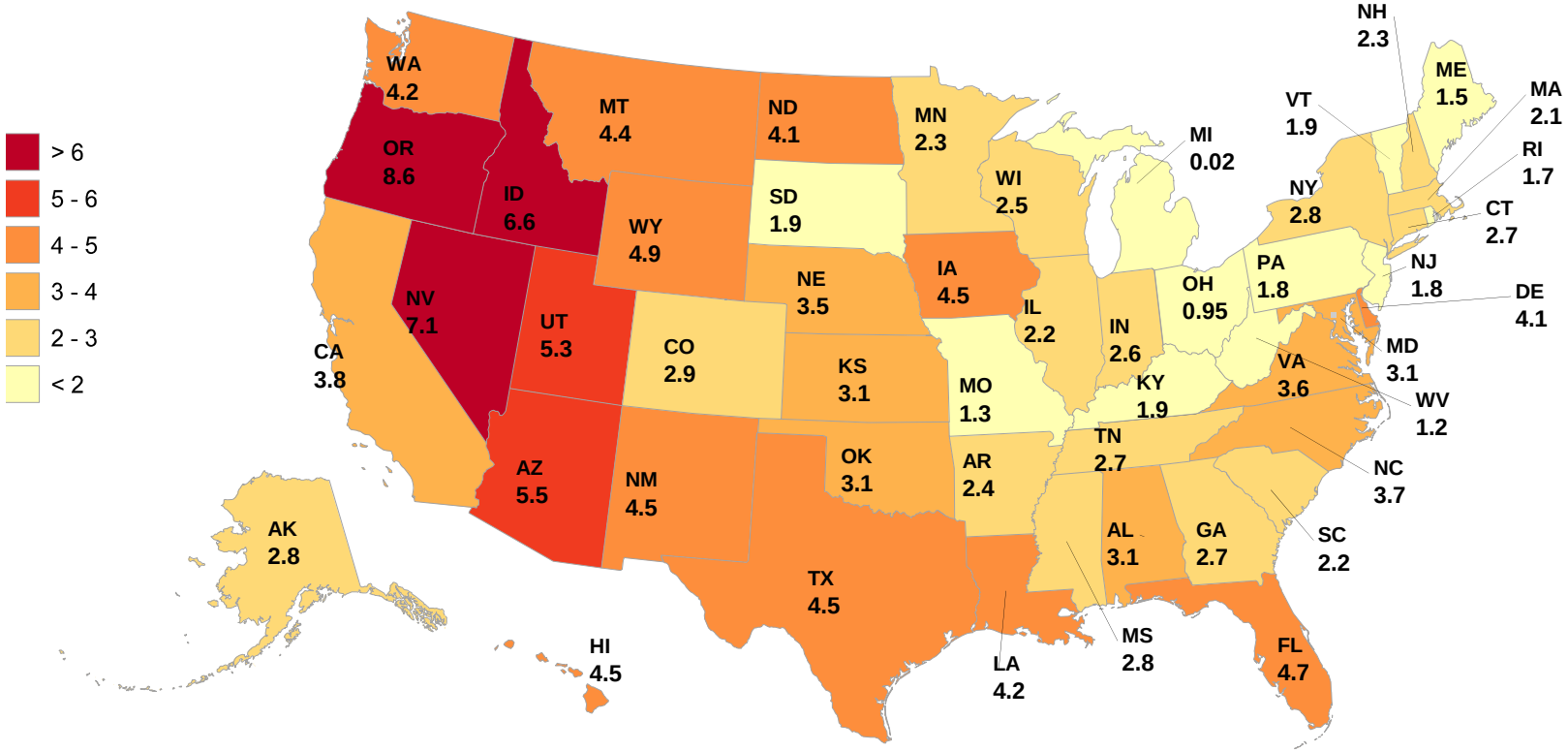
Introduction

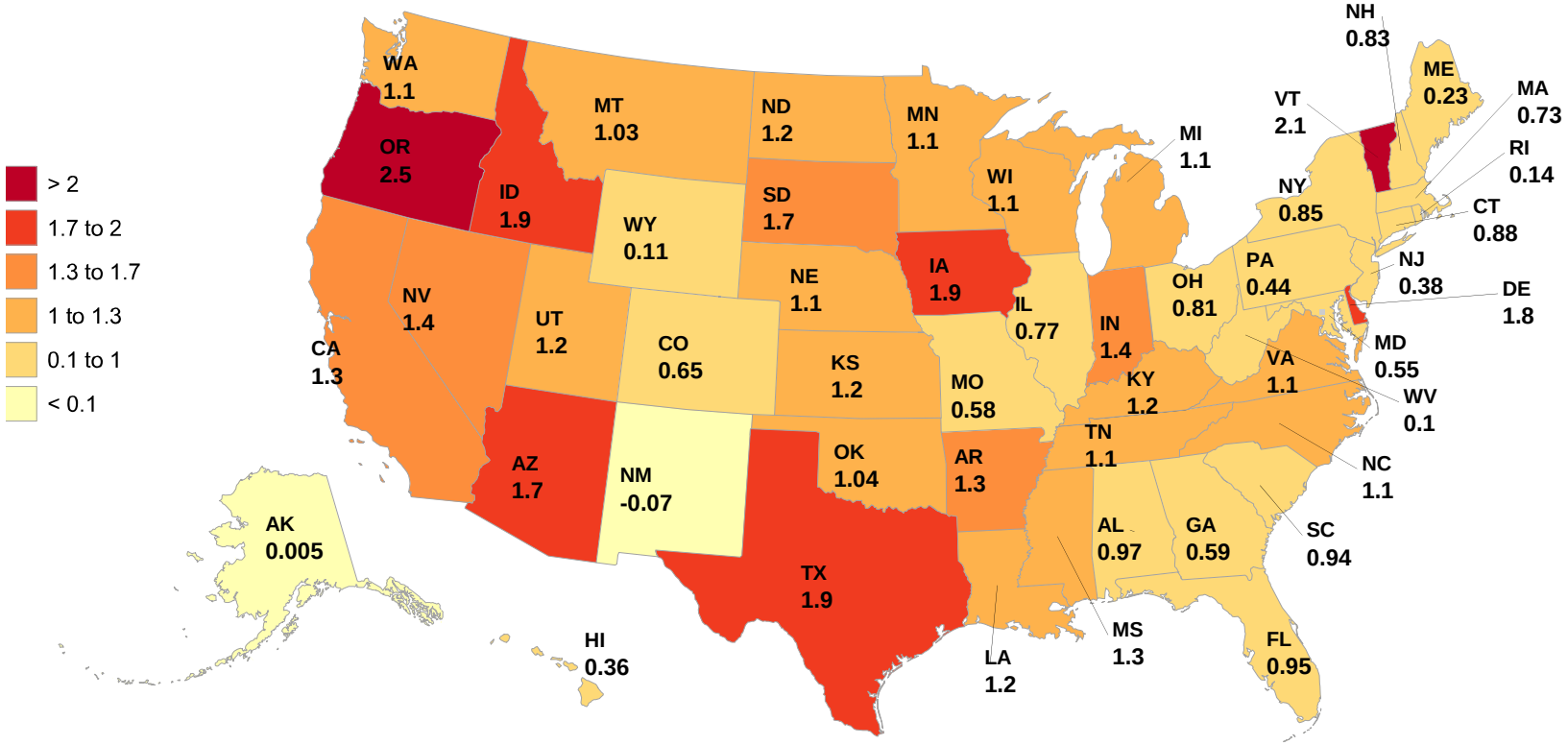
- Growth of GDP per capita varies substantially across space
- Due to:
  - Local shocks
  - Differences in innovation across space
  - Factor mobility and adjustment costs
  - Institutional differences and changes in institutions
- Variation in growth rates is large even within countries or regions
- Is the distribution of economic activity important for aggregate growth?
  - What is the the role of agglomeration for growth
  - What are the growth consequences of **spatial frictions**
- How do local growth differences affect the distribution of economic activity?
  - What are the implications for spatial segregation and inequality?

Annualized GDP Growth, 2002 - 2007



Source: Caliendo, et al. (2018)

Annualized TFP Growth, 2002 - 2007



Source: Caliendo, et al. (2018)

Cities and Growth

- Cities and regional agglomerations are the result of **scale economies**
  - Elasticity of output to reproducible factors is greater than one
- But aggregate increasing returns are inconsistent with **balanced growth**
  - As shown in Jones (1999)
  - One of the most reliable economic facts in advanced economies
- How can we reconcile this apparent tension? **Congestion!**
  - Balance of agglomeration and congestion forces leads to linear aggregate production function
    - See Proposition 2 in Rossi-Hansberg and Wright (2007)
  - Expansion through concentration and the use of more land, more cities
  - Local differences are reflected in resulting local productivity and size
- So urban economics and growth are inevitably intertwined (Lucas, 1988)

Space and Growth

- Spatial frictions: frictions to move goods, factors, or ideas/information across space
  - Trade, commuting, migration or diffusion costs
- Spatial shocks: shocks to local characteristics
  - Prominent examples include transport infrastructure or **climate change**
- Studying the effect of spatial friction/shocks requires **geographically ordered space**
  - Lacking in models of systems of cities and growth (e.g. Black and Henderson, 1999)
- Do spatial frictions/shocks affect dynamics, or just levels?
  - Dynamics in the presence of **factor adjustment costs** or **investments**
    - ⋆ Adjustment costs: Leads to short term factor mobility dynamics
    - ⋆ Investments: Leads to long term growth effects

A Hard Problem

- Spatial dynamics involves **inter-temporal decisions across locations**
  - Forward-looking agents predict the implications of their decisions in the future
  - Future economy is affected by the aggregation of these actions
  - Evaluation of individual action depends on the future economy
- Agents need to predict the future, not only in their location but everywhere
  - In many macro problems, only aggregate future characteristics matter
  - Here, all locations matter, since agents care more about some than others
    - For example, with spatial frictions, they care about close-by locations
- Quah (2002), Boucekkine et al. (2009) and Brock and Xepapadeas (2008) analyze this general problem **without mobility**
  - Even then, they can only analyze particular cases or guess certain equilibrium configurations
  - Spatial structure is simplified: linear space

A Simplification

Factor location does not affect the future

- Forward-looking agents but they do not affect future fundamentals
  - No firm capital or innovation investments
  - Agents consume what they earn, so no consumption-savings decision
  - Use renewal actions to solve dynamic discrete choice problem
  - ... then solve equilibrium problem given agent's location choices
- Features **anticipatory effects**, namely, agents react to future exogenous (changes in) fundamentals
- Great to analyze labor mobility frictions and short term effects of spatial frictions/shocks
  - Arty and McLaren (2010): Trade and labor dynamics
  - Caliendo, et al. (2019): Local dynamic effects of the China shock
  - Balboni (2019): Cost of flooding conditional on infrastructure investments
- Not suited to study effects on investments or consumption/savings decision

An Alternative Simplification

Make decisions effectively static

- Eliminate the need to predict the future by making decisions of firms and agents static in practice
  - Agents can be myopic or future economy does not enter in their problems
  - Can lead to rich dynamics, but no anticipatory effects
- Desmet and Rossi-Hansberg (2014) proposes a linear framework where:
  - Firms make endogenous innovations but **zero future profits** since
  - ... future rents are extracted by land owners in a **competitive land market**
  - Agents are freely mobile and consume what they earn
- Desmet et al. (2018) adds realistic geography and mobility costs (**Today!**)
  - Keep worker's problem static since **mobility costs are reversible**
  - Desmet et al. (2020) uses it to study long term effects of coastal flooding
  - Nagy (2020) to study long term impact of railroads and Deventhal (2018) the declines in trade costs

What is Still Missing?

- We still lack a framework with investments, growth, and anticipatory effects
- Also important is that agents in these models are **hand-to-mouth agents**
  - There is no consumption-savings decision and no wealth accumulation
  - Also no role for financial frictions
- Bilal and Rossi-Hansberg (2020) introduces **consumption-savings decisions and credit constraints** in spatial equilibrium
  - **Location becomes an asset**: can be used to transfer income across periods
  - Framework includes mobility, but not costly trade
  - ... and therefore no role for ordered space or geography
- Other recent additions to dynamic, but not growth, frameworks are:
  - Local employment and labor market frictions as in Bilal (2020)
  - Local firm entry and firm dynamics as in Walsh (2019)
  - Information frictions as in Porcher (2019)
  - Sorting and endogenous amenities as in Almagro (2020)
- Combining all these elements outlines an exciting research agenda

The Geography of Development

Desmet, Nagy, and Rossi-Hansberg, 2018, *Journal of Political Economy*

- Each location is unique in terms of its
  - Amenities
  - Productivity
  - Geography
- Each location has firms that
  - Produce and trade subject to transport costs
  - Innovate
- 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**

Population Density and Income in G-Econ

- Model predicts that the **correlation between population density and income per capita should increase with development**
  - Dynamic agglomeration economies greater in attractive places
    - ⋆ Attractive due to amenities, productivity, or geography
  - Mobility to those locations increase market size and, therefore, innovation
- Appears consistent with
  - Cross-section of $1^\circ \times 1^\circ$ cells for the whole world
  - Evidence from U.S. zip codes

Population Density and Income

Correlation between population density and real income per capita

- Across all cells of the world: -0.38
- Weighted average across cells within countries: 0.10
- Across richest and poorest cells of the world
  - 50% poorest cells: -0.02
  - 50% richest cells: 0.10
- Weighted average across richest and poorest cells within countries
  - 50% poorest cells: 0.14
  - 50% richest cells: 0.23
- Across cells of different regions
  - Africa: -0.04
  - Asia: 0.06
  - Latin America and Caribbean: 0.14
  - Europe: 0.15 (Western Europe: 0.20)
  - North America: 0.28
  - Australia and New Zealand: 0.48 (Oceania: -0.08)

Population Density and Income

- 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

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

$$u_t^i\left(\bar{r}_-, r\right) = a_t\left(r\right)\left[\int_0^1 c_t^\omega\left(r\right)^\rho d\omega\right]^{\frac{1}{\rho}} \varepsilon_t^i\left(r\right)\prod_{s=1}^{t} m\left(r_{s-1}, r_s\right)^{-1}$$

  - $\varepsilon_t^i\left(r\right)$ is a location preference shock that is iid Fréchet (Ω)
  - $m\left(r_{s-1}, r_s\right)$ is the cost of moving from r_{s-1} to r_s
  - amenities take the form

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

- Agents earn income from work and from local ownership of land

Mobility Decision

- **Assumption 1:** $m(r,s) = m_1(r)\, m_2(s)$ and $m(r,r) = 1$ for all $r, s \in S$
- Then an agent's value function can be written as

$$V\left(r_0, \bar{\varepsilon}_1^i\right) = \frac{1}{m_1(r_0)}\left[\max_{r_1} \frac{u_1(r_1)}{m_2(r_1)} \varepsilon_1^i(r_1) + \beta \mathbf{E}\left(\max_{r_2}\left[\frac{u_2(r_2)}{m_2(r_2)} \varepsilon_2^i(r_2) + V\left(r_2, \bar{\varepsilon}_3^i\right)\right]\right)\right]$$

where

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

- Hence, current location only influences current utility and not future decisions
- **Location endowment effect:** Welfare affected by origin location

Spatial Equilibrium

- An agent's expected period-t utility including taste shocks is then given by

$$\mathbf{E}\left[u_t\left(r\right)\varepsilon_t^i\left(r\right)\right] = \Gamma\left(1-\Omega\right)m_2\left(r\right)\left[\int_S u_t\left(s\right)^{1/\Omega} m_2\left(s\right)^{-1/\Omega} ds\right]^{\Omega}$$

- The fraction of agents choosing to be at r in period t is

$$\frac{H\left(r\right)\overline{L}_t\left(r\right)}{\overline{L}} = \frac{u_t(r)^{1/\Omega} m_2\left(r\right)^{-1/\Omega}}{\int_S u_t(s)^{1/\Omega} m_2\left(s\right)^{-1/\Omega} ds}$$

Technology

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

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

where $\phi_t^{\omega}(r)$ 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 $T_t(r) = \tau_t(r) \overline{L}_t(r)^{\alpha}$ 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
  - Technology diffuses locally
  - Firm profits are linear in land and firms 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
  - **Market size determines innovation** through local prices

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

- **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

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

$$= \quad \kappa_1 \int_S \left[\frac{\overline{a}(s)}{u_t(s)}\right]^{\frac{\theta^2}{1+2\theta}} \tau_t(s)^{\frac{1+\theta}{1+2\theta}} H(s)^{\frac{\theta}{1+2\theta}} \varsigma(r,s)^{-\theta} \overline{L}_t(s)^{1-\lambda\theta+\frac{1+\theta}{1+2\theta}\chi} ds$$

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

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

  - Iterative procedure converges to unique equilibrium
  - Weaker condition guarantees that model can be solved backward

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

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

  - This condition is stricter than the condition for uniqueness and existence of the equilibrium
- In a BGP aggregate welfare and real consumption grow according to

$$\frac{u_{t+1}(r)}{u_t(r)} = \left[\frac{\int_0^1 c_{t+1}^{\omega}(r)^{\rho}\, d\omega}{\int_0^1 c_t^{\omega}(r)^{\rho}\, d\omega}\right]^{\frac{1}{\rho}} \propto \left[\int_S \overline{L}(s)^{\frac{\theta\gamma_1}{[1-\gamma_2]\xi}}\, ds\right]^{\frac{1-\gamma_2}{\theta}}$$

  - Hence, **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
$\Omega = 0.5$	Elasticity of migration flows with respect to income (Monte et al., 2018)

2. Technology

$\alpha = 0.06$	Elasticity of productivity to density (Carlino et al., 2007)
$\theta = 6.5$	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 (2014)
$\nu = 0.15$	Initial world growth rate of real GDP of 2%

4. Trade Costs

	Allen and Arkolakis (2014) and Fast Marching algorithm
$\Upsilon = 0.393$	Elasticity of trade to distance of -0.93 (Head and Mayer, 2014)

Calibration: Amenity and Technology Parameters

- Amenity parameter λ:

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

  - 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

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

    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

Simulation: Amenities and Productivity

- Use data on land, population and wages from G-Econ 4.0 to derive spatial distribution of $\overline{a}(r)/u_0(r)$ and $\tau_0(r)$ by **inverting the model**
- **Lemma 6:** Inversion yields a unique set of $\overline{a}(r)/u_0(r)$ and $\tau_0(r)$
- The inversion does not separately identify $\overline{a}(r)$ and $u_0(r)$
  - Not a problem in models with free mobility (Roback, 1982)
  - Not reasonable here
    - ⋆ Congo would have very attractive amenities
- We need additional data on utility: subjective wellbeing
  - Correlates well with log of income (Kahneman and Deaton, 2010)
  - Once we have $u_0(r)$, amenities identified as $\overline{a}(r) = \frac{\overline{a}(r)}{u_0(r)} u_0(r)$

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
  - Linear relation between subjective well-being and the log of real income
    - Within and across countries (Deaton and Stone, 2013)
- In the model: $u^i(r) = a(r)\, y(r)\, \varepsilon^i(r)$ absent moving costs
- Deaton and Stone (2013): $\tilde{u}^i(r) = \frac{1}{\psi} \ln y^i(r) + v(r) + \varepsilon^i_{DS}(r)$
- 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 $\psi = 1.8$

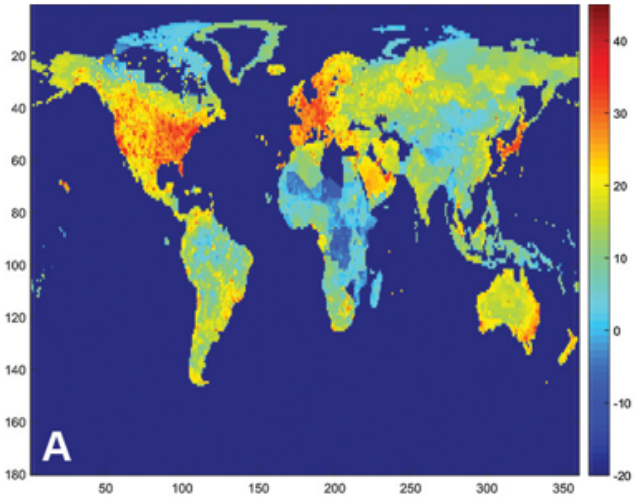
Moving Costs and Counterfactuals

- Use data on population distribution in two consecutive years to identify moving costs
  - **Lemma 7:** Given $\overline{L}_0(r)$ and $\overline{L}_1(r)$, moving costs can be uniquely identified up to a constant
    - ★ Set constant so that $\min m_2(r) = 1$
- Once we have values for $m_2(r)$, simulate model forward using moving costs

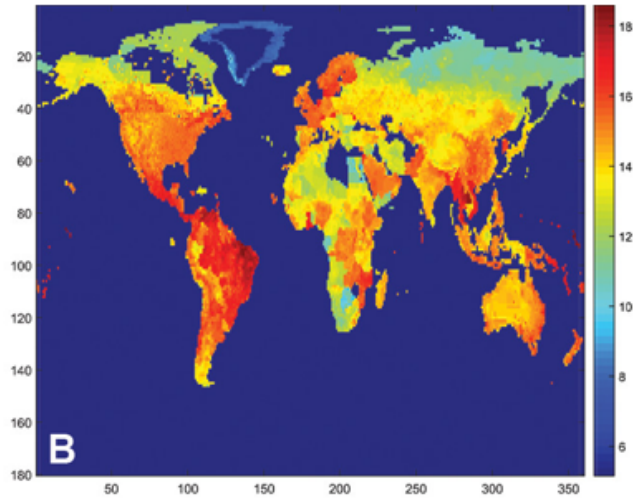
$$\widetilde{m}_2(r) = m_2(r)^{\vartheta}$$

- Counterfactual migration scenarios
  - Keep moving costs unchanged ($\vartheta = 1$)
  - Eliminate moving costs ($\vartheta = 0$)
  - Partial mobility (ϑ between 0 and 1)
    - ★ Keeps ranking of moving costs unchanged

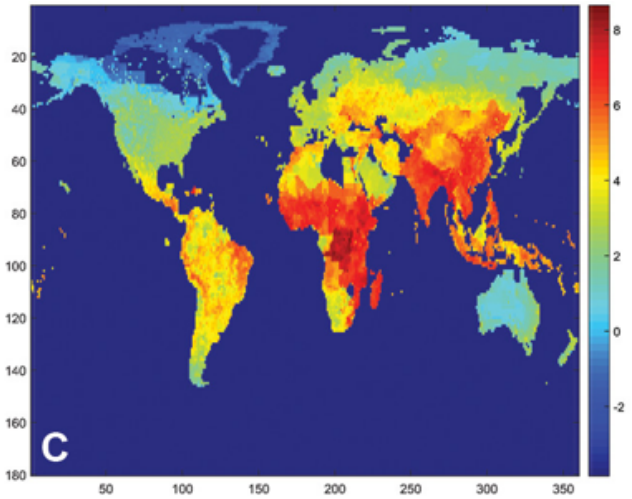
Results from Inversion and Moving Costs



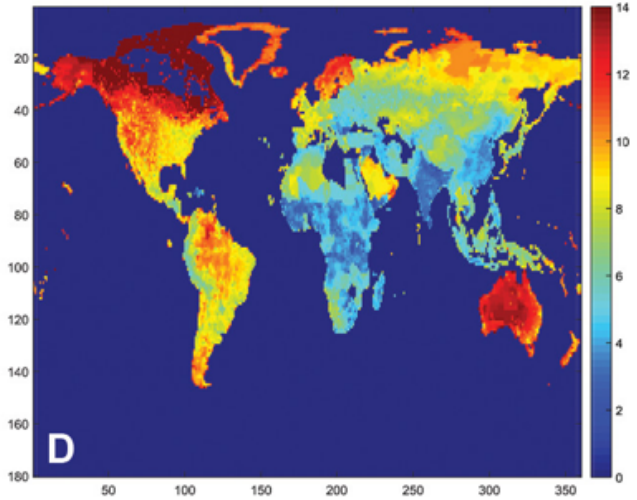
A. Fundamental Productivities: $\tau_0(r)$



B. Fundamental Amenities: $\overline{a}(r)$



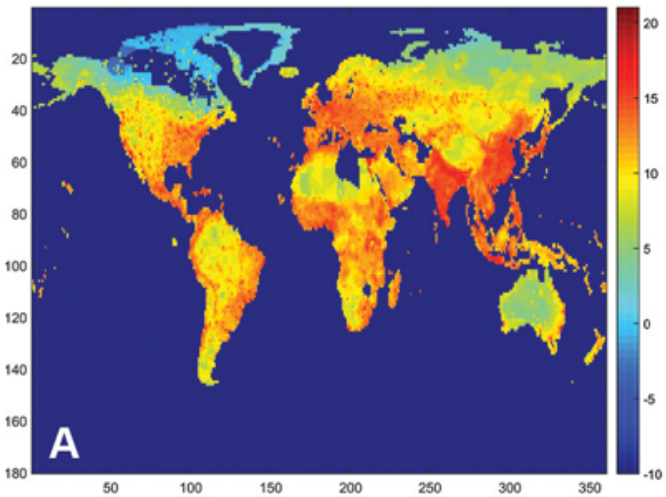
C. Amenities Over Utility: $\overline{a}(r) / u_0(r)$



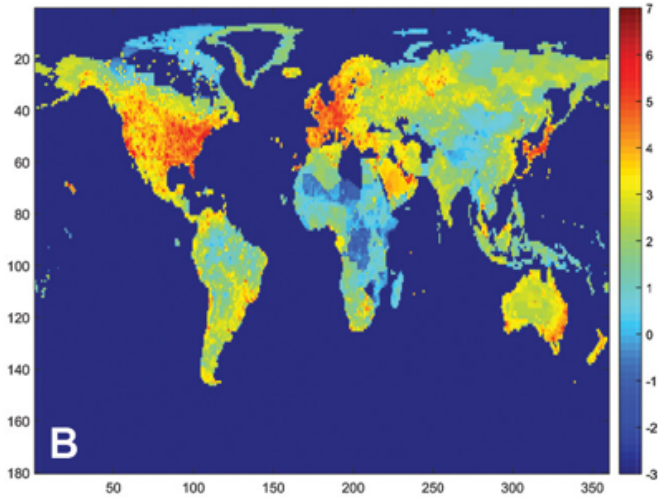
D. Moving Costs: $m_2(r)$

Correlation amenities

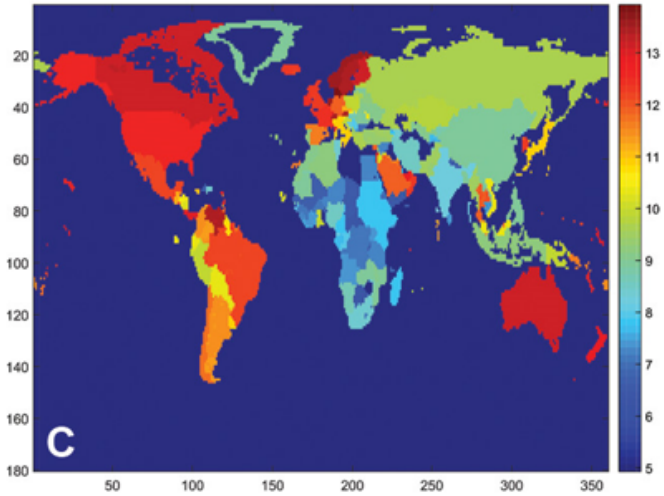
Baseline: Year 2000



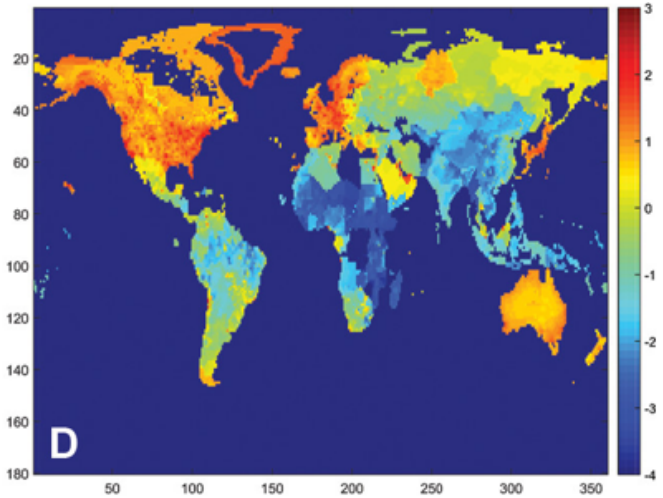
a. Population Density



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

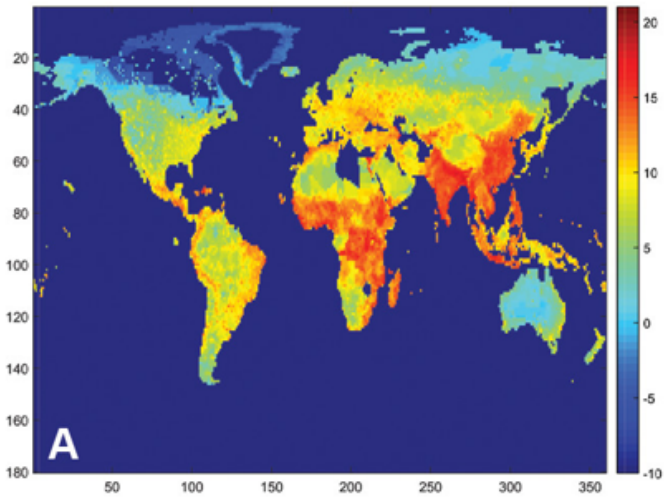


c. Utility

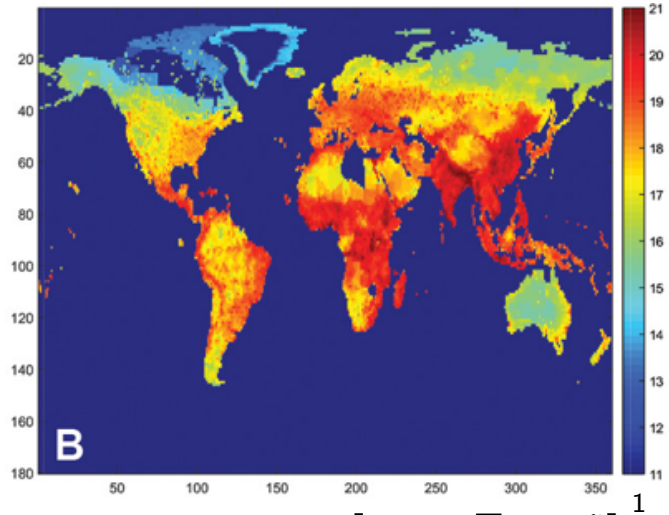


d. Real Income per Capita

Baseline: Balanced Growth Path Distributions



a. Population Density



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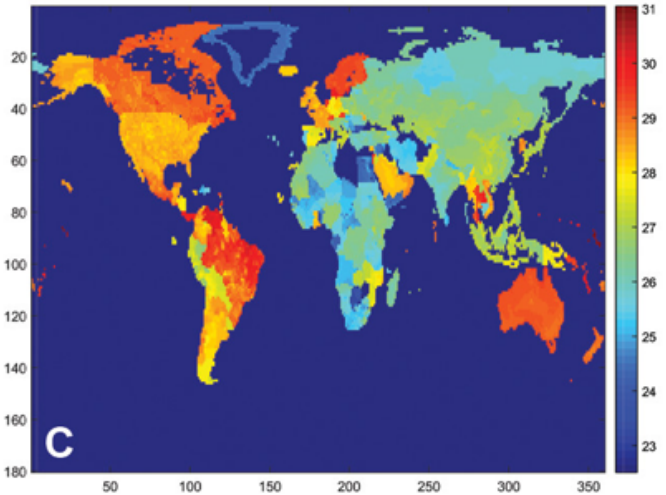
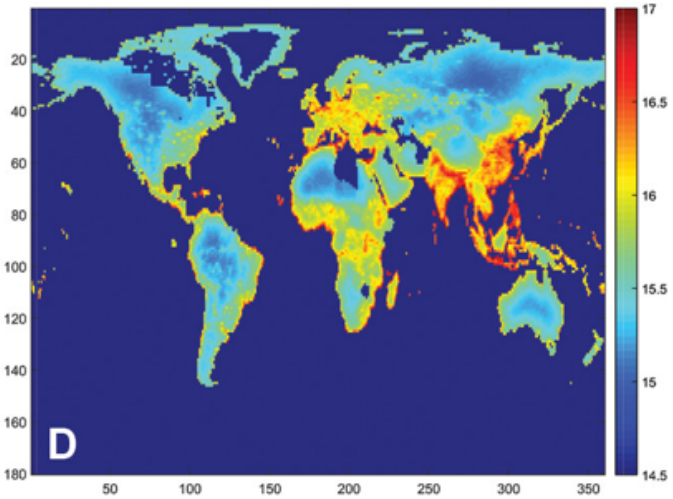
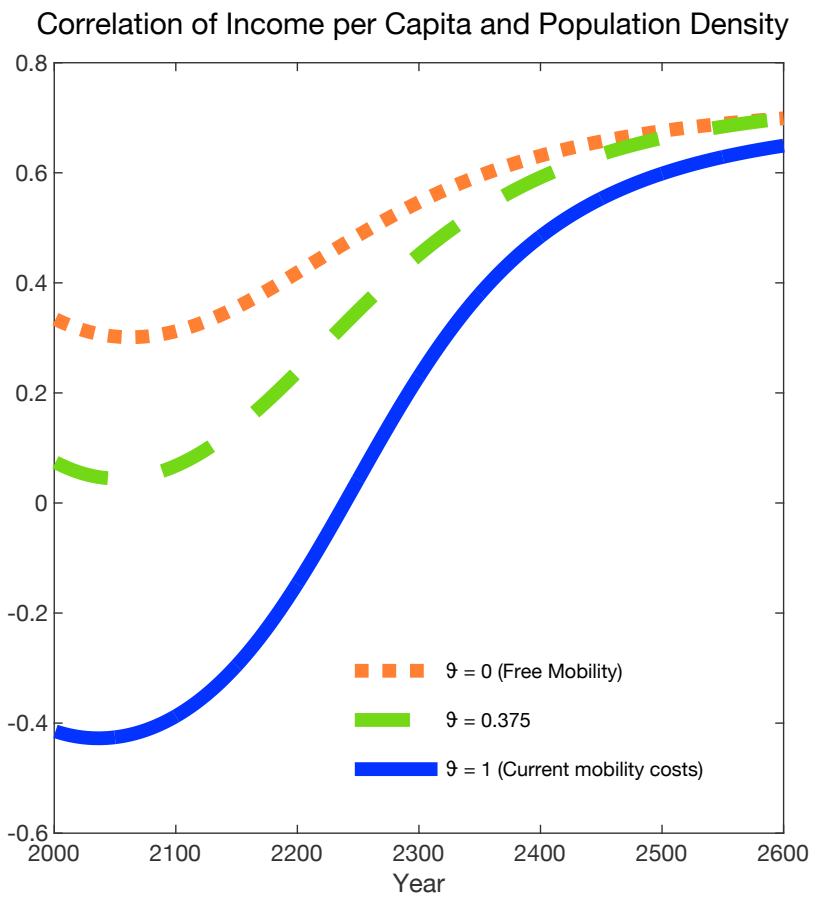


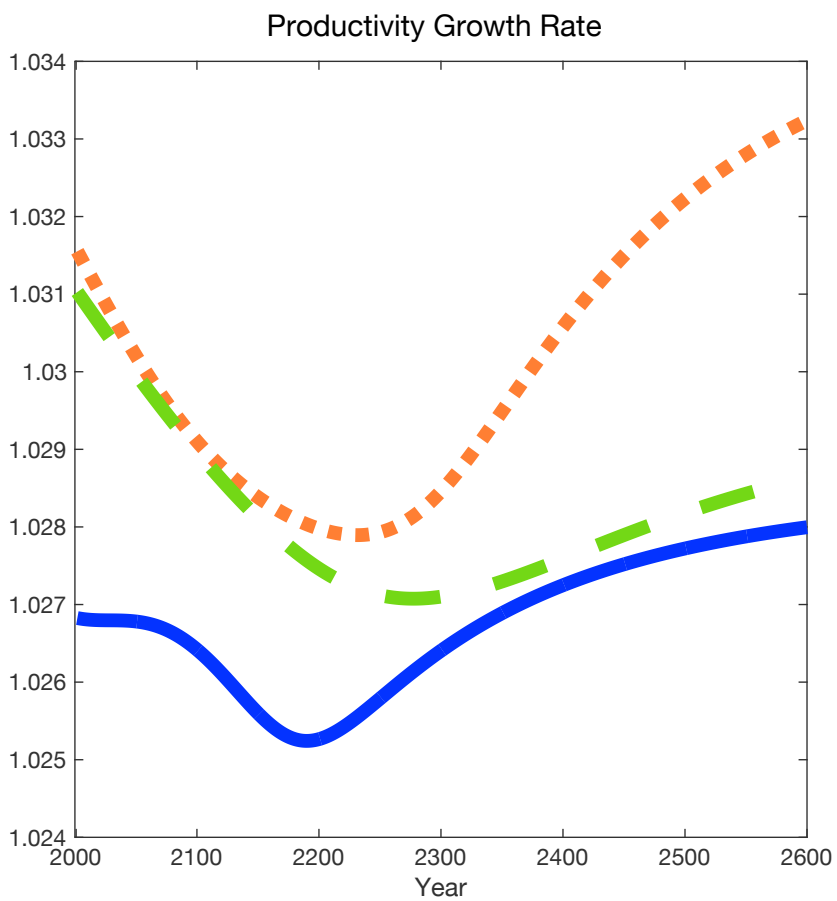
c. Utility



d. Real Income per Capita

Evolution of Income-Density Correlation and Growth Rate





2020 Lectures on Urban Economics

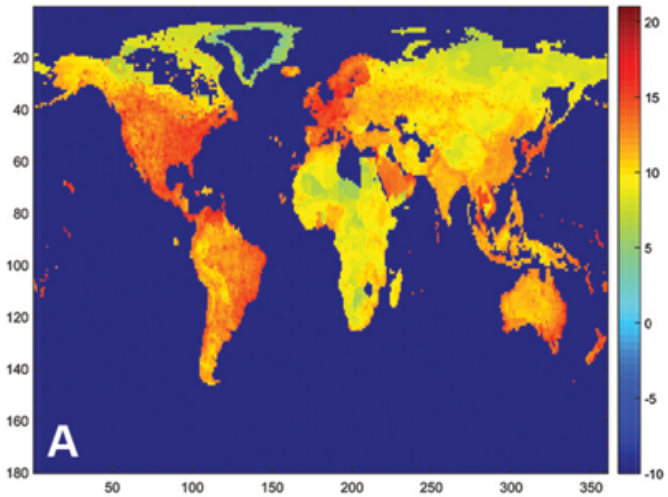
Short Break – We are back in a few minutes

Backcasting

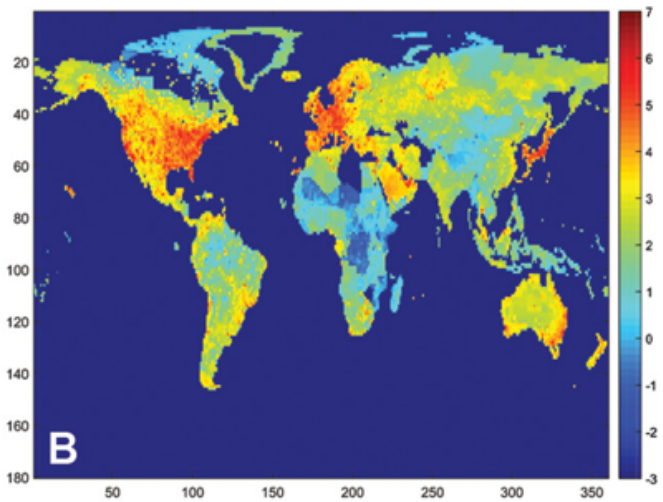
- Using the calibrated model for the year 2000 we can use the dynamics of the model to backcast the past
- We solve the model backwards
  - We show that there is a unique sequence of past allocations consistent with today's allocation
  - Simple iterative algorithm is guaranteed to converge under the assumptions of Lemma 3 or 4
- Compare model's implications for past population across countries with the data
  - Over-identification test since no past data is used

Correlations Model vs Data	Penn World Tables 8.1					Maddison	
Year t	1990	1980	1970	1960	1950	1913	1870
Corr. log population t	0.993	0.991	0.982	0.974	0.965	0.842	0.681
Corr. pop. $\%\Delta$ from t to 2000	0.414	0.535	0.504	0.671	0.742	0.462	0.344
Number of countries	152	131	131	102	53	76	76

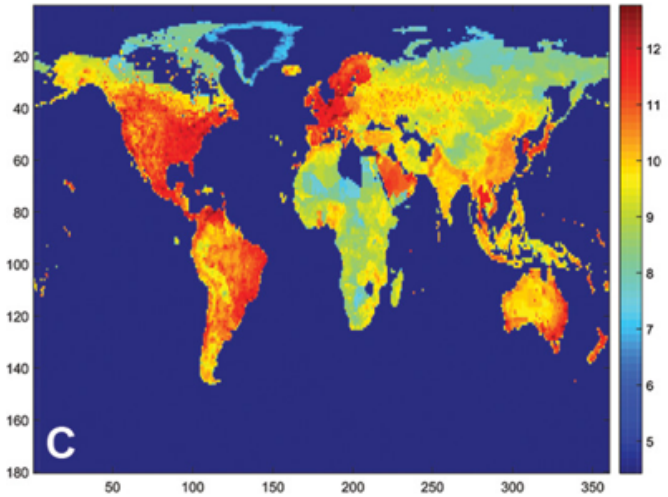
Free Mobility: Year 2000



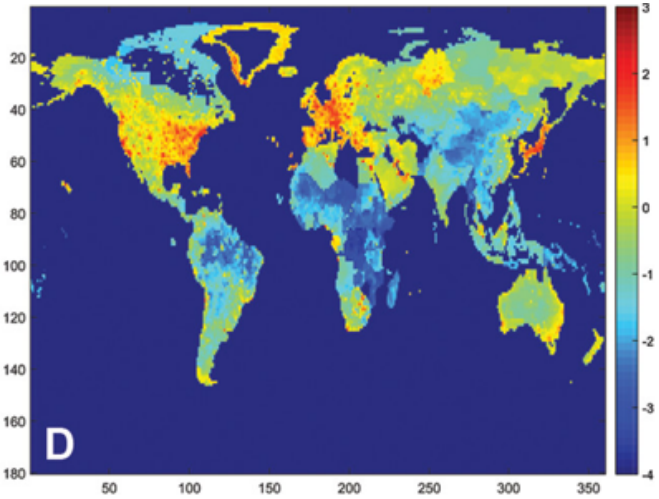
a. Population Density



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

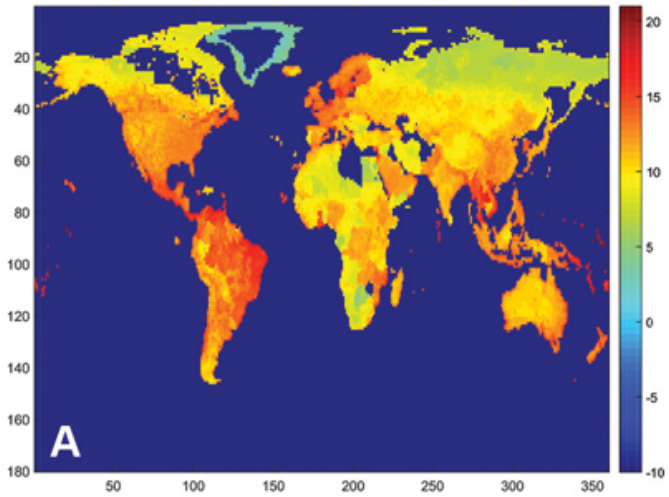


c. Utility

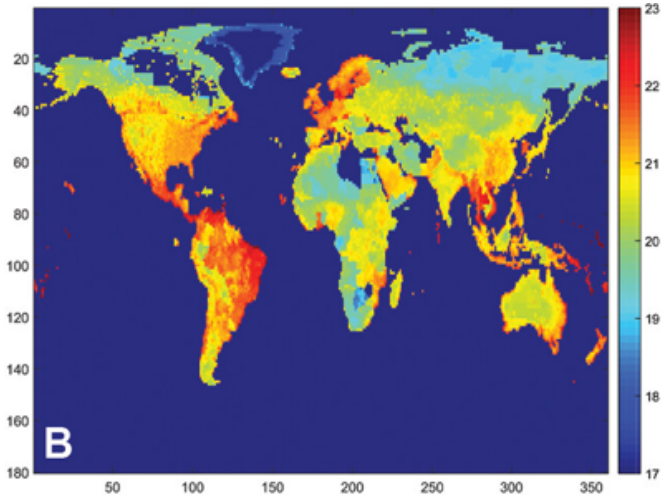


d. Real Income per Capita

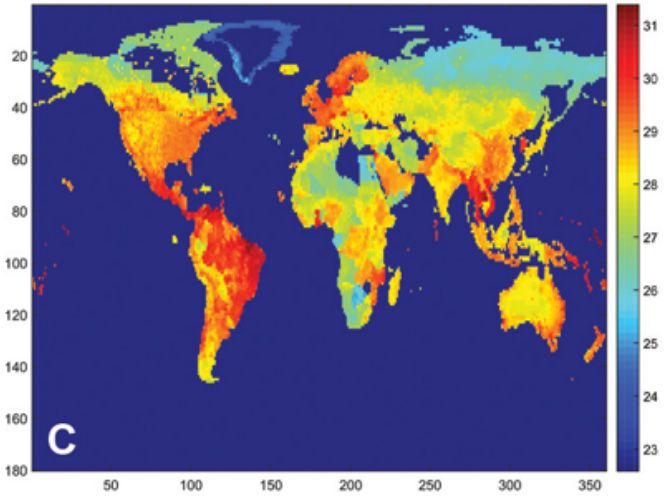
Free Mobility: Balanced Growth Path Distribution



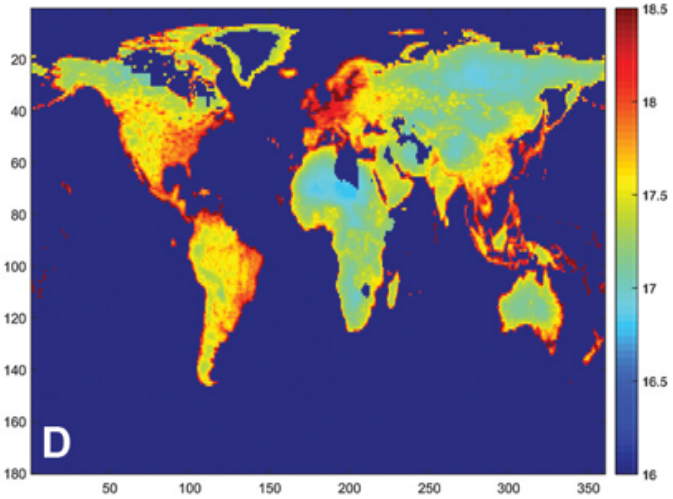
a. Population Density



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



c. Utility



d. Real Income per Capita

Welfare and Migratory Restrictions

Mobility	Discounted Real Income*	Discounted Utility**	Migration Flows***
ϑ	%Δ w.r.t. $\vartheta = 0$	%Δ w.r.t. $\vartheta = 0$	
1^a	0%	0%	0.30%
0.75	30.6%	59.8%	21.2%
0.5	69.2%	144.3%	43.2%
0.25	101.6%	228.8%	60.2%
0^b	125.8%	305.9%	70.3%

We use $\beta = 0.965$. a: Current Moving Costs. b: No Costs. *: Population-weighted average of cells' real GDP. **: 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 ϑ).

Evaluating the Economic Costs of Coastal Flooding

Desmet, et al., 2020, forthcoming *AEJ Macroeconomics*

- Rise in sea level will be major challenge in the next centuries
  - Thermal expansion of oceans
  - Melting of glaciers and retreat of ice sheets
  - Sea-level rise by 0.3 to 0.6 meter by 2100 (IPCC)
- Existing approaches to quantify effects
  - Based on today's economy (Dasgupta et al., 2007)
  - Add future economic scenarios only for large regions (Nicholls, 2004)
  - No adaptation through migration (Hsiang et al., 2017)
- A change of focus is needed
  - From computing the value of destroyed land and structures
  - To evaluating the changes in the dynamic location of economic activity
- Requires a high-resolution global dynamic framework
  - Desmet, Nagy and Rossi-Hansberg (2018)

What We Do

- Assess dynamic spatial economic impact of sea-level rise
  - Spatial economic model at 1° by 1° resolution
  - Probabilistic sea-level rise projections (Kopp et al., 2014)
- Determine flooded areas for different realizations of sea-level paths
- Compute counterfactual where people cannot live in flooded areas
  - Yields average predicted costs of flooding locally and globally
  - Provides credible intervals
  - Measures costs in terms of real income and welfare
- Sea-level rise projections are exogenous
  - No mitigation or adaptation that limits flooding
  - Our results are essential part of cost-benefit analysis to determine virtues of mitigation or adaptation

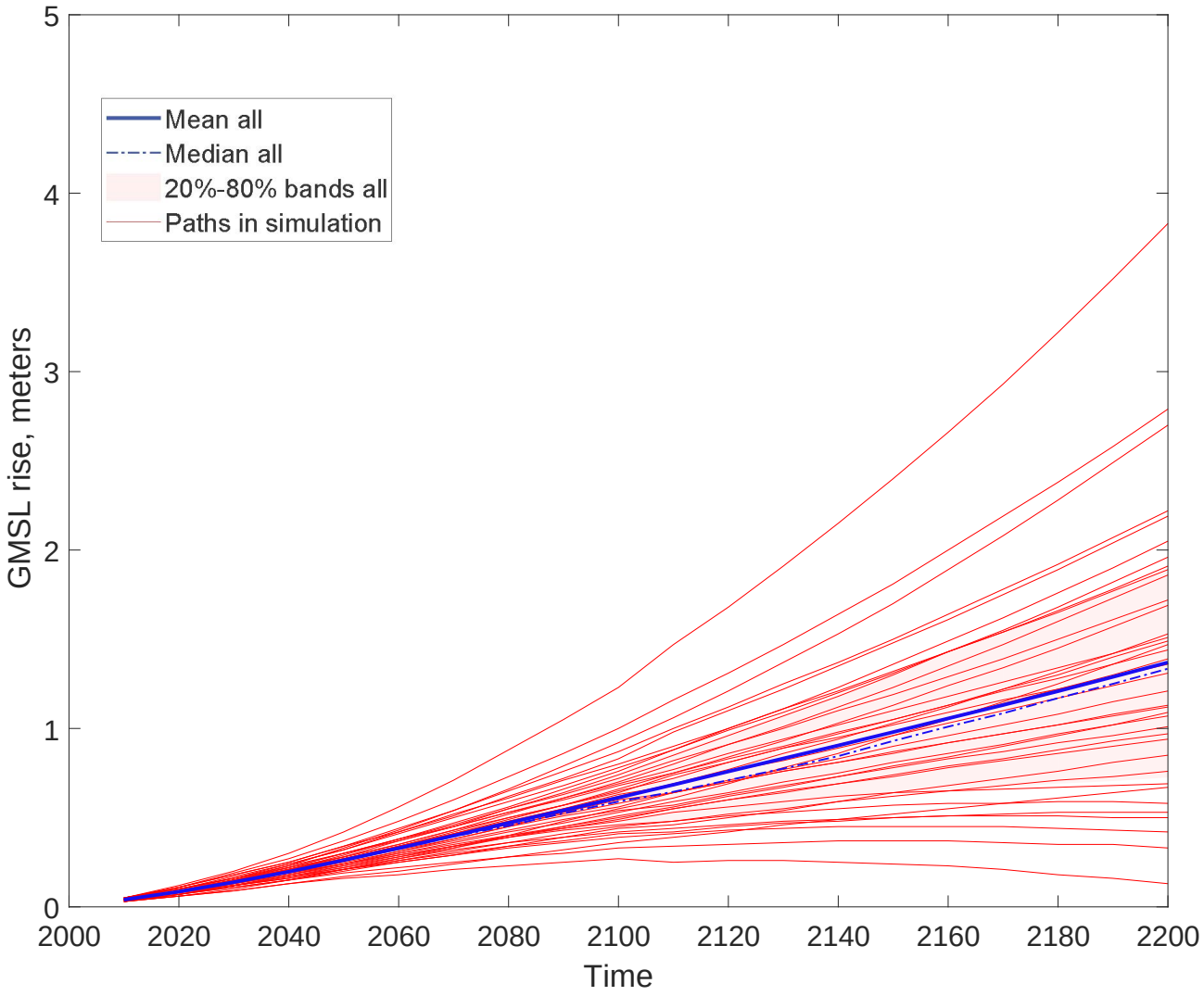
Sea-Level Rise Scenarios

- Probabilistic projections of sea-level rise (Kopp et al., 2014)
  - For 1,091 tide-gauge sites around the world from 2000 to 2200
- Three alternative pathways of future greenhouse gas concentrations
  - Representative Concentration Pathways 8.5, 4.5 and 2.6
- For each RCP, generate 10,000 Monte Carlo samples to calculate a joint probability distribution of sea-level rise
- In our analysis
  - Divide the 10,000 paths into 40 equally-sized 2.5 percentile bins and take a random path from each bin
  - For each path compute sea-level rise for all grid cells of the world by taking a distance-weighted average of the 1,091 tide-gauge sites

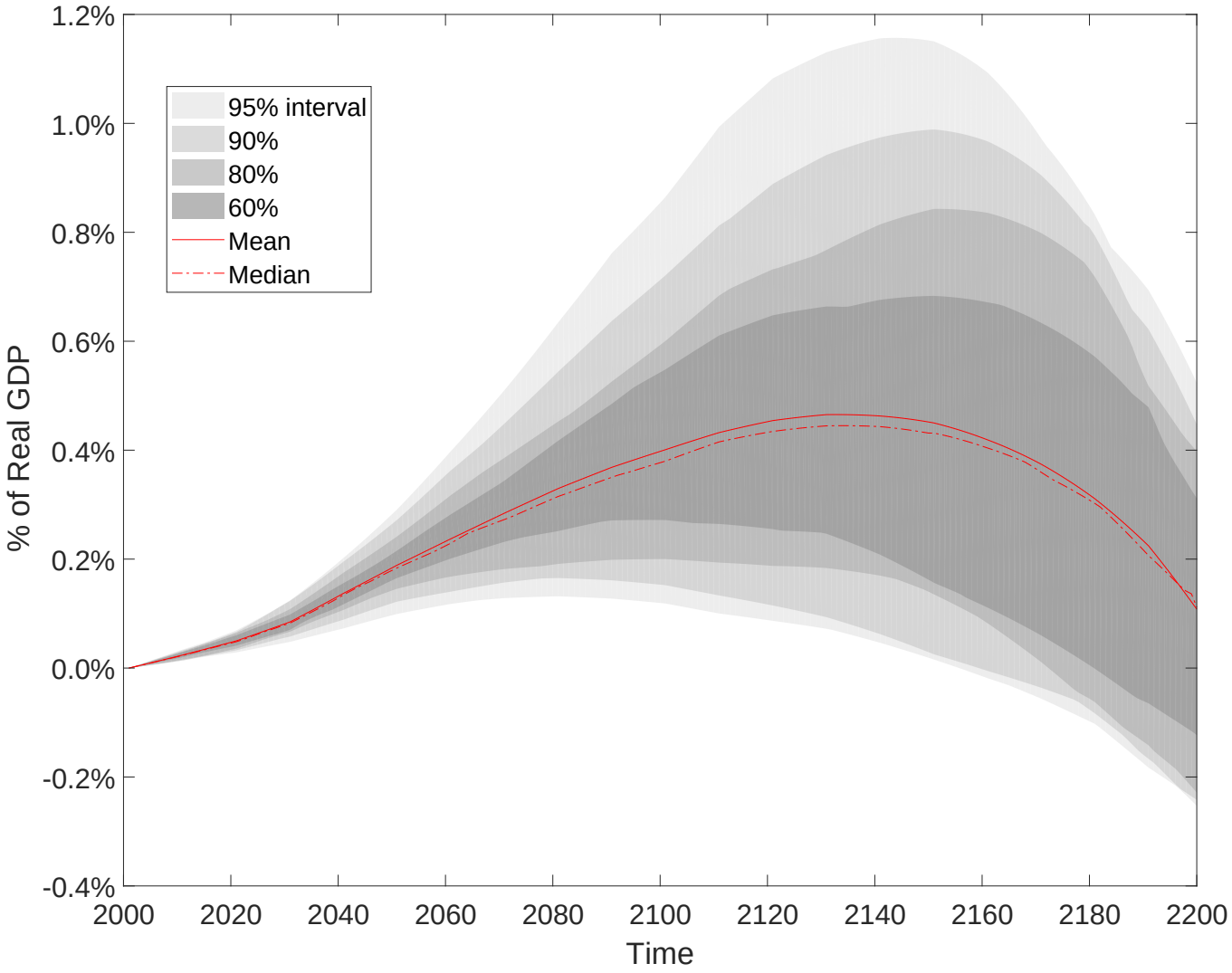
Flooding of Land

- Combine estimates of sea-level rise with information on land elevation to compute share of land flooded in each cell
- Climate Central's CoastalDEM (Kulp and Strauss, 2018)
  - Reduces vertical error caused by vegetation and population density
- Convert elevations to reference local high tide lines
  - Baseline for adding sea level projections and estimating inundated land
- For each time period and grid cell and for each sea-level path, estimate $H_t(r)$

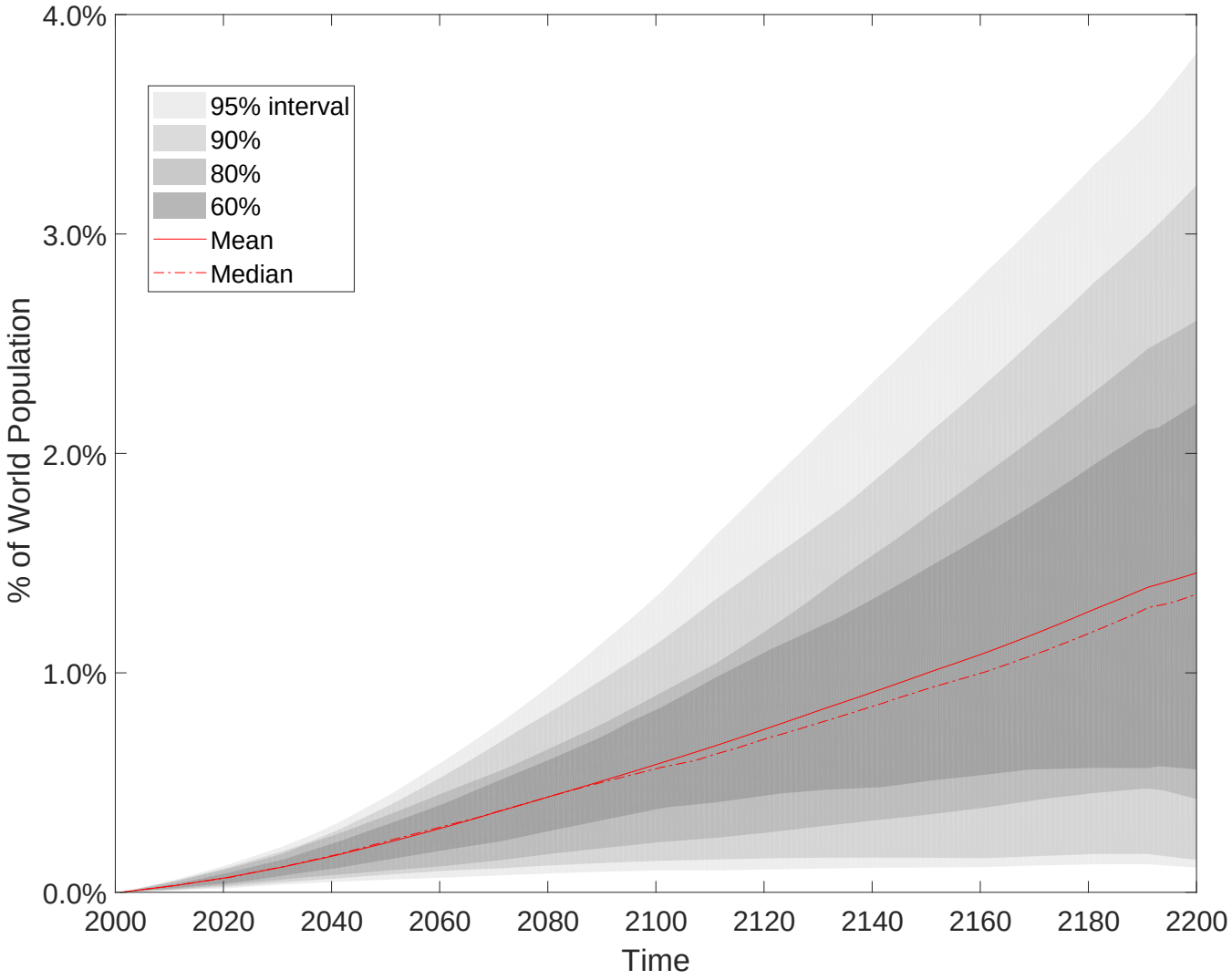
GMSL Rise under RCP 4.5



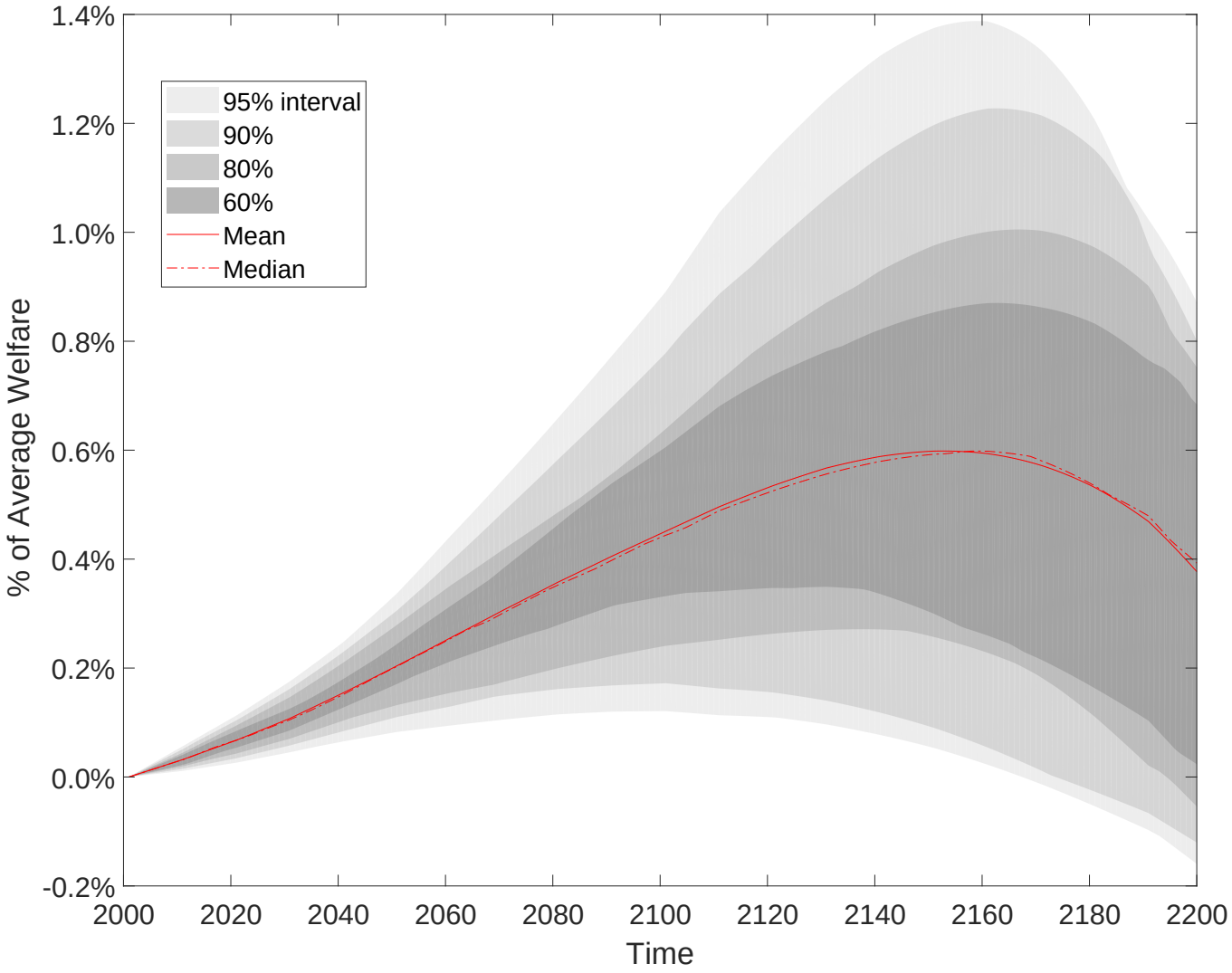
World Real GDP Losses under RCP 4.5



World Population Displaced under RCP 4.5



World Welfare Losses under RCP 4.5



World Population Displaced in 2050, 2100 and 2200

Percentage of Population Displaced by Flooding in the World

Scenario	2050		2100		2200	
1. Extreme (RCP 8.5)						
Mean	0.25%		0.79%		2.25%	
95% credible interval	*0.07%*	*0.41%*	*0.22%*	*1.60%*	*0.70%*	*4.43%*
2. Medium (RCP 4.5)						
Mean	0.22%		0.58%		1.46%	
95% credible interval	*0.07%*	*0.41%*	*0.13%*	*1.30%*	*0.15%*	*3.54%*
3. Mild (RCP 2.6)						
Mean	0.22%		0.49%		1.16%	
95% credible interval	*0.06%*	*0.36%*	*0.11%*	*1.16%*	*0.13%*	*2.93%*

Percentage of population displaced refers to the sum of differences in absolute value of cell population under no flooding scenario and cell population under the mean flooding scenario divided by twice the total population.

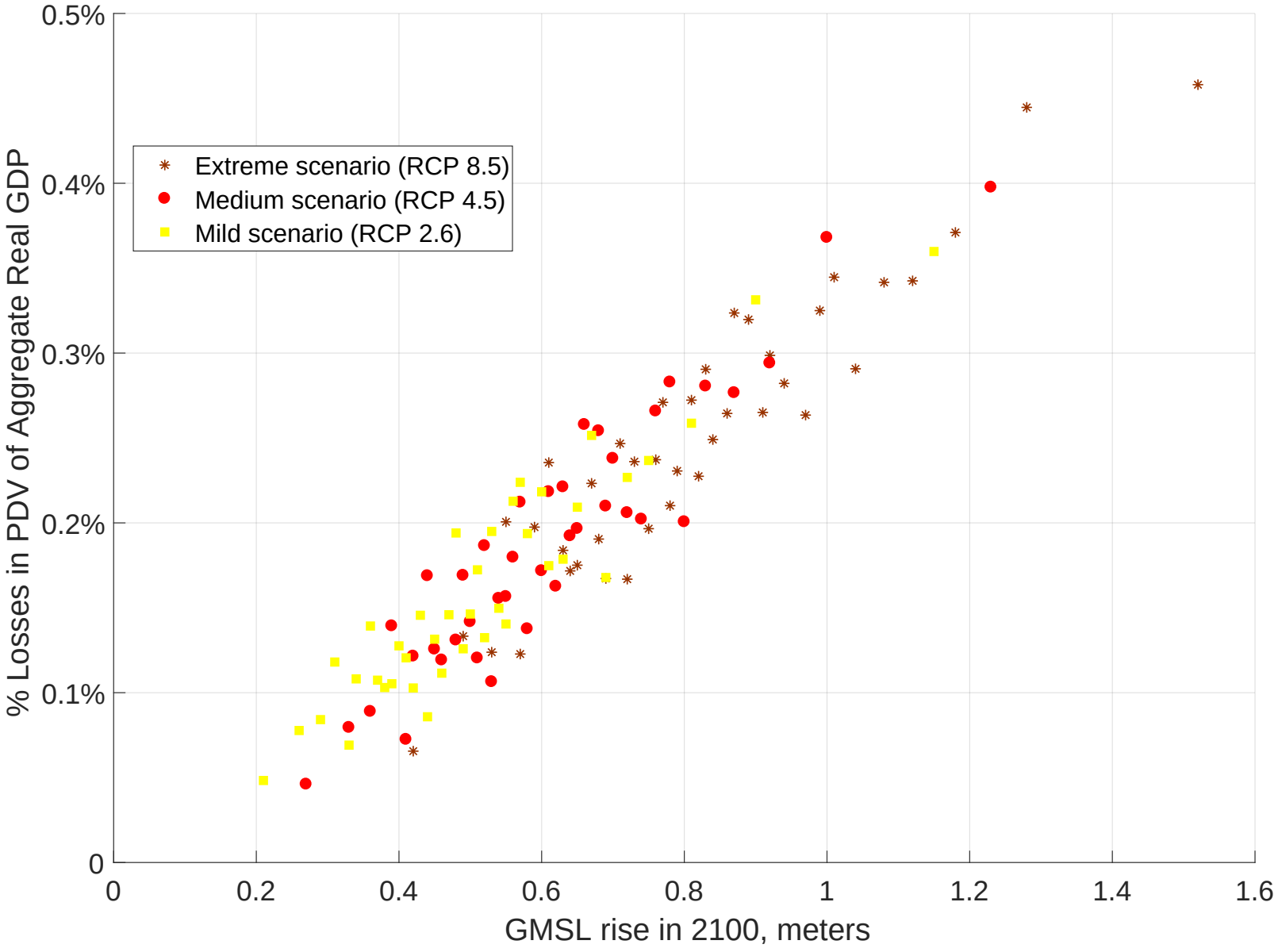
PDV World Real GDP and Welfare Losses

Percentage Flooding Losses in the World

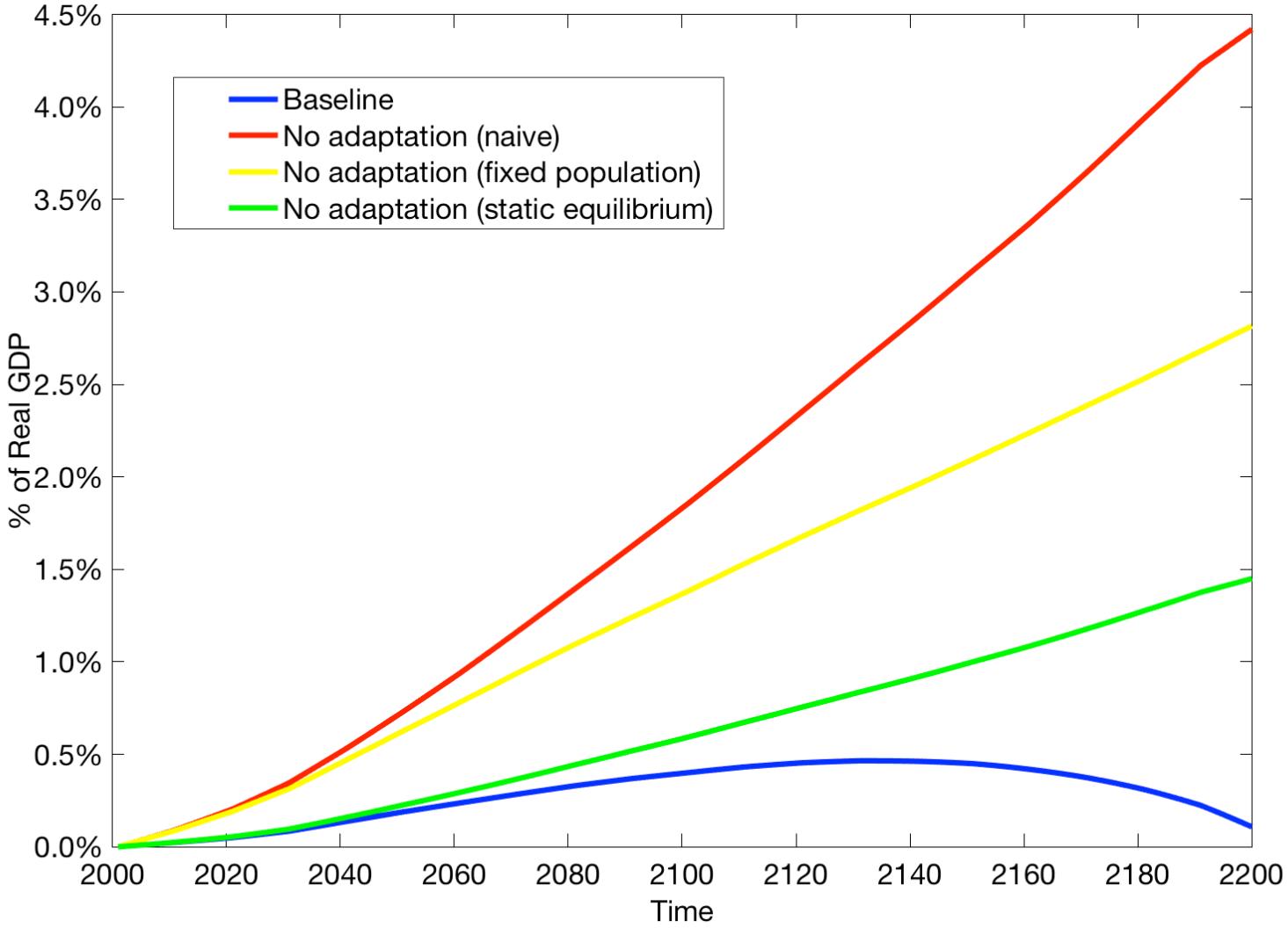
Scenario	Real GDP PDV		Welfare PDV		Real GDP Maximum		Year
1. Extreme (RCP 8.5)							
Mean	0.25%		0.31%		0.71%		2151
95% credible interval	*0.12%*	*0.44%*	*0.14%*	*0.55%*	*0.26%*	*1.36%*	
2. Medium (RCP 4.5)							
Mean	0.19%		0.24%		0.47%		2133
95% credible interval	*0.07%*	*0.37%*	*0.08%*	*0.45%*	*0.16%*	*1.08%*	
3. Mild (RCP 2.6)							
Mean	0.16%		0.21%		0.35%		2131
95% credible interval	*0.07%*	*0.33%*	*0.08%*	*0.41%*	*0.14%*	*0.81%*	

Calculations based on 4% annual discount rate. Percentage change in PDV refers to (PDV of nonflooding scenario / mean of PDV of flooding scenarios) -1, using a simulation over 200 years. Maximum refers to maximum effect of flooding for mean, 97.5th percentile and 2.5th percentile paths. Year denotes the year of the maximum effect of flooding for mean path.

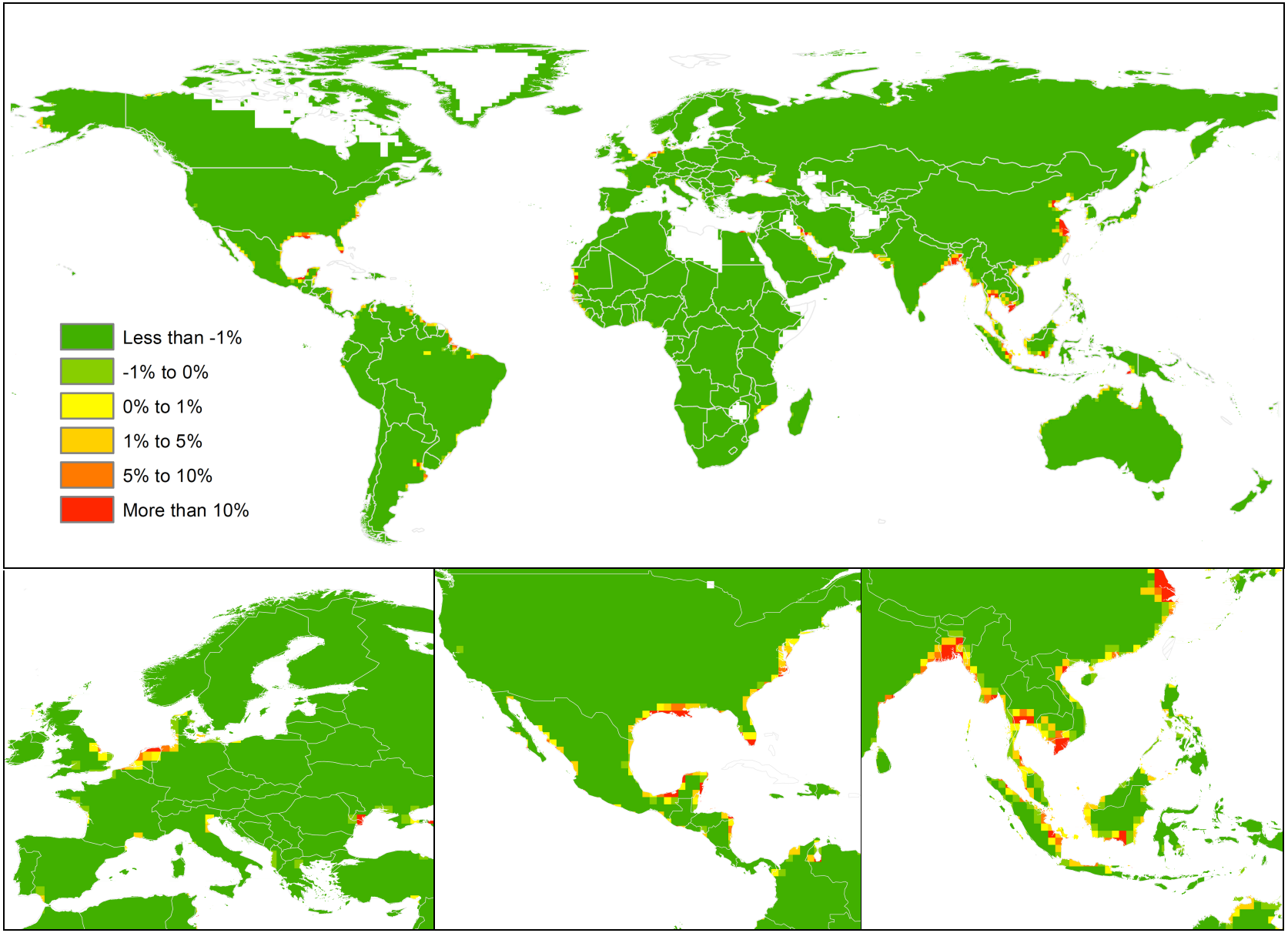
PDV of Real GDP Losses vs GMSL Rise in 2100



Accounting for Dynamic Adaptation is Crucial



Losses in Cell Real GDP in 2200 under RCP 4.5



Population and Real GDP Loss in 25 Cities in 2200

Percentage Flooding Losses in 25 Large Coastal Cities in 2200

	Real GDP Loss		Population Loss		Area Cells
Metropolitan Area	Mean	*95% c.i.*	Mean	*95% c.i.*	Flooded
Amsterdam	6.5%	*(-0.3%, 19.5%)*	6.6%	*(0.0%, 18.3%)*	14.1%
Bangkok	167.1%	*(134.0%, 188.3%)*	162.0%	*(128.9%, 187.5%)*	87.0%
Barcelona	-2.4%	*(-5.2%, -0.4%)*	-1.7%	*(-3.8%, -0.2%)*	0.1%
Buenos Aires	0.3%	*(-1.6%, 7.6%)*	0.7%	*(-0.2%, 2.7%)*	5.3%
Ho Chi Minh City	21.5%	*(-1.7%, 37.6%)*	21.8%	*(-0.4%, 37.9%)*	40.5%
Hong Kong	-0.8%	*(-1.9%, -0.3%)*	-0.4%	*(-1.2%, -0.1%)*	2.5%
Houston-Galveston-Brazoria	0.1%	*(-1.2%, 1.0%)*	0.5%	*(-0.4%, 1.2%)*	5.2%
Karachi	3.8%	*(0.1%, 8.8%)*	4.9%	*(0.7%, 10.9%)*	17.0%
Kolkota	6.9%	*(-1.1%, 38.2%)*	6.6%	*(-0.9%, 36.2%)*	15.0%
Kuala Lumpur	1.5%	*(-0.5%, 3.3%)*	1.5%	*(-0.2%, 3.5%)*	6.5%
Lagos	-1.8%	*(-2.8%, -0.4%)*	-1.2%	*(-2.1%, -0.2%)*	1.2%
Lima	-1.8%	*(-3.5%, -0.4%)*	-1.4%	*(-2.6%, -0.2%)*	0.2%
Los Angeles-Riverside-Orange Cty	-1.9%	*(-4.1%, -0.4%)*	-1.4%	*(-3.0%, -0.1%)*	0.4%
Manila	0.3%	*(-0.7%, 1.2%)*	0.7%	*(0.1%, 1.3%)*	4.7%
Miami-Fort Lauderdale	6.7%	*(0.2%, 55.1%)*	6.7%	*(0.5%, 51.1%)*	12.2%
Mumbai	1.4%	*(-0.3%, 2.7%)*	1.8%	*(0.1%, 3.2%)*	6.5%
New York-Northern NJ-Long Island	0.0%	*(-1.5%, 1.1%)*	0.4%	*(-0.9%, 1.4%)*	3.2%
Rio de Janeiro	-1.5%	*(-3.9%, -0.4%)*	-1.0%	*(-2.6%, -0.1%)*	1.8%
San Francisco-Oakland-San Jose	-1.6%	*(-3.8%, -0.3%)*	-1.1%	*(-2.5%, 0.0%)*	1.7%
Seoul	-0.4%	*(-0.9%, 0.7%)*	-0.1%	*(-0.5%, 0.9%)*	3.3%
Shanghai	159.1%	*(10.5%, 799.9%)*	149.7%	*(11.1%, 745.0%)*	82.2%
Singapore	-1.4%	*(-2.7%, -0.5%)*	-1.0%	*(-1.8%, -0.2%)*	1.2%
Sydney	-1.9%	*(-4.1%, -0.4%)*	-1.3%	*(-2.9%, -0.1%)*	0.7%
Tianjin	19.8%	*(-0.6%, 45.8%)*	20.3%	*(-0.2%, 47.7%)*	37.9%
Tokyo	0.7%	*(-0.9%, 3.1%)*	1.1%	*(-0.5%, 3.2%)*	5.9%

The geographic extent of metropolitan areas is defined as their built-up areas in 2016 and come from the Atlas of Urban Expansion (http://www.atlasofurbanexpansion.org/). Percentage loss refers to (nonflooding scenario / mean of flooding scenarios) -1, where the flooding scenarios are based on RCP 4.5. Caldulations assume that the share of a city's land flooded is the same as that of the 1º by 1º cells the city belongs to.

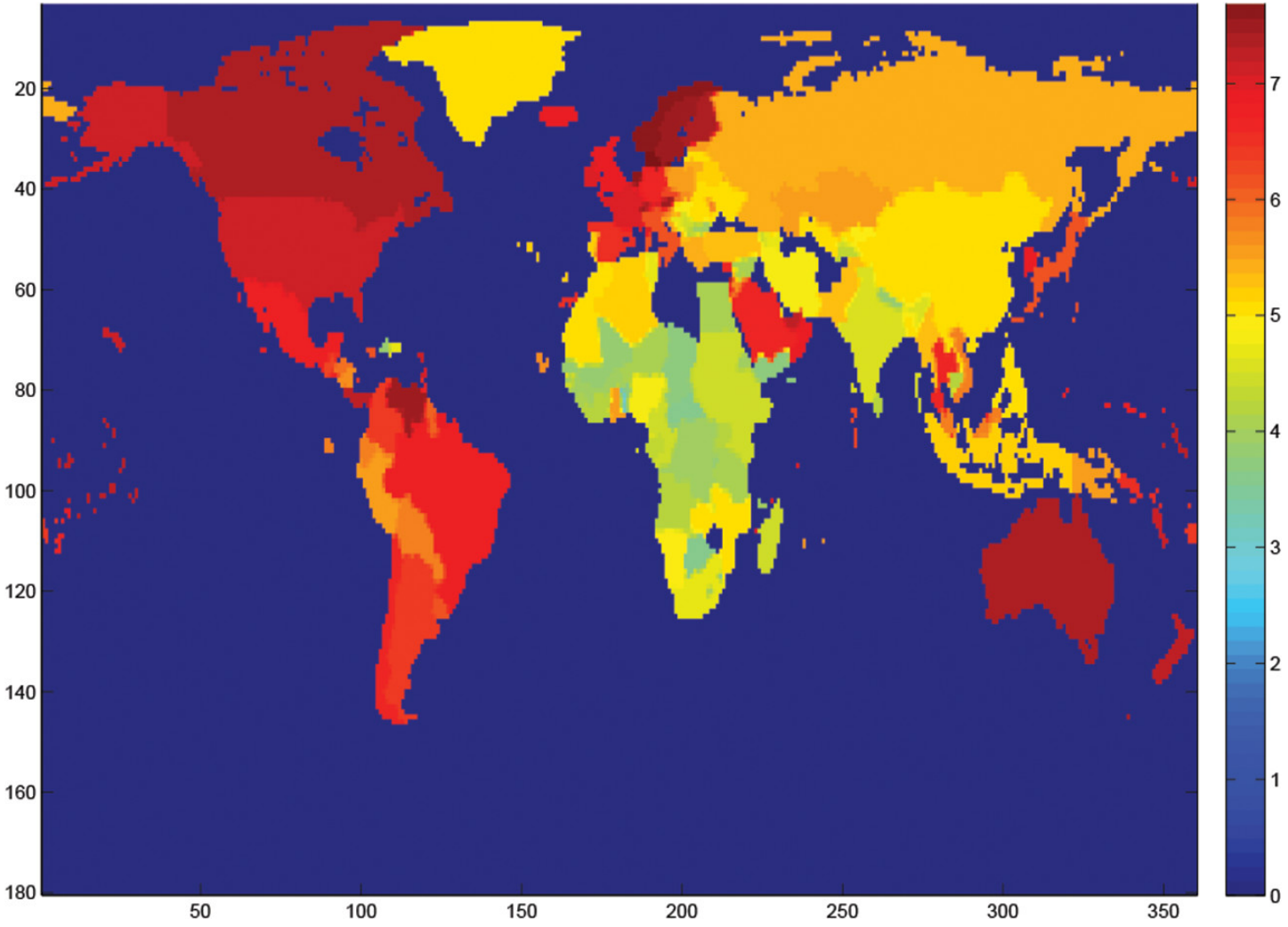
A Final Word

- There is still a lot to learn about spatial dynamics
- Most urgent is a spatial framework with factor mobility and
  - anticipatory effects,
  - consumption-savings decisions,
  - capital accumulation, and
  - innovation
- Essential to evaluate the growth effects of
  - large infrastructure investments,
  - localized technological evolution (e.g. silicon valley)
  - changes in spatial frictions including trade and migration policy,
  - climate change
- Numerical methods used to study dynamic economies with heterogeneous agents in macroeconomics could be promising
- Plenty of room to contribute: Jump in

Thank You

Map Subjective Well-Being

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



Return

Correlation Amenities

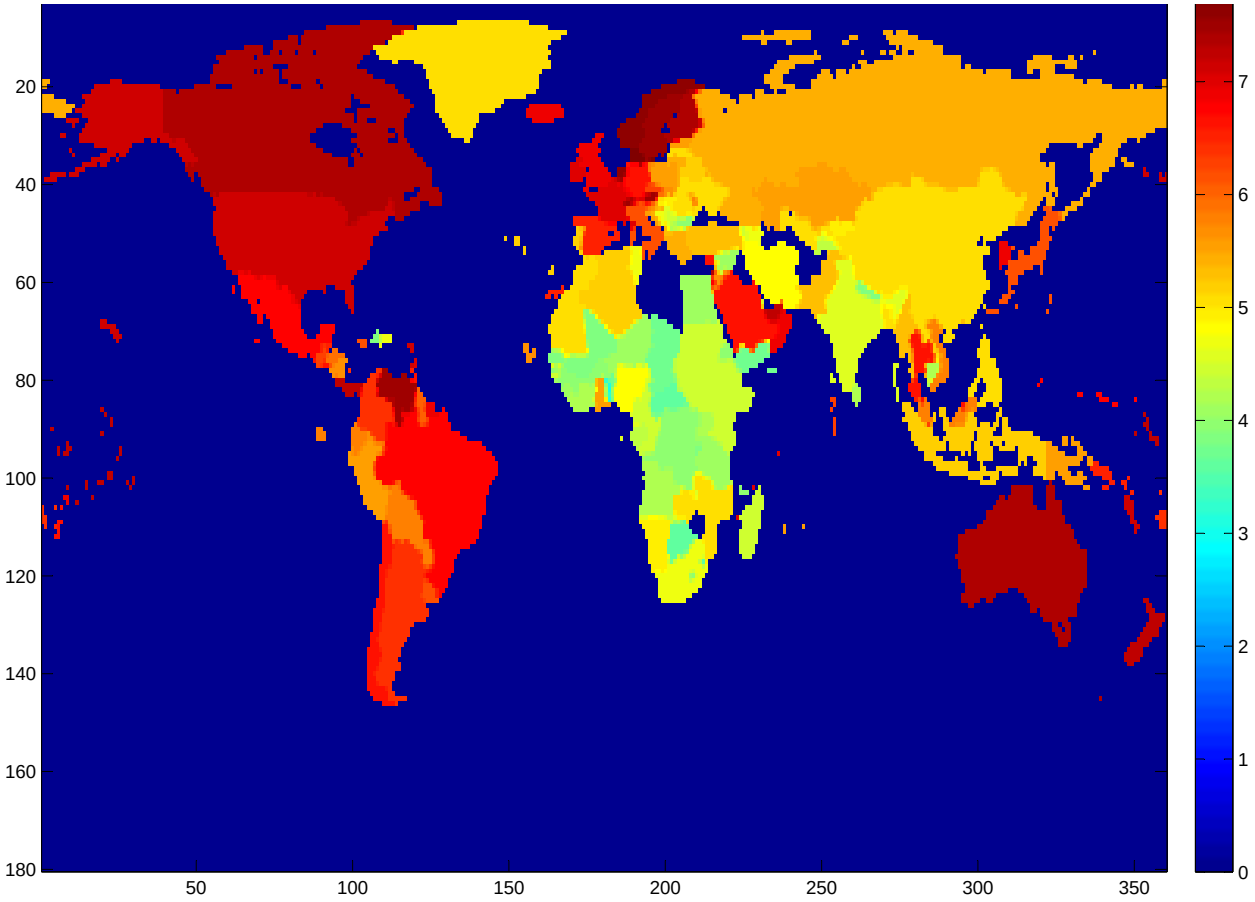
Correlations with Estimated Amenities (logs)					
	(1) All cells	(2) U.S.	(3) One cell per country	(4) Placebo of (1)	(5) Placebo of (3)
A. Water					
Water < 50 km	0.2198***	0.1286***	0.1232**	0.1064***	-0.1363**
B. Elevation					
Level	-0.4152***	-0.1493***	-0.2816***	-0.2793***	0.1283**
Standard deviation	-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 5)

Return

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					
Distance to ocean	-0.3288***	0.0544**	-0.1102*	-0.1277***	0.3181***
Distance to water	-0.4894***	-0.3045***	-0.2054***	-0.3675***	0.1638***
Water $<$ 50 km	0.2653***	0.1731***	0.1123*	0.1442***	-0.1428**
B. Elevation (logs)					
Level	-0.4536***	-0.2116***	-0.2491***	-0.3151***	0.2694***
Standard deviation	-0.4912***	-0.3018***	-0.2781***	-0.3597***	0.2023**
C. Precipitation					
Average	0.4301***	0.1350***	0.3860***	0.3350***	0.1016**
Maximum	0.4462***	0.1733***	0.2383***	0.4443***	0.2992***
Minimum	0.2279***	0.2653***	0.2150***	0.0064	-0.2613***
Standard deviation	0.4126***	0.0833***	0.1969***	0.4824***	0.3954***
D. Temperature					
Average	0.5920***	0.7836***	0.1123*	0.6832***	0.4652***
Maximum	0.5045***	0.8141***	-0.0498	0.6449***	0.4034***
Minimum	0.5867***	0.7029***	0.1621***	0.6529***	0.4131***
Standard deviation	-0.5455***	-0.3953***	-0.2438***	-0.5576***	-0.2983**
E. Vegetation					
Desert, ice or tundra	-0.3553***	-0.4412***	-0.1771***	-0.2775***	-0.0919

- Correlations using all cells, U.S. cells, or one cell per country are similar (see (1), (2) and (3)).
- Placebo correlations under free mobility are not (see (2), (4) and (5))

Return

Population Density and Income

Correlation between population density and real income per capita

- Across all cells of the world: -0.41
- Weighted average across cells within countries: 0.17
- Across richest and poorest cells of the world
  - 50% poorest cells: -0.06
  - 50% richest cells: 0.11
- Weighted average across richest and poorest cells within countries
  - 50% poorest cells: 0.16
  - 50% richest cells: 0.48
- Across cells of different regions
  - Africa: -0.11
  - Asia: 0.06
  - Latin America and Caribbean: 0.18
  - Europe: 0.15 (Western Europe: 0.33)
  - North America: 0.50
  - Australia and New Zealand: 0.70