The Geography of Development:
Evaluating Migration Restrictions and Coastal Flooding

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Introduction

- 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 propose 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
  - Allow for migration restrictions

- Dynamic part of model
  - Desmet and Rossi-Hansberg (2014)
  - Land competition and technological diffusion
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

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

- 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 \( \nu \phi_t^\omega (r)^{\bar{\xi}} \) 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 \( \omega \)
Prices, Export Shares and Trade Balance

- Price of good produced at \( r \) and sold at \( r \)

\[
p_t^\omega (r, r) = \frac{mc_t (r)}{z_t^\omega (r)}
\]

- 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 \( s \)

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

- Trade balance location by location

\[
w_t (r) H (r) \overline{L}_t (r) = \int_S \pi_t (s, r) w_t (s) H (s) \overline{L}_t (s) ds \quad \text{all } r \in S
\]
Equilibrium: Definition, Existence and Uniqueness

- Standard definition of dynamic competitive equilibrium

- Equilibrium implies

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

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

where \( \chi = \left[ \alpha - 1 + \left[ \lambda + \frac{\gamma_1}{\zeta} - [1 - \mu] \right] \theta \right] \)

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

\[
\frac{\alpha}{\theta} + \frac{\gamma_1}{\zeta} \leq \lambda + 1 - \mu
\]

- 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

\[
\frac{\alpha}{\theta} + \frac{\gamma_1}{\zeta} + \frac{\gamma_1}{[1 - \gamma_2]\zeta} \leq \lambda + 1 - \mu
\]

  ▶ 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

\[
\frac{\bar{u}_{t+1}^W}{\bar{u}_t^W} = \left[ \frac{\int_0^1 c_t^\omega (r)^\rho \, d\omega}{\int_0^1 c_t^\omega (r)^\rho \, d\omega} \right]^{\frac{1}{\rho}} = \eta^{\frac{1-\gamma_2}{\theta^2}} \left[ \frac{\gamma_1 / \nu}{\gamma_1 + \mu \zeta} \right]^{\frac{\gamma_1}{\zeta}} \left[ \int_S L (s)^{\theta \gamma_1 [1 - \gamma_2] \zeta} \, ds \right]^{\frac{1-\gamma_2}{\theta}}
\]

  ▶ Growth depends on population size and its distribution in space
## Calibration: Summary

### 1. Preferences

- \( \rho = 0.75 \) \hspace{1cm} \text{Elasticity of substitution of 4 (Bernard et al., 2003)}
- \( \lambda = 0.32 \) \hspace{1cm} \text{Relation between amenities and population}
- \( \psi = 1.8 \) \hspace{1cm} \text{Deaton and Stone (2013), data on migration and subjective well-being}

### 2. Technology

- \( \alpha = 0.06 \) \hspace{1cm} \text{Elasticity of productivity to density (Ciccone and Hall, 1996)}
- \( \theta = 6.5 \) \hspace{1cm} \text{Trade elasticity (Simonovska and Waugh, 2014)}
- \( \mu = 0.8 \) \hspace{1cm} \text{Labor or non-land share in production}
  \hspace{1cm} \text{(Greenwood et al., 1997; Desmet and Rappaport, 2014)}
- \( \gamma_1 = 0.319 \) \hspace{1cm} \text{Relation between population distribution and growth}

### 3. Evolution of productivity

- \( \gamma_2 = 0.993 \) \hspace{1cm} \text{Relation between population distribution and growth}
- \( \zeta = 125 \) \hspace{1cm} \text{Desmet and Rossi-Hansberg (2014a)}
- \( \nu = 0.2 \) \hspace{1cm} \text{Initial world growth rate of real GDP of 2%}

### 4. Trade Costs

- Allen and Arkolakis (2014)
Calibration: Amenity and Technology Parameters

- **Amenity parameter \( \lambda \):**
  \[
  \log(a(r)) = E(\log(\bar{a}(r))) - \lambda \log(L(r)) + \varepsilon(r)
  \]
  - Estimate using data on amenities and population for 192 U.S. MSAs
  - Instrument for \( \bar{L} \) using productivity

- **Technology parameters \( \gamma_1 \) and \( \gamma_2 \)**
  - 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 \( \alpha_1, \alpha_2 \) and \( \alpha_3 \) are functions of \( \gamma_1 \) and \( \gamma_2 \)
  - 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

$$
\log \sigma (r) = \beta_{\text{rail}} \text{rail}(r) + \beta_{\text{no\_rail}} [1 - \text{rail}(r)] + \beta_{\text{major\_road}} \text{major\_road}(r) + \ldots + \beta_{\text{water}} \text{water}(r) + \beta_{\text{no\_water}} [1 - \text{water}(r)]
$$

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

$$
\log \zeta (r, s) = \inf_{g(r, s)} \int_{g(r, s)} \log \sigma (u) \, du
$$
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: inversion yields a unique set of $\overline{a}(r)/\overline{u}(c)$ and $\tau_0(r)$.

- The inversion does not separately identify $\overline{a}(r)$ and $\overline{u}(c)$.
  - 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).
  - Not needed if mobility restrictions kept unchanged.
  - But if we change mobility restrictions, levels of $\overline{u}(c)$ change.
  - Also important if we want estimate of $\overline{a}(r)$. 
Subjective Well-Being

- Data on subjective well-being from the Gallup World Poll
  - Cantril ladder from 0 to 10
  - 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 $\bar{a}(r) = e^{1.8\tilde{u}(c)} \frac{a(r)}{\bar{u}(c)}$

- Once we have values for $\bar{a}(r)$, simulate model forward using ratio of amenities to utility of

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

- Counterfactual migration scenarios
  - Keeping mobility restrictions unchanged ($\psi = 0$)
    - Keep values $\bar{a}(r) / \bar{u}(c)$ 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 $e^{1.8\tilde{u}(c)} \bar{a}(r) / \bar{u}(c)$
  - Partial mobility ($\psi$ in between 0 and 1.8)
    - Keeps ranking of migration restrictions unchanged
Benchmark Calibration: Results from Inversion

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

b. Fundamental Amenities: $\bar{a} (r)$
Benchmark Calibration: Period 1

a. Population Density

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

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

d. Real Income per Capita
Keeping Migratory Restrictions Unchanged: Period 600

a. Population Density

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

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

d. Real Income per Capita

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Correlations under Different Scenarios

- Corr (log real GDP per capita, log population density)
- Corr (log productivity, log population density)
- Corr (log productivity, log real GDP per capita)

Empirical correlation density and income

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Growth Rates and Levels under Different Scenarios

- **Growth rate of productivity**
  - **ψ = 0**
  - **ψ = 0.9**
  - **ψ = 1.8**

- **Growth rate of real GDP**

- **Growth rate of utility**

- **Log world average productivity**

- **Log world average real GDP**

- **Log world utility (not normalized)**

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Free Mobility: Period 1

a. Population Density

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

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

d. Real Income per Capita
Free Mobility: Period 600

a. Population Density

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

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

d. Real Income per Capita

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## Welfare and Migratory Restrictions

<table>
<thead>
<tr>
<th>Mobility $\psi$</th>
<th>Discounted Real Income* $%\Delta$ w.r.t. $\psi = 0$</th>
<th>Discounted Utility** $%\Delta$ w.r.t. $\psi = 0$</th>
<th>Migration Flows***</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0$^a$</td>
<td>0%</td>
<td>0%</td>
<td>0.74%</td>
</tr>
<tr>
<td>0.3</td>
<td>3.5%</td>
<td>71%</td>
<td>24.5%</td>
</tr>
<tr>
<td>0.5</td>
<td>13.9%</td>
<td>131%</td>
<td>42.0%</td>
</tr>
<tr>
<td>0.9</td>
<td>39.8%</td>
<td>244%</td>
<td>65.0%</td>
</tr>
<tr>
<td>1.3</td>
<td>56.2%</td>
<td>298%</td>
<td>73.9%</td>
</tr>
<tr>
<td>1.8$^b$</td>
<td>68.6%</td>
<td>312%</td>
<td>78.2%</td>
</tr>
</tbody>
</table>

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 $\psi$).
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

Legend
- No Population Flooded
- 0-50,000
- 50,000-500,000
- 500,000-1,000,000
- 1,000,000-3,000,000
- 3,000,000-25,000,000

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## Static Effect of Flooding Depending on Date

<table>
<thead>
<tr>
<th></th>
<th>Period 1</th>
<th>Period 100</th>
<th>Period 500</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Keeping mobility restrictions unchanged</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage land flooded</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Percentage population flooded</td>
<td>6.6</td>
<td>7.5</td>
<td>5.7</td>
</tr>
<tr>
<td>Percentage land rents lost</td>
<td>6.3</td>
<td>8.0</td>
<td>6.2</td>
</tr>
<tr>
<td>Percentage technology lost (land weighted)</td>
<td>2.4</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Percentage technology lost (population weighted)</td>
<td>9.5</td>
<td>10.5</td>
<td>5.7</td>
</tr>
<tr>
<td>Percentage amenities lost (land weighted)</td>
<td>2.2</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Percentage amenities lost (population weighted)</td>
<td>8.8</td>
<td>9.6</td>
<td>9.6</td>
</tr>
<tr>
<td><strong>B. Free mobility</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage land flooded</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Percentage population flooded</td>
<td>11.2</td>
<td>14.9</td>
<td>81.4</td>
</tr>
<tr>
<td>Percentage land rents lost</td>
<td>8.4</td>
<td>13.7</td>
<td>89.1</td>
</tr>
<tr>
<td>Percentage technology lost (land weighted)</td>
<td>2.4</td>
<td>3.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Percentage technology lost (population weighted)</td>
<td>11.6</td>
<td>19.4</td>
<td>97.4</td>
</tr>
<tr>
<td>Percentage amenities lost (land weighted)</td>
<td>1.2</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Percentage amenities lost (population weighted)</td>
<td>11.9</td>
<td>18.0</td>
<td>80.9</td>
</tr>
</tbody>
</table>
### Dynamic Effects of Flooding

<table>
<thead>
<tr>
<th>Mobility $\psi$</th>
<th>Discounted Present Value of Real Income* Ratio (NF/F)</th>
<th>Welfare** Ratio (NF/F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0(^a)</td>
<td>1.037</td>
<td>1.082</td>
</tr>
<tr>
<td>0.3</td>
<td>1.028</td>
<td>1.079</td>
</tr>
<tr>
<td>0.5</td>
<td>1.021</td>
<td>1.075</td>
</tr>
<tr>
<td>0.9</td>
<td>1.016</td>
<td>1.072</td>
</tr>
<tr>
<td>1.3</td>
<td>1.024</td>
<td>1.076</td>
</tr>
<tr>
<td>1.8(^b)</td>
<td>1.037</td>
<td>1.078</td>
</tr>
</tbody>
</table>

*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.
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

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Dynamics of No Flooding vs Flooding

Ratio of real GDP (No flooding / flooding)

Ratio of utility (No flooding / flooding)

$\psi = 0$
$\psi = 0.9$
$\psi = 1.8$
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)
Correlation Amenities

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

- 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))
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

- 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

<table>
<thead>
<tr>
<th>Year</th>
<th>&lt; 25th</th>
<th>25-50th</th>
<th>50th-75th</th>
<th>&gt;75th</th>
<th>&lt; Median</th>
<th>≥ Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>-0.1001***</td>
<td>0.0495***</td>
<td>0.1499***</td>
<td>0.2248***</td>
<td>-0.0609***</td>
<td>0.3589***</td>
</tr>
<tr>
<td>2007-2011</td>
<td>-0.0930***</td>
<td>0.0175</td>
<td>0.0733***</td>
<td>0.2420***</td>
<td>-0.0781***</td>
<td>0.3234***</td>
</tr>
</tbody>
</table>

*Percentiles based on per capita income

- Also holds across zip codes within CBSAs
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

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Discounted Present Value of Real Income*</th>
<th>Welfare**</th>
</tr>
</thead>
<tbody>
<tr>
<td>ψ</td>
<td>Ratio (NF/F)</td>
<td>Ratio (NF/F)</td>
</tr>
<tr>
<td>0.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.011</td>
<td>1.036</td>
</tr>
<tr>
<td>0.3</td>
<td>1.011</td>
<td>1.040</td>
</tr>
<tr>
<td>0.5</td>
<td>1.010</td>
<td>1.041</td>
</tr>
<tr>
<td>0.9</td>
<td>1.008</td>
<td>1.041</td>
</tr>
<tr>
<td>1.3</td>
<td>1.012</td>
<td>1.039</td>
</tr>
<tr>
<td>1.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.014</td>
<td>1.034</td>
</tr>
</tbody>
</table>

We use β = 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.