Spatial Environmental Economics
Lecture 8: Climate Change and Migration

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Roadmap

1. Global Emissions and Global Temperature Rise
2. Deforestation Contribution to Climate Change
3. Regional Impacts of Climate Change
4. Spatial Model with Migration
5. Application: Climate Change with Migration

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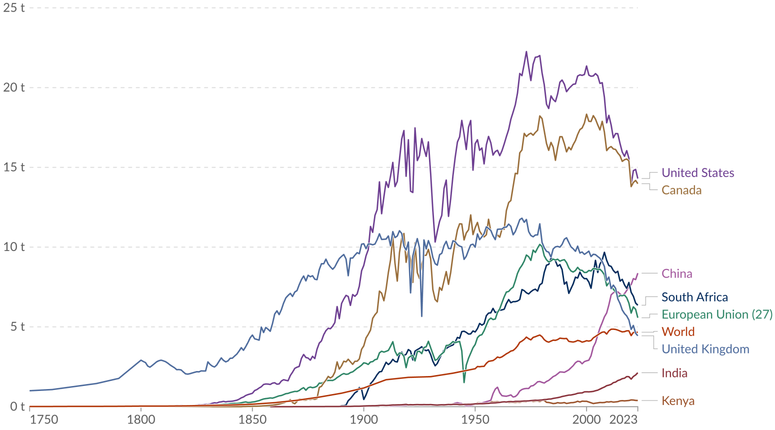
Per capita CO_2 emissions

Carbon dioxide (CO_2) emissions from fossil fuels and industry[1]. Land-use change is not included.



Data source: Global Carbon Budget (2024); Population based on various sources (2024)

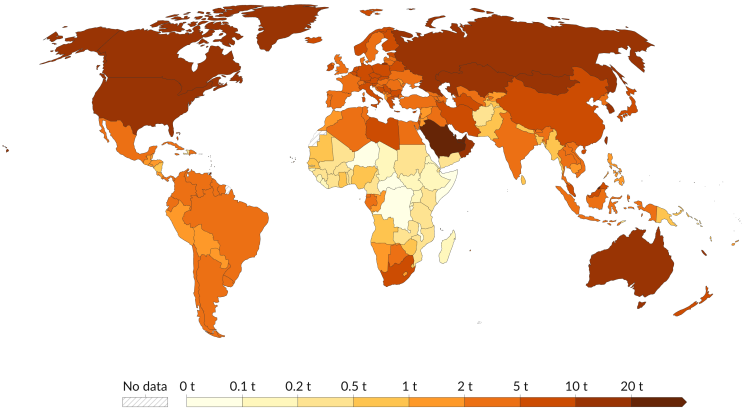
OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

1. Fossil emissions Fossil emissions measure the quantity of carbon dioxide (CO_2) emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production.
Fossil CO_2 includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes.
Fossil emissions do not include land use change, deforestation, soils, or vegetation.

Per capita CO_2 emissions, 2023

Carbon dioxide (CO_2) emissions from fossil fuels and industry[1]. Land-use change is not included.

Our World in Data



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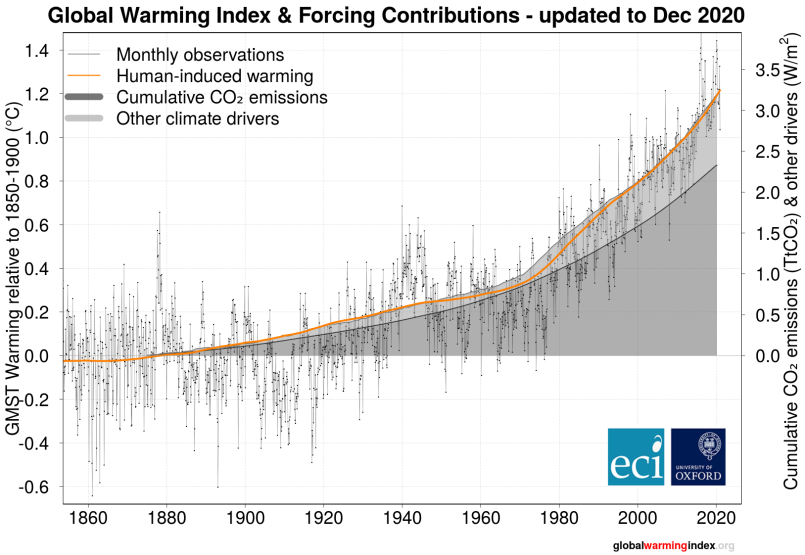
Global Temperature Rise

- Following Krusell and Smith (2022), we can write:

$$T_t = \frac{\lambda}{\ln 2} \ln\left(\frac{S_t}{\bar{S}}\right)$$

  - T_t: global temperature in year t (relative to pre-industrial)
  - S_t: the stock of carbon in the atmosphere (in giga-tonnes)
  - $\bar{S}$: the pre-industrial stock of carbon
  - λ: the sensitivity of the global temperature to changes in the stock of atmospheric carbon (around 3)

T_t and S_t over time



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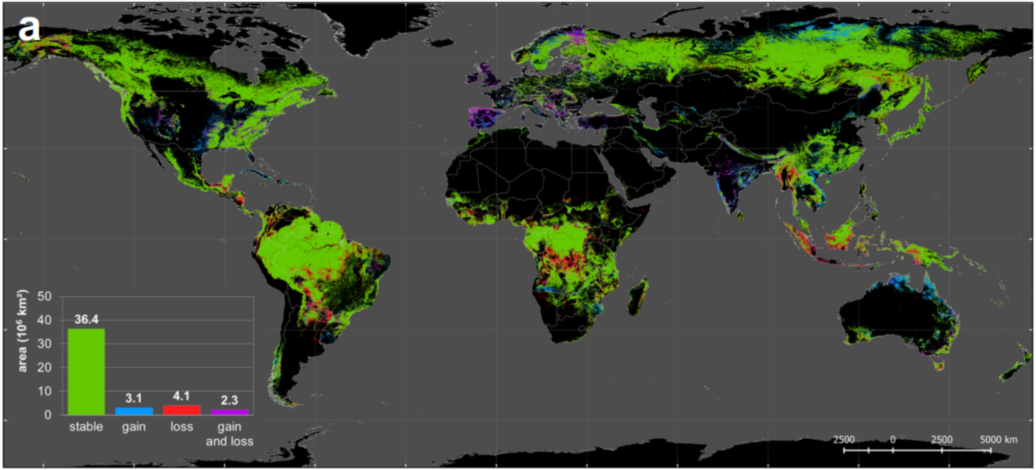
Deforestation contribution to climate change

- Deforestation is a major driver of climate change
  - Second largest source of carbon dioxide to the atmosphere, after fossil fuel combustion
  - Contributes 8-20% of total human greenhouse gas emission
- Over the 20-year period from 2001-2020, 1.48 million km^2 of forest area in the tropics was deforested
- There is significant spatial variability in
  - Where deforestation happened
  - The carbon "importance" of different types of forests

Global distribution of deforestation 1960-2019



Source: Winkler et al. (2021)

Global distribution of deforestation 2001-2020

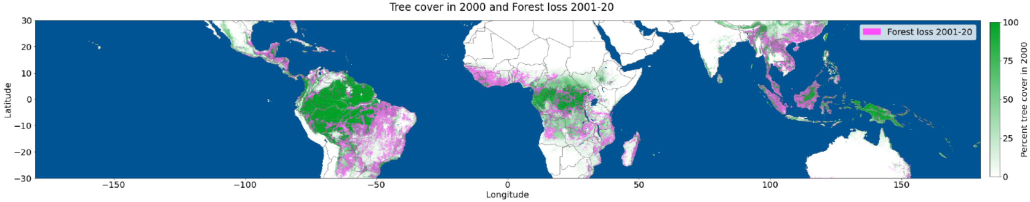


Figure 2. Tree cover in 2000 and forest loss from 2001–2020. Data on tree canopy cover in 2000 and gross forest cover loss from 2001–2020 are from (Hansen et al., 2013). Forest is defined as 50% tree cover. Loss data indicate binary occurrence of a forest loss event in a given pixel and the year in which the event primarily occurred. We multiply binary forest loss occurrence by 2000 tree cover to calculate the extent of the loss by year.

Source: Balboni et al. (2023)

Deforestation concentrated in Brazil, Indonesia, and DRC

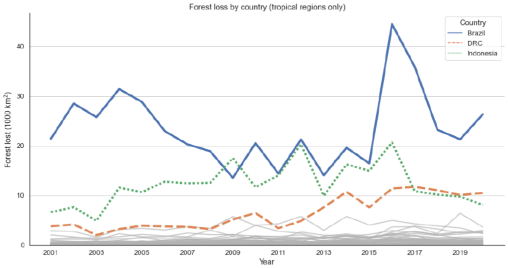


Figure 3. Forest loss by country, tropical regions only. Data on tree canopy cover in 2000 and gross forest cover loss from 2001-2020 taken from Hansen et al. (2013). Forest defined as 50% tree cover. Loss data indicates binary occurrence of a forest loss event in a given pixel and the year in which the event primarily occurred. Binary forest loss occurrence was multiplied by 2000 tree cover to indicate the extent of the loss by year, and then aggregated by intersections of country boundaries (from www.gadm.org) and the climate zone inside the region between the Tropics of Cancer and Capricorn.

Source: Balboni et al. (2023)

- Brazil, Indonesia, and the Democratic Republic of the Congo account for 32%, 16%, and 9% of global 2001-10 loss

Carbon storage varies dramatically between forests

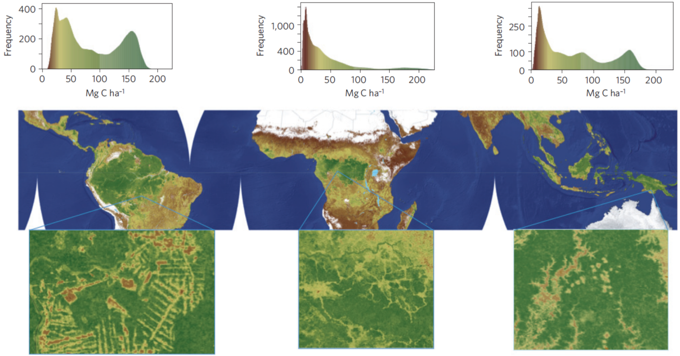


Figure 1 | Carbon contained in the aboveground live woody vegetation of tropical America, Africa and Asia (Australia excluded). The upper panels show the frequency distribution of carbon in units of Mg C ha^{-1} for each region. Inset figures across the bottom provide higher-resolution examples of the spatial detail present in the satellite-derived biomass data set. Carbon amount is represented in the maps as a colour scheme from dark brown (low carbon) to dark green (high carbon). See upper panels for numeric values.

Source: Baccini et al. (2012)

- Satellite data allows to estimate carbon density of vegetation at high spatial resolution

Deforestation contribution to climate change

- Emissions due to deforestation can be calculated combining
  1. Carbon density for each region
  2. Deforestation maps
- Lawrence and Vandecar (2015): complete loss of tropical forest cover can increase mean global temperatures by 0.1-0.7 $^{\circ}$C

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Regional climate responses to global warming

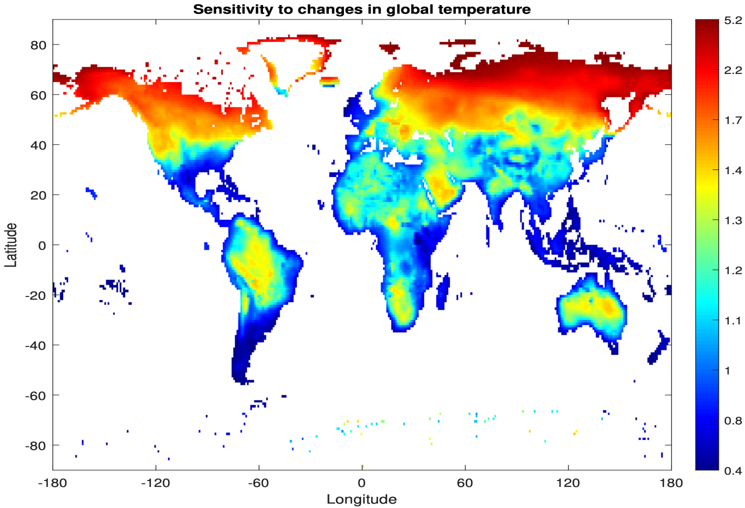
Krusell and Smith (2022)

- How does each region's climate respond to global warming?
  - Answer given by complex global and regional climate models
  - Use "pattern scaling" (aka "statistical downscaling"): statistical description of temperature in a given region as a linear function of global temperature T_t
- Regional temperature in period t is

$$T_{it} = T_{i0} + \gamma_i \left(T_t - T_0 \right)$$

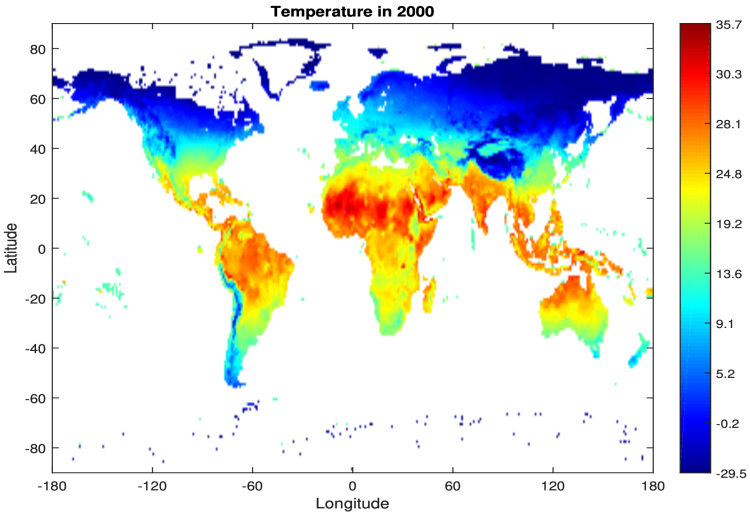
  - T_{i0}: the temperature in region i in year 1990
  - γ_i: region-specific sensitivity to a change in the global temperature

Sensitivity to changes in global temperature (γ_i)



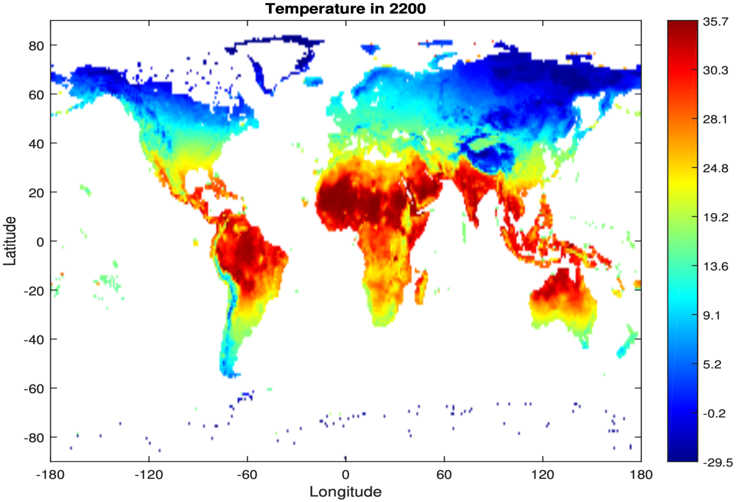
Source: Krusell and Smith (2022)

Temperature in 2000 (T_{2000})



Source: Krusell and Smith (2022)

Temperature in 2200 (T_{2200})

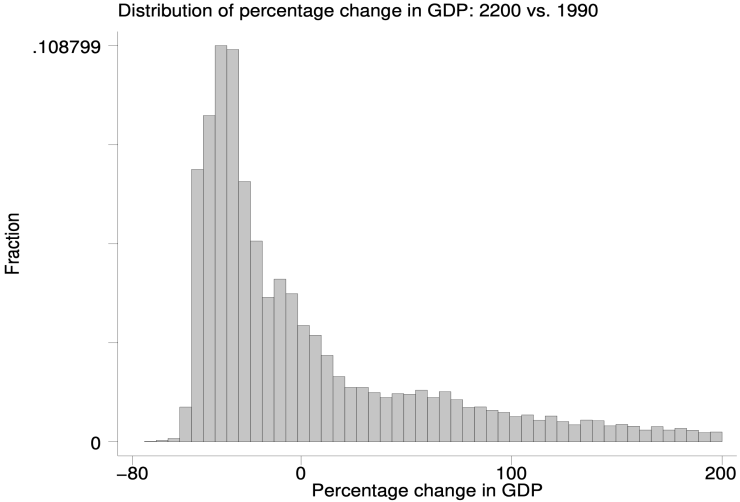


Source: Krusell and Smith (2022)

Krusell and Smith (2022)

- Question: How will the economic impacts vary across space?
- Approach:
  - Build a global economy-climate model with a high degree of geographic resolution (1° x 1°)
  - Use it to simulate the global and regional impacts of climate change
- Main findings:
  - Effects of climate change vary dramatically across space
  - Global average effect is negative, but many regions gain
  - The magnitude of global effects is dwarfed by the differences across space
  - Tax on carbon would affect welfare positively on average, but there is a large disparity across regions (56% of regions gain, while 44% lose)

Impact of global warming on regional GDPs



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Imperfect mobility

- Roback model implies real wage (indirect utility) equalization across locations
  - Assuming perfect or costless labor mobility
- We will now extend the model to incorporate imperfect labor mobility
  - We can call this a modern **quantitative spatial equilibrium (QSE)** model
- To model migration (or relocation) decisions we will:
  1. Add labor migration frictions in the form of migration costs: μ_{ij}
  2. Modify slightly the notion of spatial equilibrium
  3. Need an initial allocation of labor L_{i0}

Modeling the migration decision (I/II)

- Individuals start in a location i, and choose a location for the next period
- The welfare of individuals who start in i and go to j is

$$W_{ij} = \frac{w_j \bar{u}_j}{\mu_{ij}}$$

  - $w_j \bar{u}_j$ is the indirect utility at the destination location j
  - μ_{ij} are **mobility costs**

- **Spatial equilibrium**: utility equalization among people who start at the same location

$$W_{ij} = W_i \text{ for any destination } j,$$

and everyone lives somewhere $\sum_j L_{ij} = L_{i0}$

Modeling the migration decision (II/II)

- Assume that mobility costs take the form

$$\mu_{ij} = \kappa_{ij} \left(\frac{L_{ij}}{L_{i0}} \right)^{\beta}$$

  - $\kappa_{ij} \geq 1$ are the exogenous migration costs, assume $\kappa_{ii} = 1$ (no cost of staying)
  - L_{i0} is the initial number of people in i
  - L_{ij} is the number of people who move from i to j
- Now, congestion forces are a function of how many people from an individual's location move with that individual to another location
  - β governs the extent to which migration flows generate congestion externalities

Equilibrium solution

- Individual optimization + mobility cost + utility equalization:

$$L_{ij} = \left(\frac{w_j \bar{u}_j}{\kappa_{ij}}\right)^{\frac{1}{\beta}} \frac{L_{i0}}{W_i^{\frac{1}{\beta}}} \tag{1}$$

- Plug into $\sum_j L_{ij} = L_{i0}$ to solve for W_i:

$$W_i = \left(\sum_j \left(w_j \bar{u}_j / \kappa_{ij}\right)^{1/\beta}\right)^{\beta}$$

- Replacing back into L_{ij}:

$$\frac{L_{ij}}{L_{i0}} = \frac{\left(w_j \bar{u}_j / \kappa_{ij}\right)^{1/\beta}}{\sum_\ell \left(w_\ell \bar{u}_\ell / \kappa_{i\ell}\right)^{1/\beta}}$$

Equilibrium conditions

- Therefore the equilibrium for each location i is

$$
\begin{aligned}
L_{ij} &= \frac{\left(w_j \bar{u}_j / \kappa_{ij}\right)^{1/\beta}}{\sum_\ell \left(w_\ell \bar{u}_\ell / \kappa_{i\ell}\right)^{1/\beta}} L_{i0} \\
W_i &= \left(\sum_j \left(w_j \bar{u}_j / \kappa_{ij}\right)^{1/\beta} \right)^{\beta}
\end{aligned}
$$

- These equations map exogenous variables $(L_{i0}, w_j, \bar{u}_j, \kappa_{ij})$ to endogenous variables (L_{ij}, W_i)

Model implications

- The migration equation (1) is known as a **gravity equation** of worker flows

$$\ln L_{ij} = -\frac{1}{\beta} \underbrace{\ln \kappa_{ij}}_{\text{"distance"}} + \frac{1}{\beta} \underbrace{\ln \left(w_j \bar{u}_j \right)}_{\text{"pull" factors}} + \frac{1}{\beta} \underbrace{\ln \left(L_{i0}^{\beta} / W_i \right)}_{\text{"push" factors}}$$

- More workers move from i to j if:
  - There are a lot of workers starting in i (L_{i0} high)
  - Wages in j are high (w_j high)
  - Amenities in j are high ($\bar{u}_j$ high)
  - Migration costs from i to j are low (κ_{ij} low)

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Cruz and Rossi-Hansberg (2021)

"The Economic Geography of Global Warming"

- Approach:
  - Develop a spatial growth model with migration, trade, and innovation
  - Simulate the world economy forward to evaluate the consequences of global warming
- Their model is richer than the one we developed, but we can have 2 key ingredients:
  - Costly migration (the extension we just discussed)
  - Damage functions mapping temperature to amenities and productivities

Damages to amenities

- Local amenities in a region i at time t depend on fundamental amenity $\bar{u}_{it}$ and congestion $L_{it}^{-\beta}$:

$$u_{it} = \bar{u}_{it} L_{it}^{-\beta}$$

- Incorporate impacts of local temperature on amenities:

$$\bar{u}_{it} = \left(1 + \delta^{u}\left(T_{it-1}\right) \Delta T_{it}\right) \bar{u}_{it-1}$$

  - The function $\delta^{u}\left(T_{it-1}\right)$ captures the marginal damages from changes in temperatures
  - Damage depends on the level of temperature, T_{it-1}, not just the change ΔT_{it}
  - E.g., warmer climate decrease amenities in hot places (like Congo) while benefit amenities in cold places (like Siberia)

Damages to productivity

- Local productivity in a region i at time t depends on fundamental productivity $\bar{A}_{it}$ and agglomeration L_{it}^{α}:

$$A_{it} = \bar{A}_{it} L_{it}^{\alpha}$$

- Incorporate impacts of local temperature on productivities:

$$\bar{A}_{it} = \left(1 + \delta^{A}\left(T_{it-1}\right)\Delta T_{it}\right)\bar{A}_{it-1}$$

  - The function $\delta^{A}\left(T_{it-1}\right)$ captures the marginal damages from changes in temperatures
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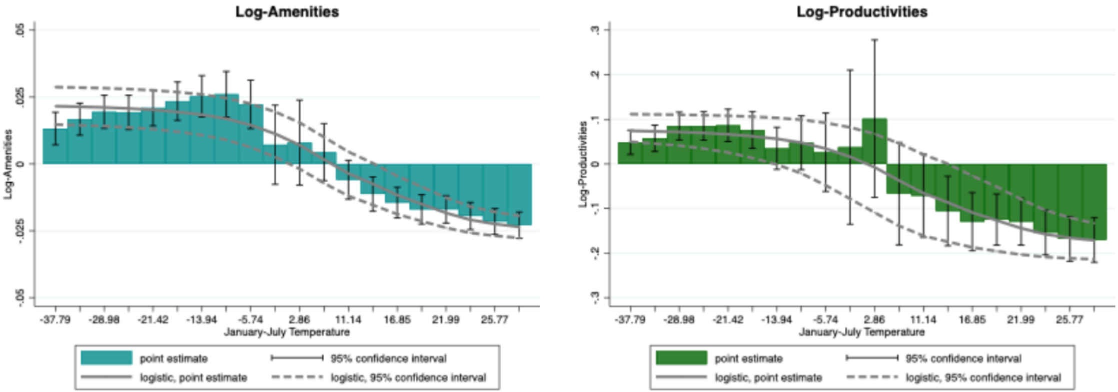
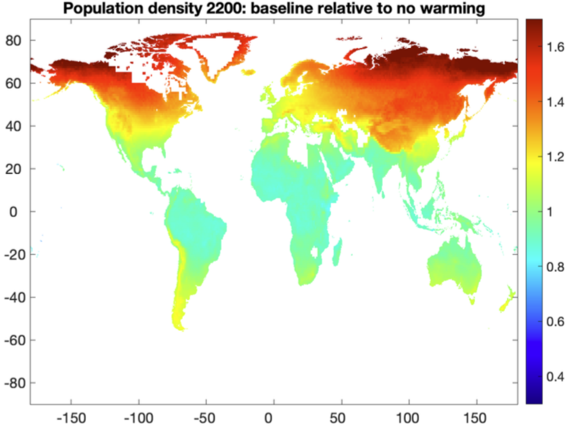
Results: estimates of $\delta^u(T_{it-1})$ and $\delta^A(T_{it-1})$



Notes: effect of $+1^\circ$C on amenities and productivities

Results: effects of global warming (RCP 8.5) by the year 2200

- Average welfare down by 6%
  - Hottest regions have losses, coldest regions have gains
- Increases inequality across space
  - Losses negatively correlated with current real income per capita
- 1/2 a Billion people are displaced
- If migration costs rise 25%, welfare loss rises to 9%



Results: discussion

- Results underscore the importance of economic adaptation through migration
  - Trade costs are less important, innovation lies in between
- Is the 6% welfare loss a best case scenario?
  - Parameters are from long run, slow movement of people
  - But we are talking of migration on historically large scale (congestion?)
- More in general, the quantitative predictions of these models depend on the extent to which market frictions constraint optimal adjustment to climate change

Appendix

References I

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