Virtual Seminar on Climate Economics

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Climate Change Around the World

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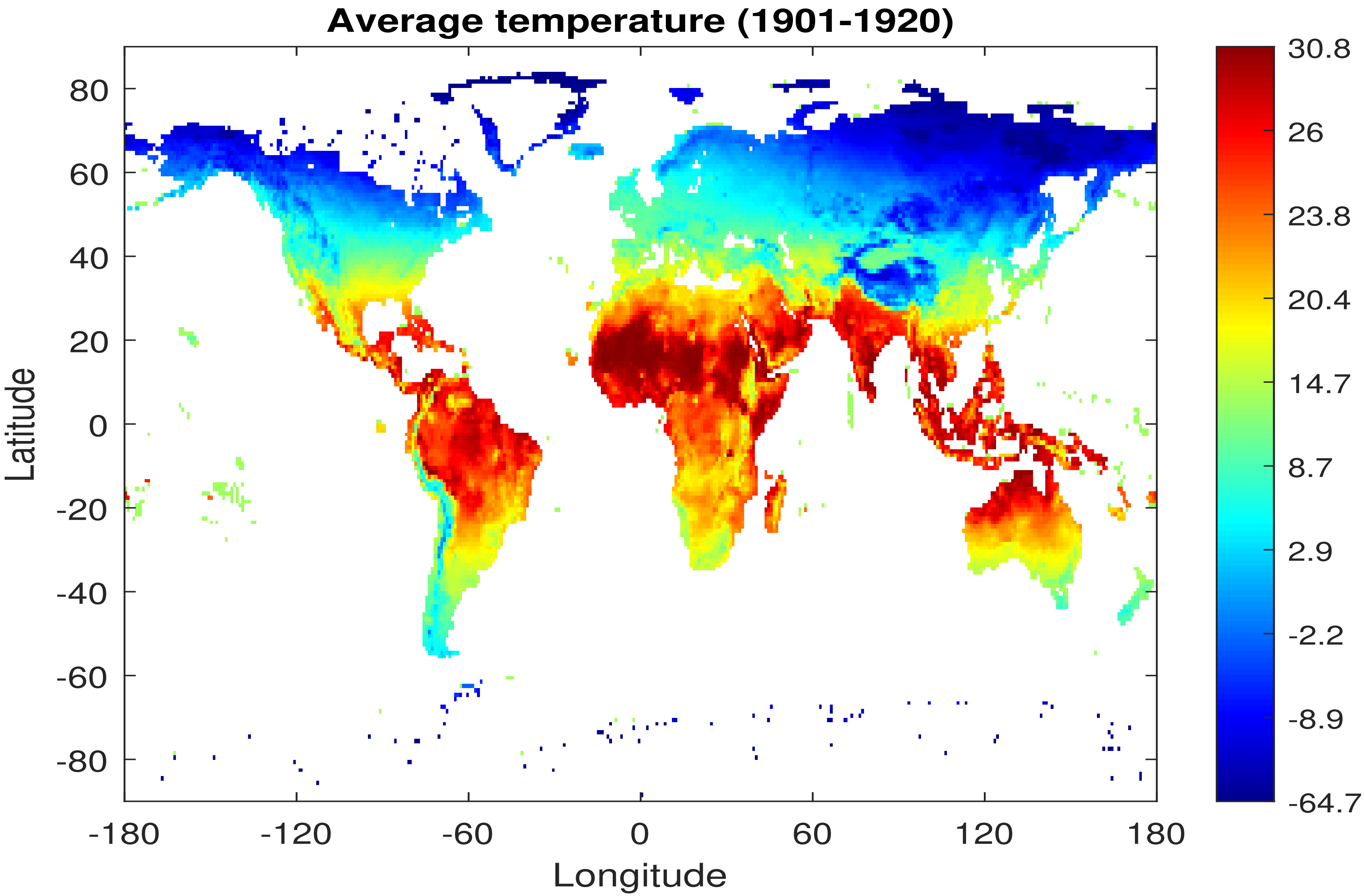
Goals of the project

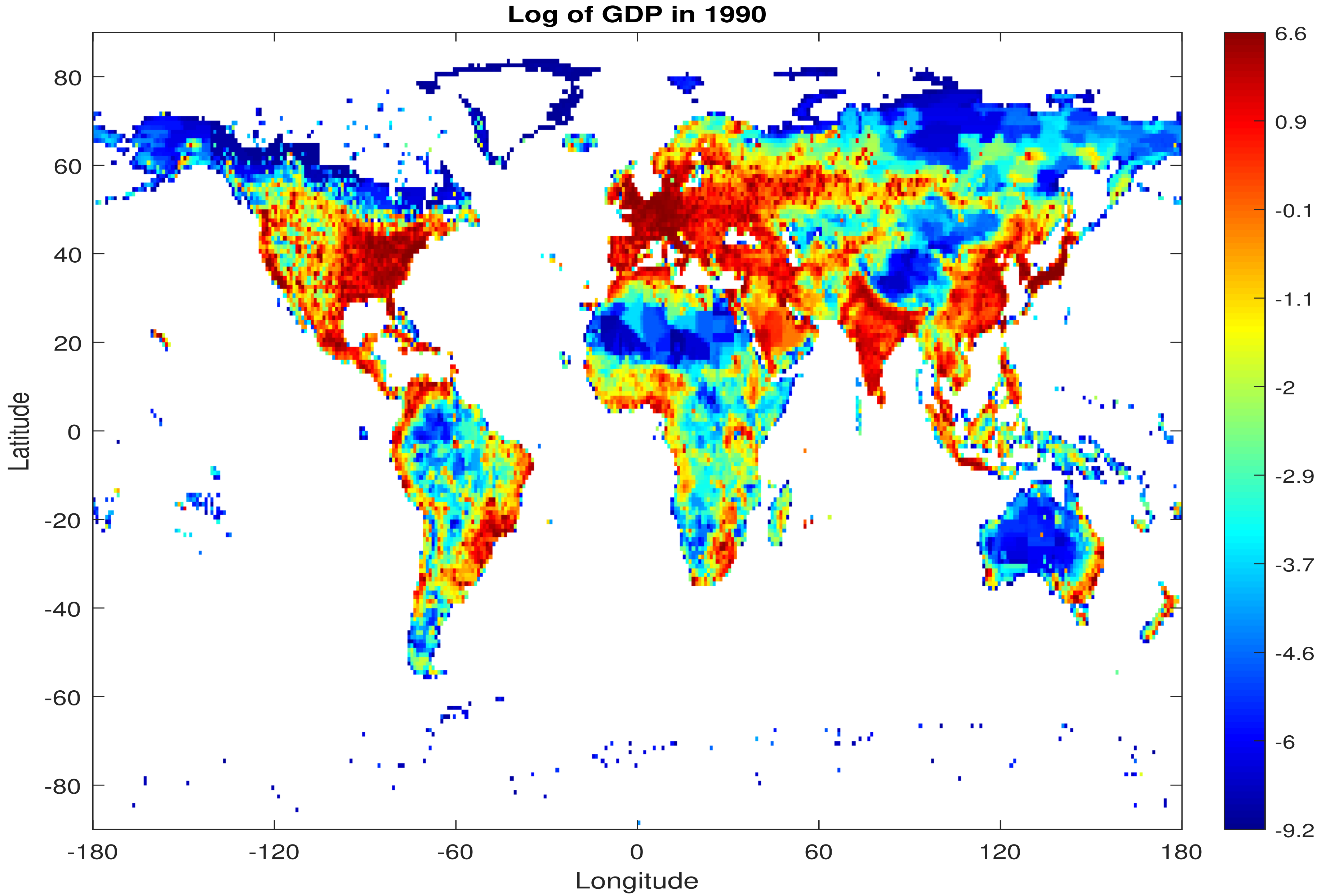
- Construct a global model of economy-climate interactions featuring a high degree of geographic resolution ($1^\circ \times 1^\circ$ regions). The model extends Nordhaus's DICE and RICE models—which have little (or no) regional detail—to a dynamic, general equilibrium setting with many regions.
- Use the model as a laboratory to quantify the distributional effects of climate change and climate policy.
- If a set of regions imposes a carbon tax, how does the path of global emissions respond? Which regions gain and which lose, and by how much?
- Growing literature on spatial equilibrium models of climate change: Brock, Cai, and Xepapadeas; Brock, Engström, Grass, and Xepapadeas; Cruz; Cruz and Rossi-Hansberg; Desmet and Rossi-Hansberg; Hassler and Krusell; Fried; Hassler, Krusell, Olovsson, and Reiter; Hillebrand and Hillebrand.

The regional data

- Unit of analysis: $1^\circ \times 1^\circ$ cells containing land.
- The model contains $\sim 19,000$ regions (or cell-countries).
- Matsuura and Willmott: gridded ($0.5^\circ \times 0.5^\circ$) monthly terrestrial temperature data for 1900–2008.
- Nordhaus's G-Econ database: gross domestic product (GDP) and population for all such cells in 1990.



Average temperature (1901-1920)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
30.8
26
23.8
20.4
14.7
8.7
2.9
-2.2
-8.9
-64.7



Log of GDP in 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6.6
0.9
-0.1
-1.1
-2
-2.9
-3.7
-4.6
-6
-9.2

The climate system and the carbon cycle

- Global temperature, T_t (relative to pre-industrial), is:

$$T_t = \lambda \frac{\ln(S_t/\bar{S})}{\ln(2)},$$

  where S_t and $\bar{S}$ are time-t and pre-industrial stocks of carbon. $\lambda \approx 3 \pm 1.5$ is "climate sensitivity".
- $S_t = S_{1t} + S_{2t}$, the first stock permanent, the second depreciating.
- Half-life of a freshly-emitted unit of carbon is 30 years; half-life of the depreciating stock is 300 years.

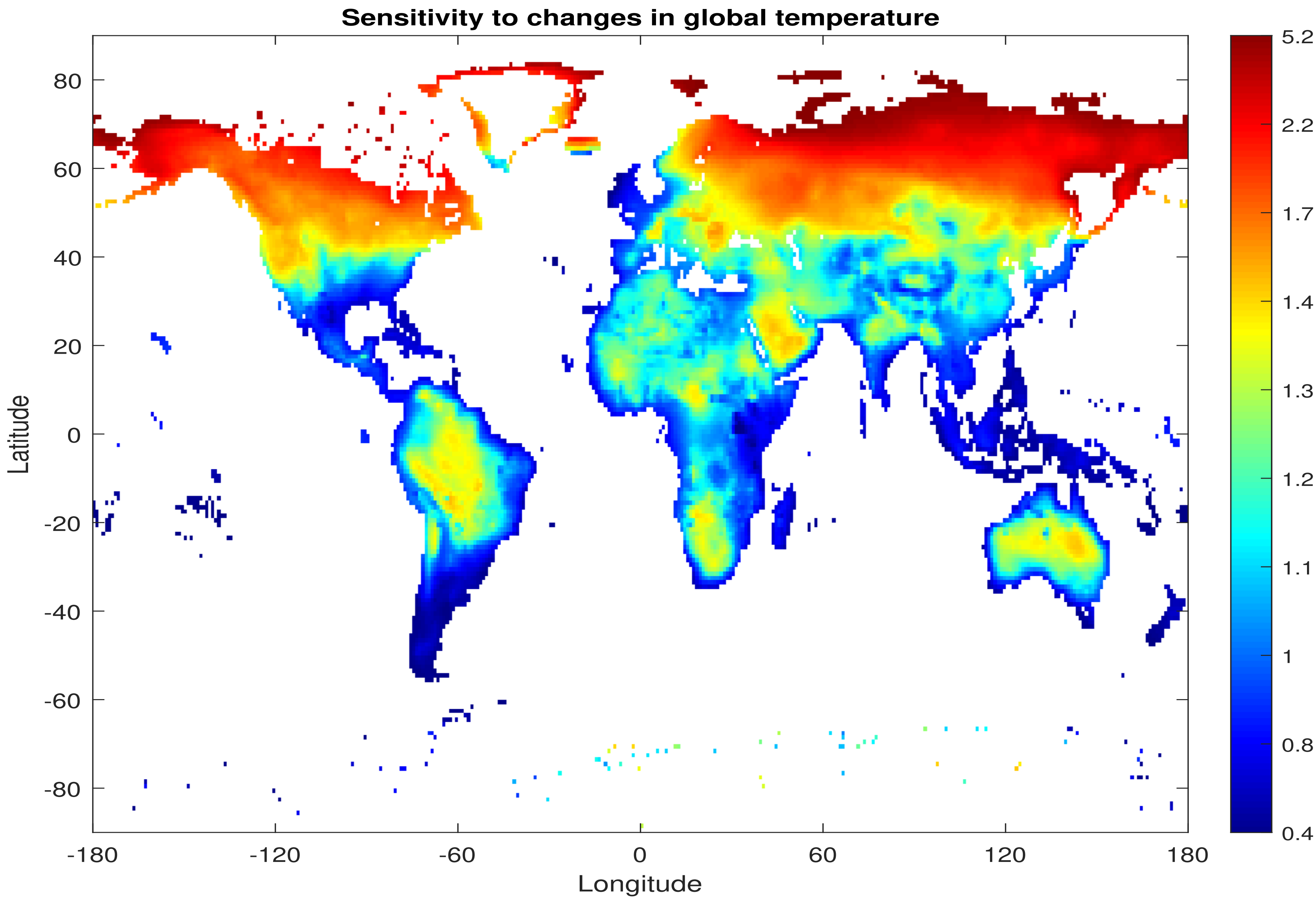
The economic model

- Forward-looking consumers and firms in each region determine their consumption, saving, and energy use. No migration.
- Neoclassical technologies for producing both final goods and energy, using capital, labor, and energy as inputs.
- Think of energy as coal (non-exhaustible). Energy slowly, exogenously, becomes green over time.
- Regional TFP is the product of two components: the first is exogenous and the second varies with regional temperature.
- Market structure: two cases.
  - Autarky (regions only linked via emission externality).
  - Unrestricted borrowing/lending.
- Summary: like Aiyagari/Angeletos, though no shocks (such as weather) in this version.
- Adaptation: consumption smoothing and, in case with international markets, capital mobility ("leakage").

Pattern scaling

How does region *i*'s climate respond to global warming?

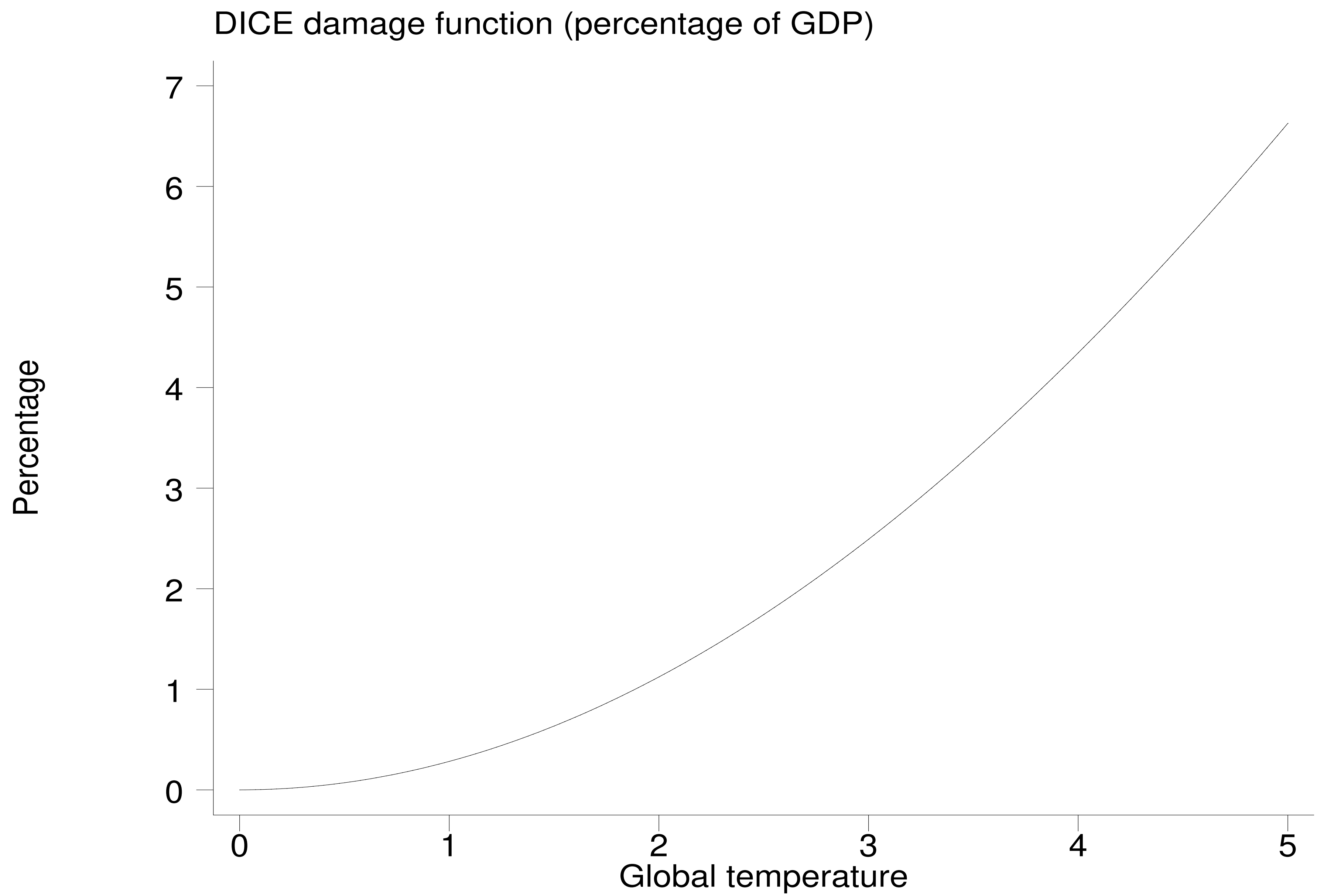
- Answer given by complex global and regional climate models. But not feasible (yet) to combine these with economic model.
- Therefore, use "pattern scaling" (aka "statistical downscaling"): statistical description of temperature in a given region as a function of a single state variable—average global temperature.
- Capture sensitivity of temperature in region *i* to global temperature using a region-specific linear relationship.
- With help of climate scientists, use runs of (highly) complex climate models into the future to estimate sensitivities.



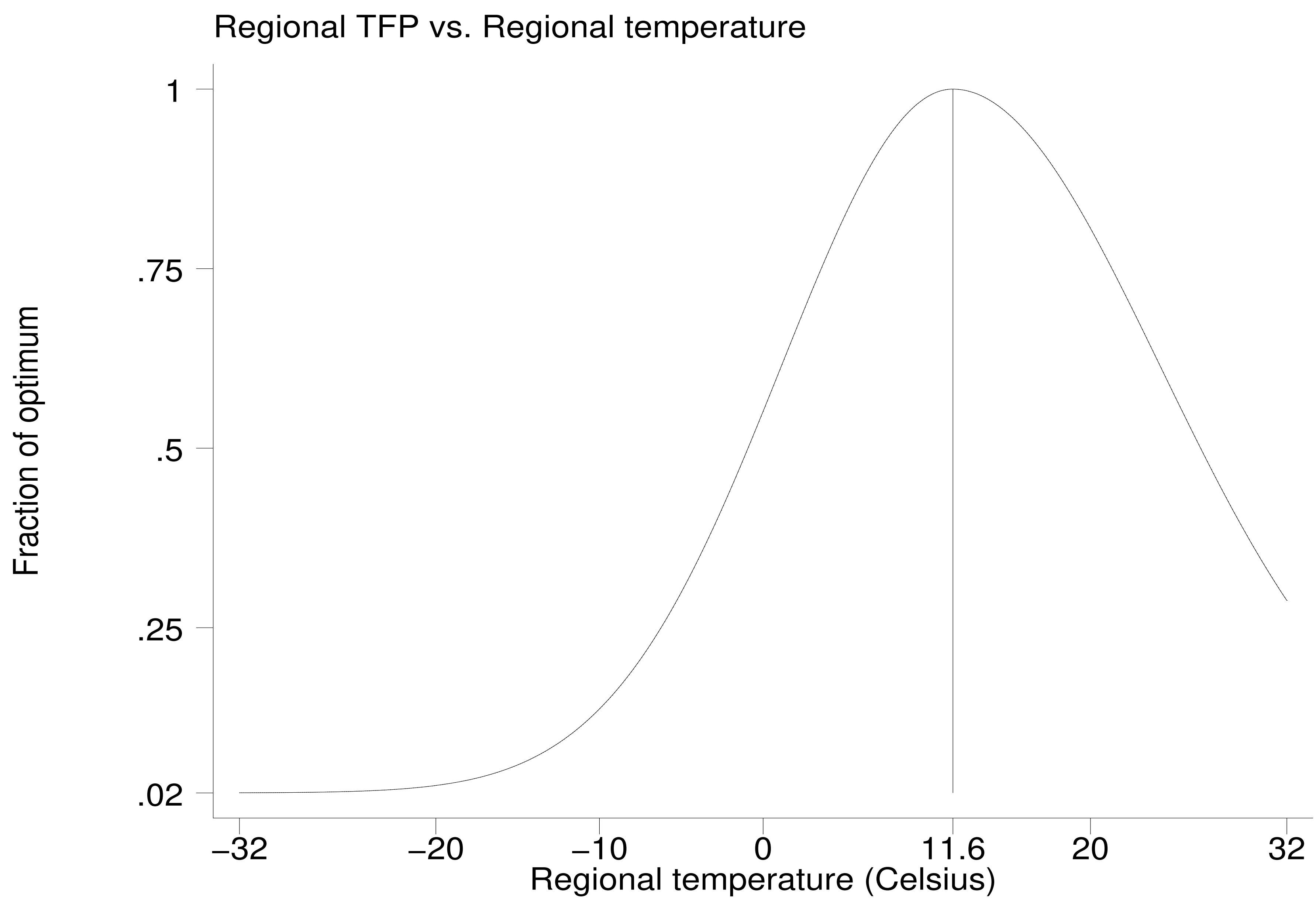
Sensitivity to changes in global temperature
80
60
40
20
0
-20
-40
-60
-80
Latitude
-180
-120
-60
0
60
120
180
Longitude
5.2
2.2
1.7
1.4
1.3
1.2
1.1
1
0.8
0.4

Our damage specification

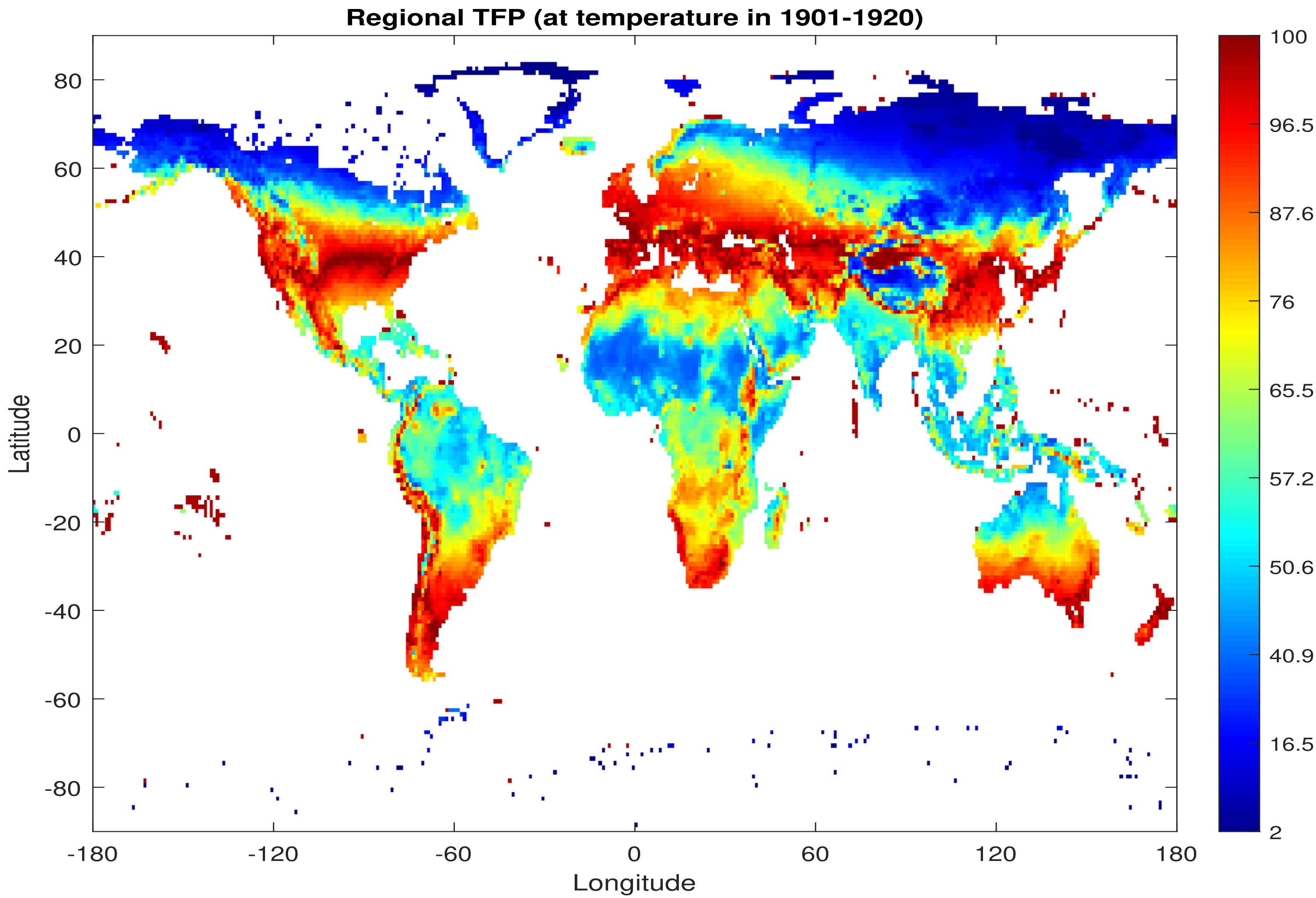
- What are the economic damages in region i as a result of global warming?
- Our approach: let TFP in region i be a function D of *local temperature* that is common across all regions.
- D has an inverse U-shape and varies between 0 and 1 (so it captures variations in regional TFP *relative to* the exogenous component of regional TFP).
- Calibrate D so that the high-resolution model generates *aggregate* damages from changes in the global temperature (expressed as a percentage of global GDP) that match Nordhaus's DICE damage function (itself also modelled as a drag on global TFP).

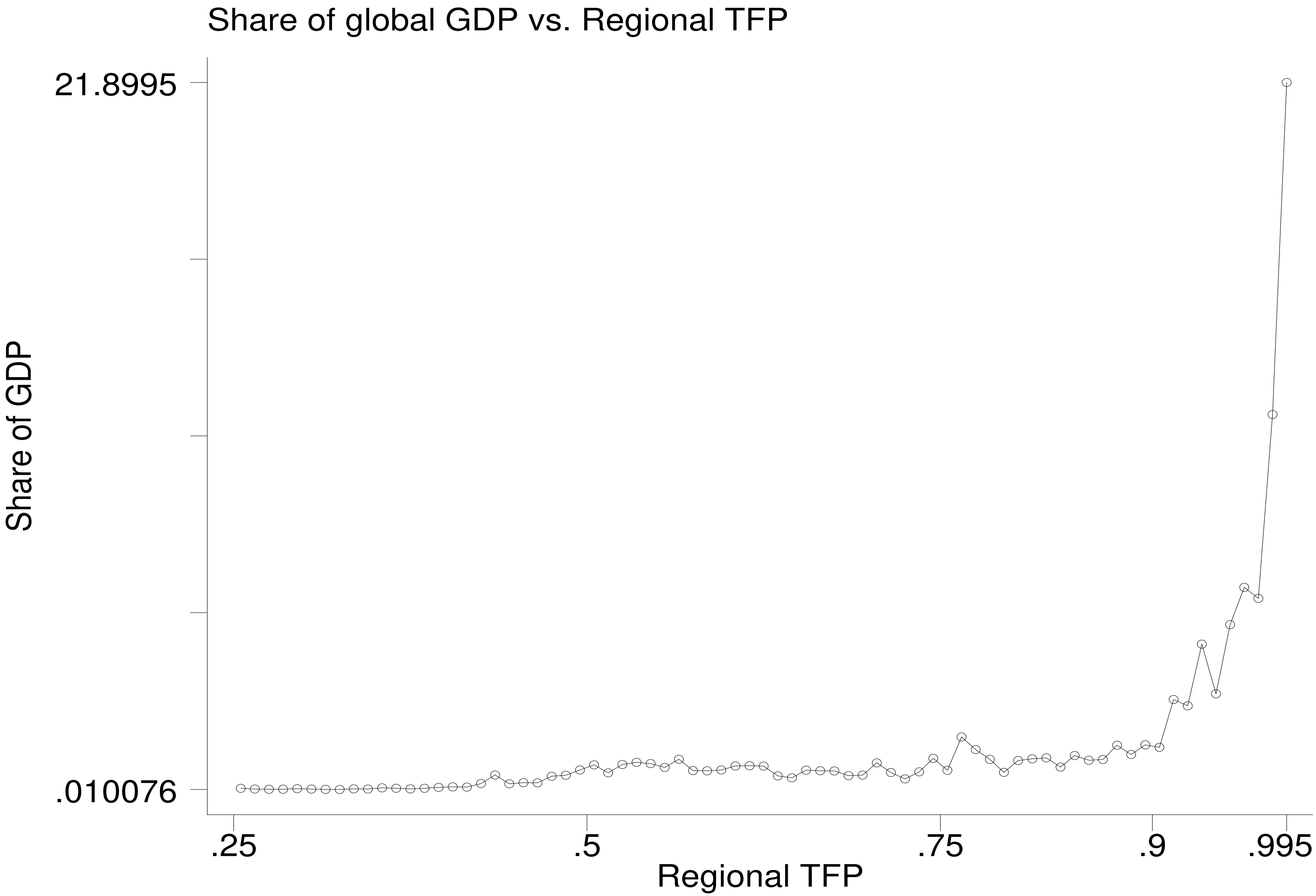


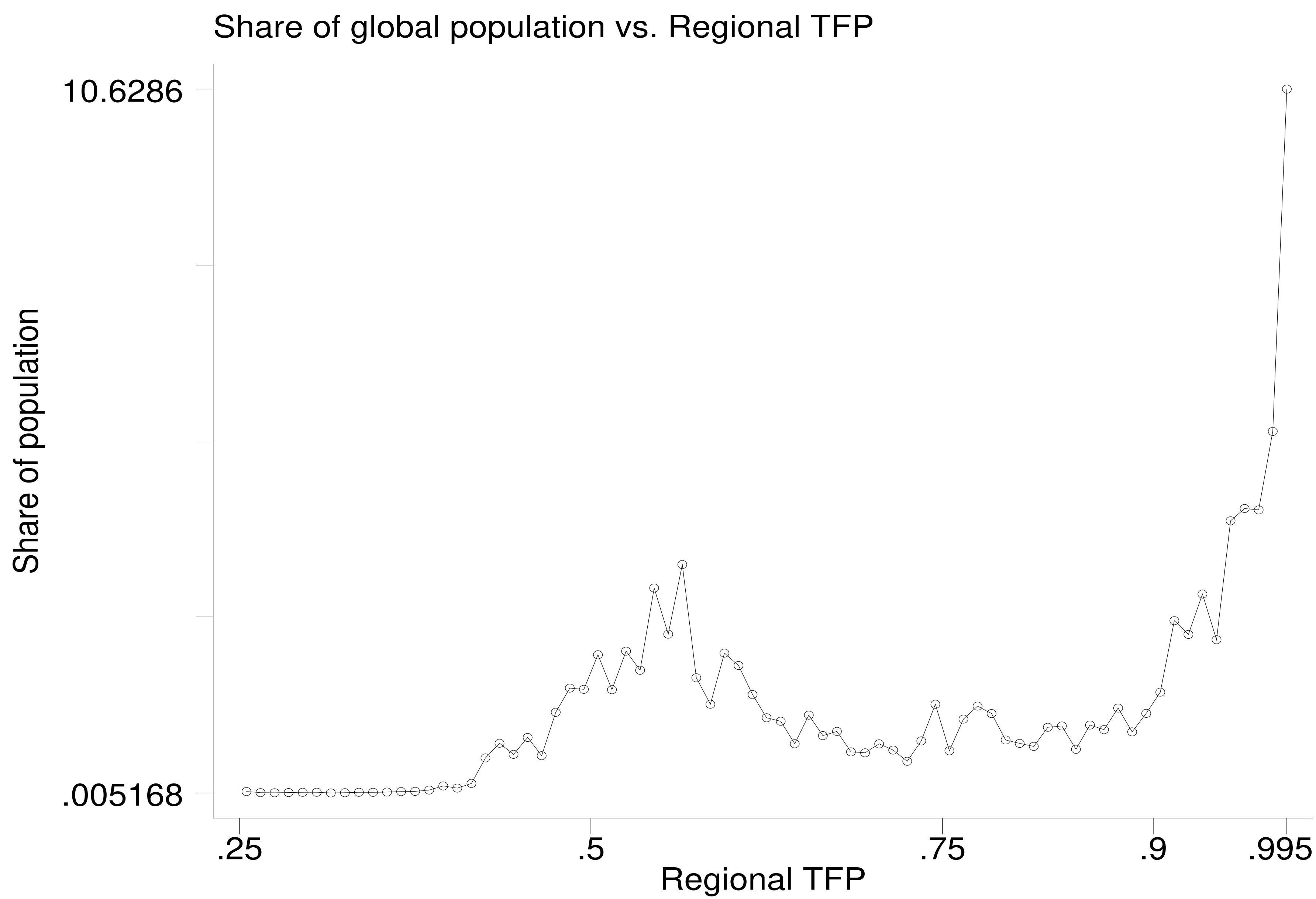
DICE damage function (percentage of GDP)
Percentage
0
1
2
3
4
5
6
7
0
1
2
3
4
5
Global temperature



Regional TFP vs. Regional temperature
1
.75
.5
.25
.02
Fraction of optimum
–32
–20
–10
0
11.6
20
32
Regional temperature (Celsius)

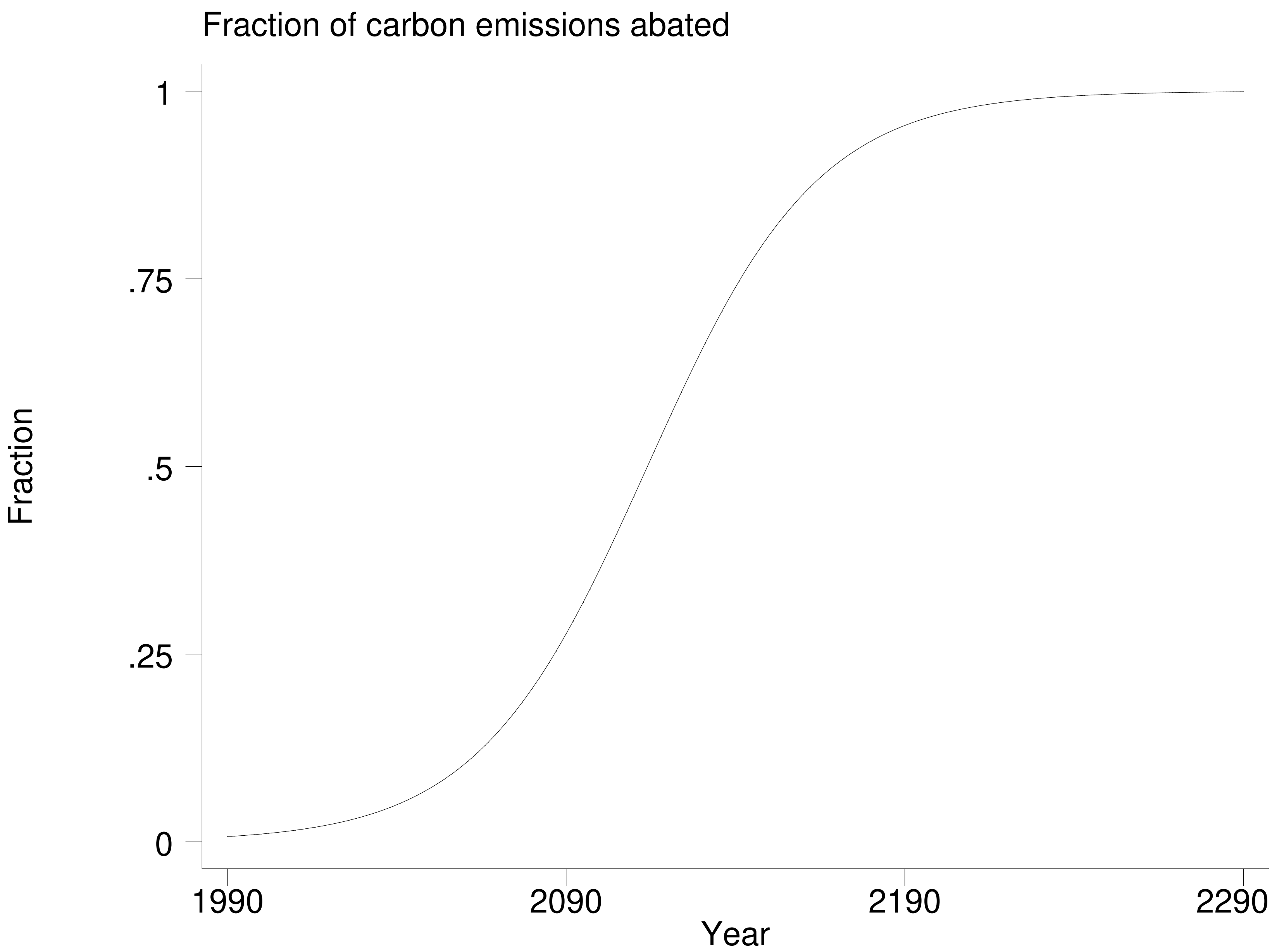

Regional TFP (at temperature in 1901-1920)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
100
96.5
87.6
76
65.5
57.2
50.6
40.9
16.5
2


Share of global GDP vs. Regional TFP
21.8995
.010076
Share of GDP
.25
.5
.75
.9
.995
Regional TFP


Share of global population vs. Regional TFP
Share of population
10.6286
.005168
.25
.5
.75
.9
.995
Regional TFP

The rest of the calibration

- Annual time step, log utility, discount factor of 0.985.
- Production function: Cobb-Douglas in capital, labor, and energy with capital's share of 36% and energy's share of 6%.
- Exogenous component of regional TFP grows at 1% per year.
- Capital depreciates at 6% per year.
- Initial region-specific capital and region-specific TFP chosen to match regional GDP per capita and equalize MPKs in 1990.
- Relative price of a BTU of energy chosen to match total carbon emissions in 1990.
- Energy use slowly becomes green (exogenous logistic curve).


Fraction of carbon emissions abated
Fraction
1
.75
.5
.25
0
1990
2090
2190
2290
Year

Global equilibrium

- Equilibrium conditions:
  - Consumer-entrepreneurs in each region behave optimally given paths for the global temperature and the global interest rate.
  - The implied path of global emissions generates the path for global temperature.
  - The global bond market clears in every period.
- With free capital mobility, the model aggregates: need to solve only the problem of a global "stand-in" consumer, working backwards from the long-run balanced growth path, taking the global temperature path as given.
- In autarky, need to solve $\sim$19,000 dynamic programs! But can be done quickly using nonlinear interpolation across regional "types" and parallel methods.

Comments on the model

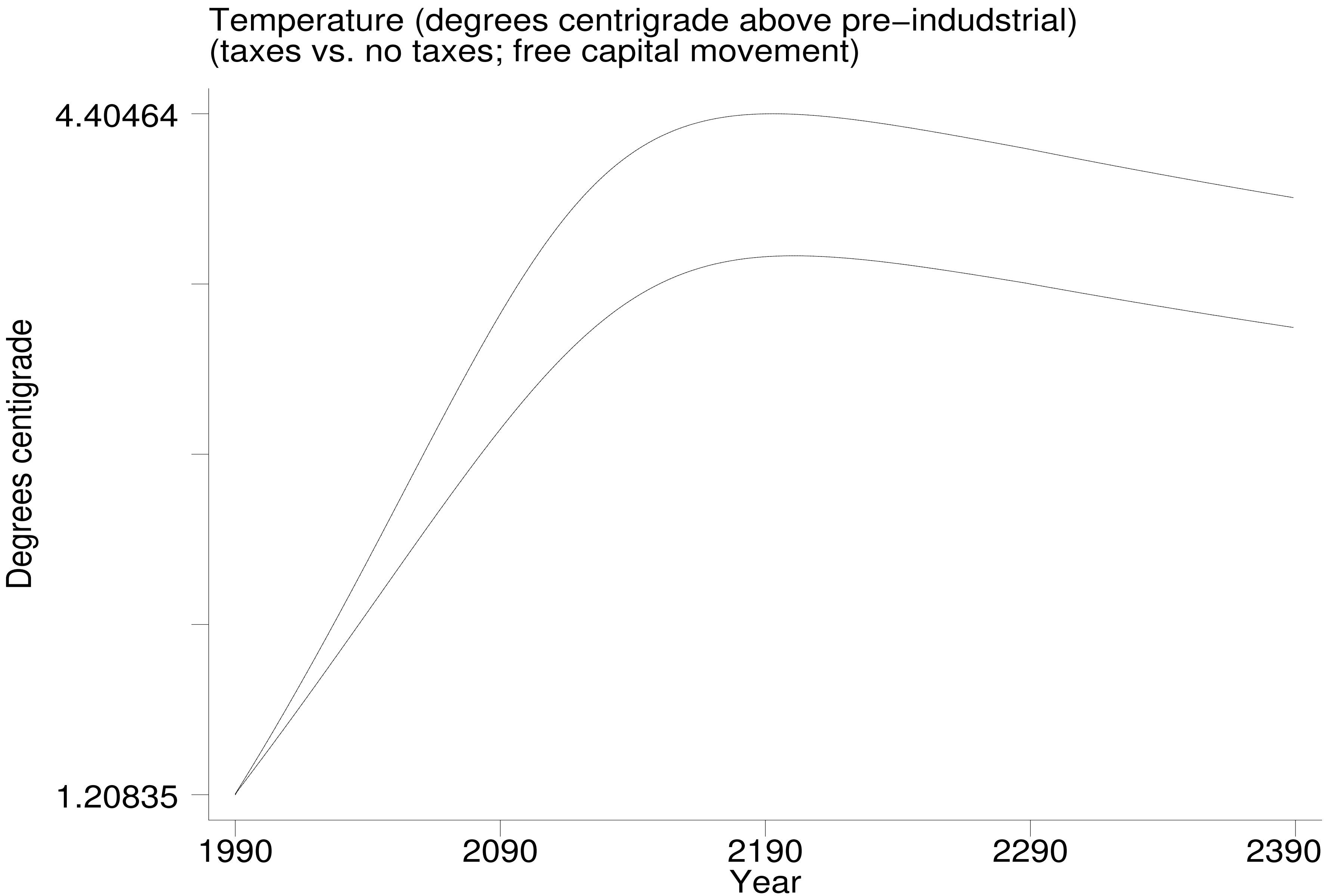
- At the aggregate level, the spatial model with free capital mobility nests the DICE model.
- Regional damages are assumed to have an inverse-U shape calibrated to match aggregate damages in DICE model.
- Spatial adaptation takes places through differing patterns of capital accumulation across regions.
- Quantitative results differ little under autarky.

Experiments

- Laissez-faire.
- Main policy experiment: all regions impose common path for carbon taxes, financed locally (no interregional transfers).
- Throughout: focus on relative effects, not aggregates.

Main findings

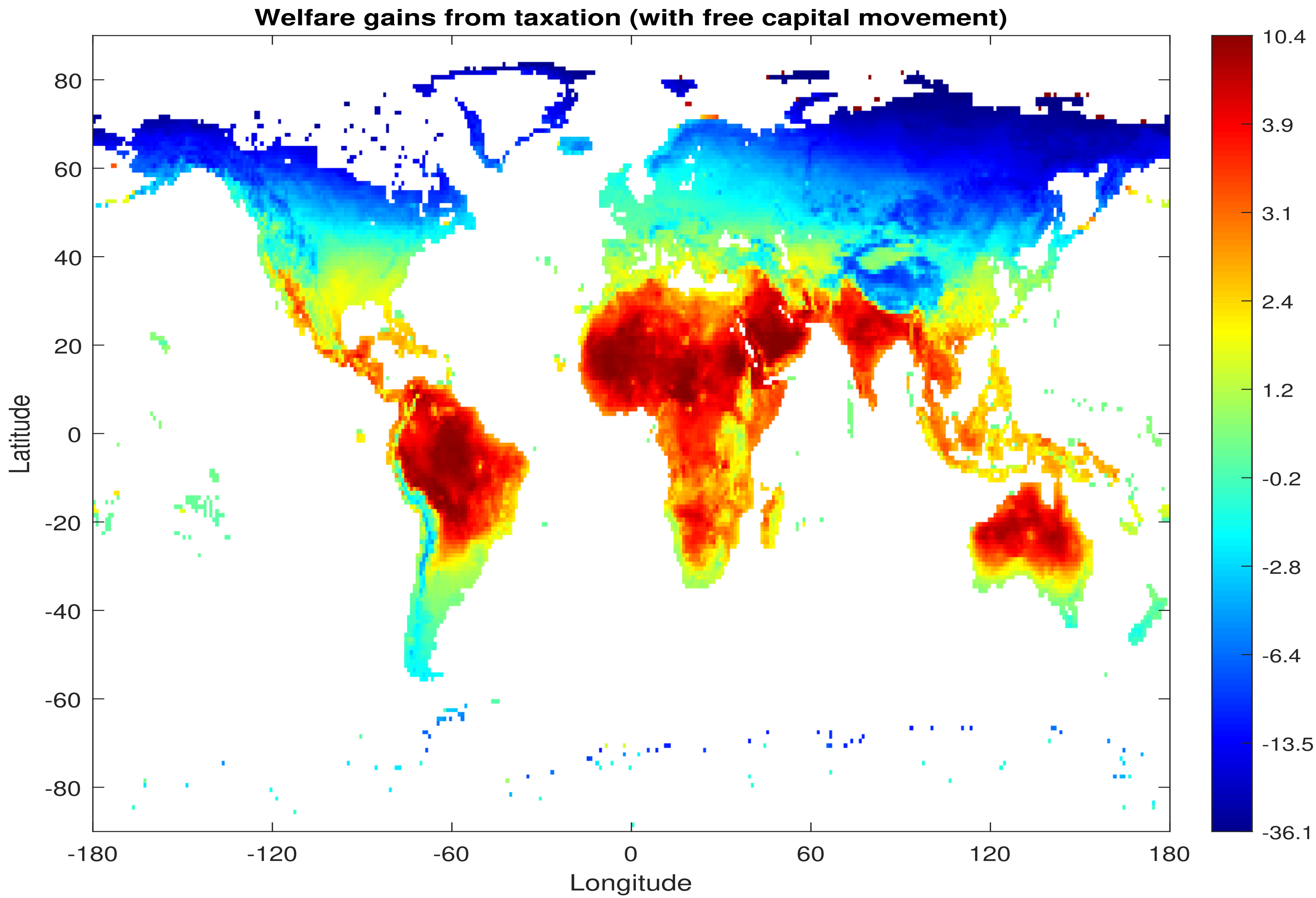
- Climate change affects regions *very* differently. Stakes big at regional level.
- Though an optimal tax on carbon would affect welfare positively in an average sense, there is a large disparity of views across regions (56% of regions gain, while 44% lose).
- Findings are very close for two extreme market structures (autarky and international capital markets).
- Climate change leads to large increases in global inequality in GDP per capita (both across regions and across countries); the tax on carbon mitigates these increases only to a small degree.


Temperature (degrees centrigrade above pre−indudstrial)
(taxes vs. no taxes; free capital movement)
4.40464
1.20835
Degrees centigrade
1990
2090
2190
2290
2390
Year

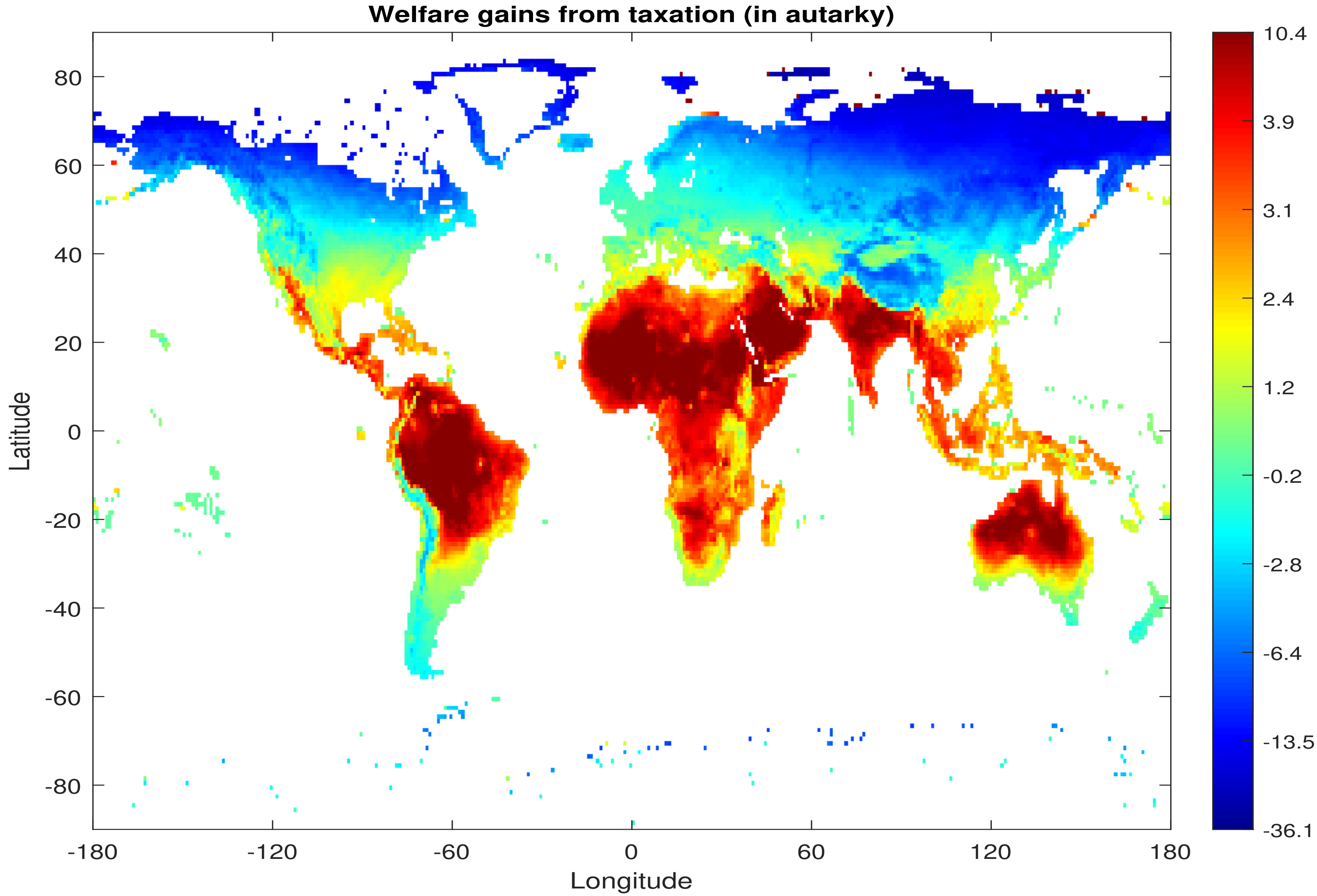
movie: change in temperature, laissez-faire
animation: www.econ.yale.edu/smith/deltatemperature1.mp4

movie: regional TFP, laissez-faire
animation: www.econ.yale.edu/smith/damage1.mp4

movie: percentage change in gdp, laissez-faire
animation: www.econ.yale.edu/smith/pctgdp1.mp4



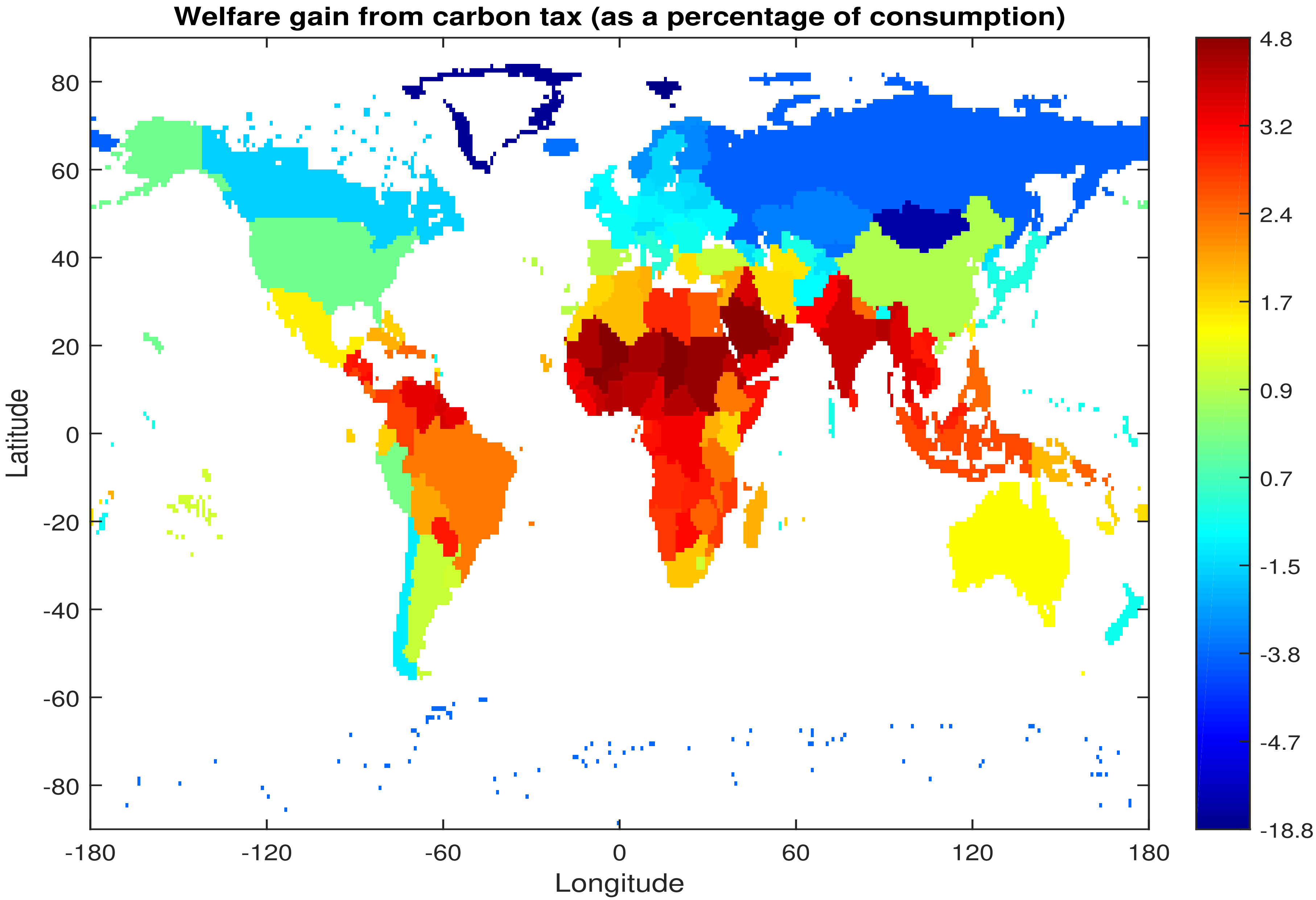
Welfare gains from taxation (with free capital movement)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
10.4
3.9
3.1
2.4
1.2
-0.2
-2.8
-6.4
-13.5
-36.1

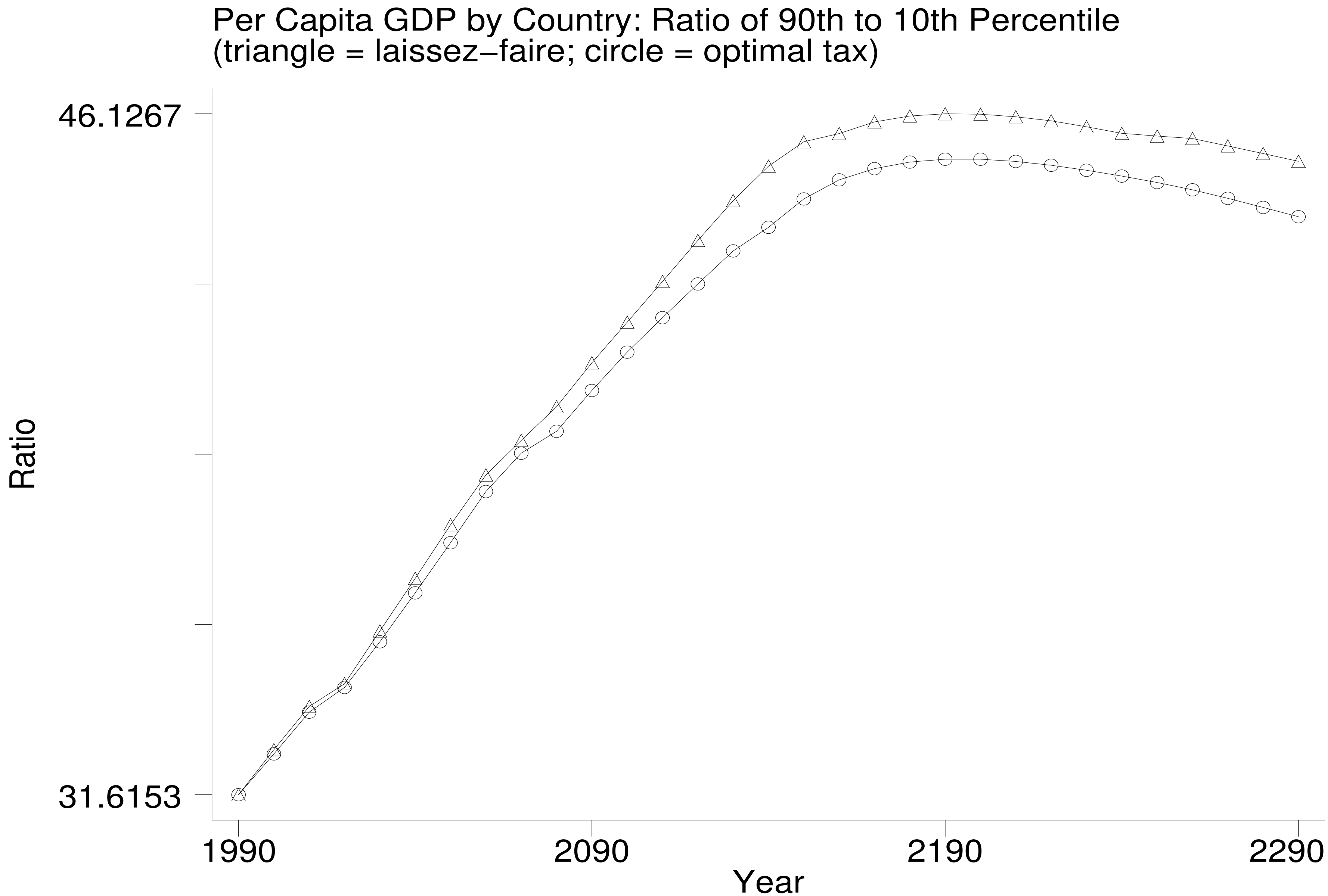


Welfare gains from taxation (in autarky)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
10.4
3.9
3.1
2.4
1.2
-0.2
-2.8
-6.4
-13.5
-36.1

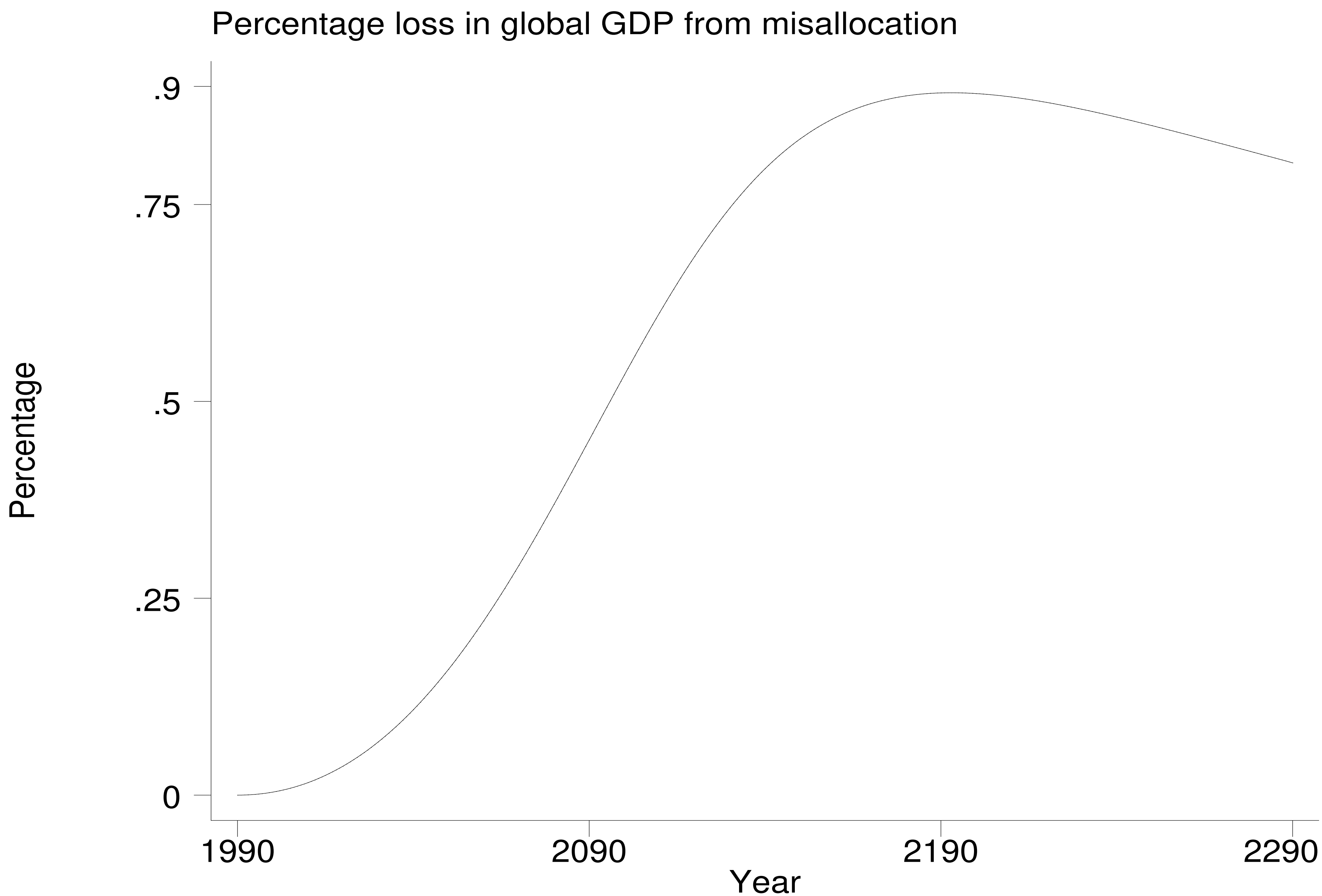
Welfare changes from tax: summary measures

- One region = one vote: 56% gain.
- One person = one vote: 84% gain.
- One dollar = one vote: 68% gain.
- Average gain across all regions: -2.1% (of consumption).
- Average gain weighted by regional GDP: 0.6%.
- Average gain weighted by regional population: 1.7%.
- World consumption path: gain of 0.4%.


Welfare gain from carbon tax (as a percentage of consumption)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
4.8
3.2
2.4
1.7
0.9
0.7
-1.5
-3.8
-4.7
-18.8



Per Capita GDP by Country: Ratio of 90th to 10th Percentile
(triangle = laissez–faire; circle = optimal tax)
46.1267
31.6153
Ratio
1990
2090
2190
2290
Year


Percentage loss in global GDP from misallocation
.9
.75
.5
.25
0
Percentage
1990
2090
2190
2290
Year

Takeaways

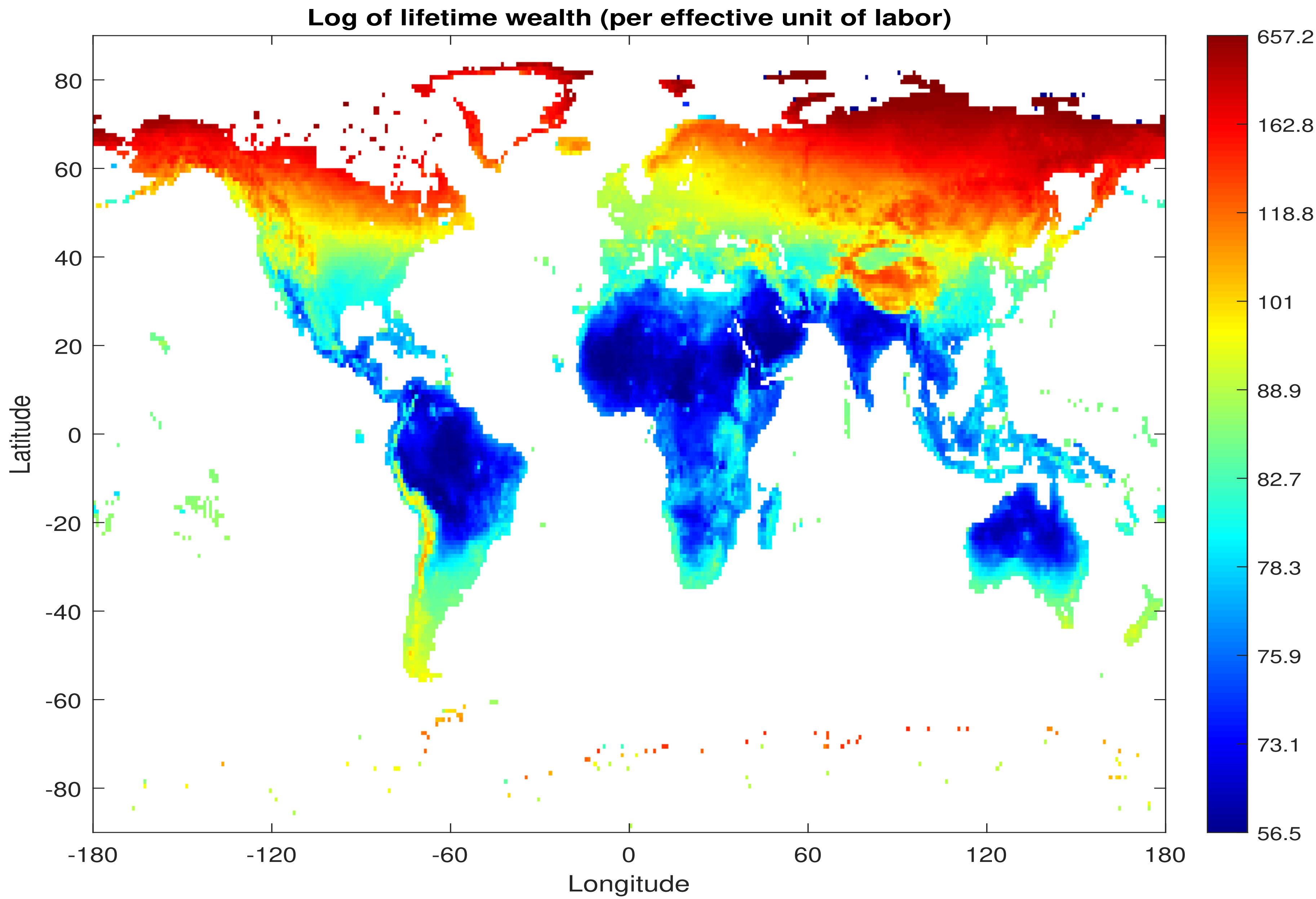
- Results from our model: climate change is about relative effects much more than about average effects!
- In particular, large disagreements about climate policy (so large transfer payments needed to compensate the losers).
- Methodological insight: we thought the market structure (because it admits more or less adaptation) would be important for the results, but it isn't.

Richer calibration

- Sea-level rise (can handle region-specific damage functions).
- Region-specific population growth rates.
- Region-specific growth rates for exogenous component of regional TFP.
- Region-specific energy shares and energy prices.

Building on the platform

- Weather as well as climate: "couple" with the Norwegian Earth System Model. No need to simplify climate system. Gain access to a rich set of stochastic weather variables (extreme temperatures, precipitation, wind) on which damages can depend. Working on methods . . . .
- Damages "too local"—no common aggregate damages such as effects of climate change on:
  - world technology development (level or growth);
  - ecosystems, biodiversity, ocean acidification, ...
- More heterogeneity in regional damages: rural vs. urban and/or manufacturing vs. agriculture, with separate U-shapes.
- Incorporate more margins of spatial adaptation (migration and trade).



Log of lifetime wealth (per effective unit of labor)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
657.2
162.8
118.8
101
88.9
82.7
78.3
75.9
73.1
56.5