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° × 1° 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.
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.
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)
Regional TFP vs. Regional temperature

Fraction of optimum vs. Regional temperature (Celsius)
Regional TFP (at temperature in 1901-1920)
Share of global population vs. Regional TFP

Share of population

Regional TFP

.005168

.25

.5

.75

.9

.995
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

Year

Fraction
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 centigrade above pre-industrial) (taxes vs. no taxes; free capital movement)
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 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%.
Per Capita GDP by Country: Ratio of 90th to 10th Percentile
(triangle = laissez-faire; circle = optimal tax)
Percentage loss in global GDP from misallocation
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)