Climate Change Economics over Time and Space

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(with Bilal, Conte, Cruz, Desmet, and Nagy)

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The Basic Problem

- CO_2 concentration in the atmosphere has grown rapidly since 1850
  - Anthropogenic effect on climate due to industrialization, etc.
  - Has led to increases in global average temperature of $\sim 1.2^\circ$C
  - Also related to sea-level rise and changes in extreme weather patterns
- Impact will be global, protracted, and heterogeneous across space
  - Need equilibrium models to assess
  - Models need to be **dynamic** and exhibit **spatial detail**
- Overall effects depend on the costs of adaptation
  - Winners and losers so costs are related to **spatial frictions**
  - Namely, cost of moving people, goods, and investments
- Goal is to develop and quantify dynamic **"Spatial Integrated Assessment Models"** (S-IAM)

Developing a Spatial Growth Model

- The ideal model features:
  - Heterogeneous locations in productivity, amenities, and geography
  - Agglomeration and congestion forces
  - Firms that can invest in innovation and capital
  - Individuals that can save, and move and import subject to costs
  - Spatial growth that can be solved for unique transition and BGP
- Complicated because state-space is large and hard to reduce
  - State space is the spatial distribution of population, capital, and technology
  - Agents care about the spatial distribution differently depending on their own location

Our Current Model

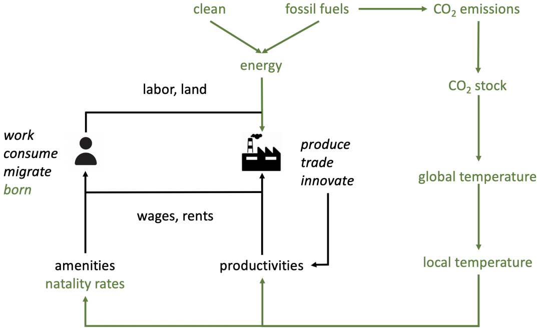
- In **Desmet, Nagy, and Rossi-Hansberg (2018)** we developed a spatial growth model that has these characteristics but ...
  - Features technological innovation but not capital accumulation
    - Technology diffuses locally and firms compete for land
    - Competition for land implies that land, the fixed factor, obtains rents
    - Yields model with perfect competition, innovation, and static investment decisions
    - Innovation depends on endogenous market size
  - Individuals can move and import subject to costs, but they cannot save
    - Moving is reversible since flow migration costs are of the form $m(r, s) = m_1(r)m_2(s)$
    - Yields static location decisions
  - Decisions and spatial interactions have **rich dynamic implications but no anticipatory effects**

Quantification and Performance

- Model can be quantified using data on current local population, income, HDI, trade, and net population flows
  - "Invert" model in current period to obtain local amenities and productivities
  - Obtain trade and migration costs to satisfy "gravity" in goods and match net migration flows exactly
  - Solve forward the very protracted transition to unique BGP
- Use GEcon data at $1^\circ \times 1^\circ$ for 17048 locations with land mass
- Solve backwards to test out-of-sample performance: **Model accounts for past changes in population quite well**
  - **Correlation in changes** over 50 years is .74 and over 130 years is .34

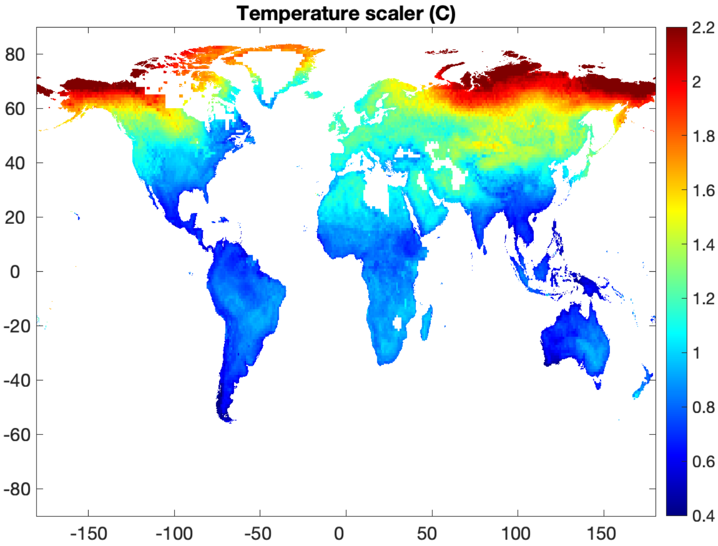
Adding the Climate Component

- Incorporate energy use, emissions, carbon cycle, and consequences of temperature rise



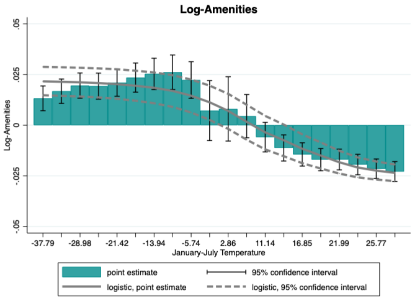
  - Scientist give us carbon cycle and physical consequences
  - Temperature downscaling: $T_{t+1}(r) - T_t(r) = g(r) \cdot (T_{t+1} - T_t)$
  - Need to estimate effects on economic fundamentals: productivity, amenities, and natality

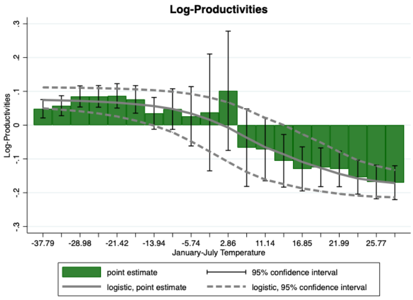
Warming Impact of 1°C Increase in Global Temperature



Temperature Damage Functions

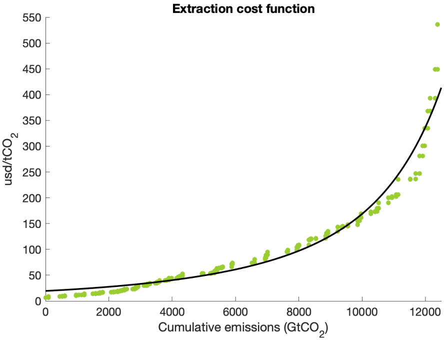
- In **Cruz and Rossi-Hansberg (2021)** we:
  - Invert the model using panel data to obtain a panel of fundamentals (amenities and productivities)
  - Estimate panel regression to obtain semi-elasticity of temperature on fundamentals by temperature bin
    - ★ Include location FE, regional trends, and spatially correlated errors





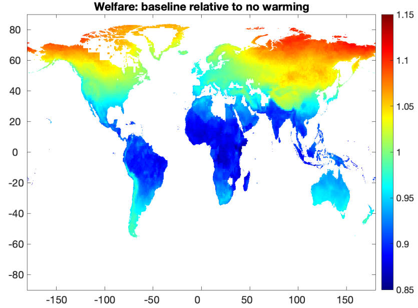
Energy Production

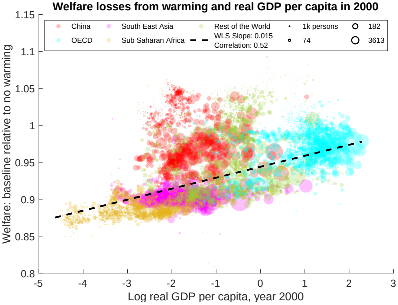
- CES energy composite between **fossil fuels** and **clean sources**
- Cost of fuels vary across time and space to match observed use and evolution
- However, fossil fuels are finite and extraction costs increase with use



Implications: Unequal Losses

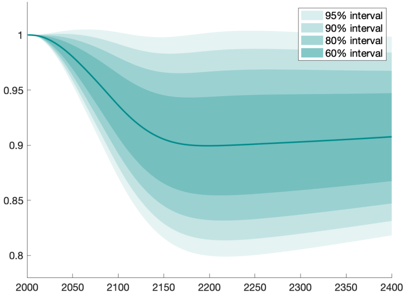
- Average welfare losses from global warming amount to 6.3%
- Large differences across locations: from -15% to +15%
- Global warming will **increase inequality across space**



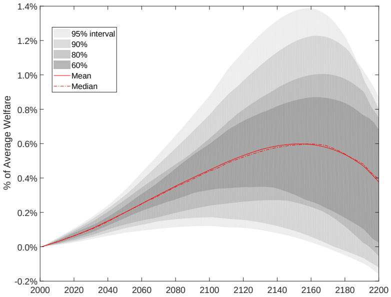


Implications: Large Uncertainty

- Costs of global warming, or **coastal flooding (Desmet et al., 2021)**, are highly uncertain:



Global Warming

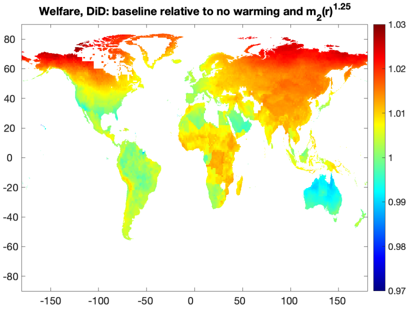


Coastal Flooding

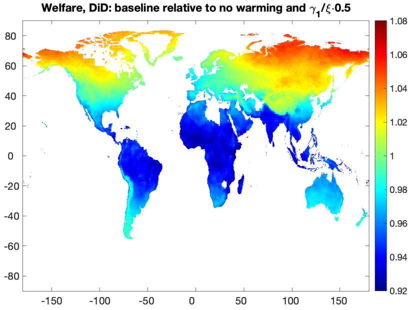
- Distribution of **relative** losses is much more certain
- Policy should incorporate this uncertainty (Barnett et al., 2022)

Implications: The Importance of Adaptation, Warming

- Adaptation is important to reduce the losses from global warming
- Adaptation through migration and local innovation are particularly relevant



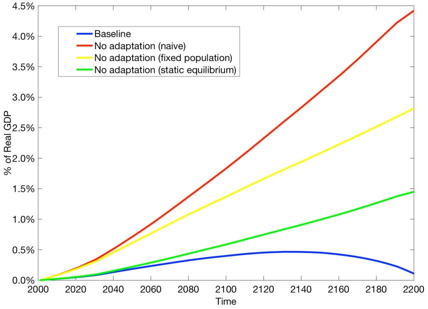
Migration Costs



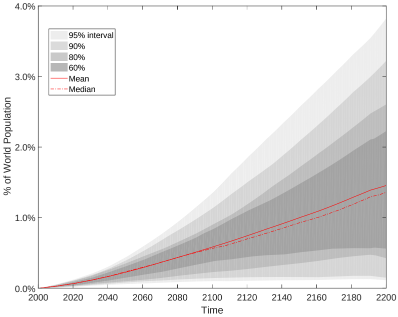
Innovation Costs

Implications: The Importance of Adaptation, Flooding

- Adaptation is even more important to reduce **costs of sea-level rise**
- Rich geographic detail, interactions, and local growth dynamics all essential



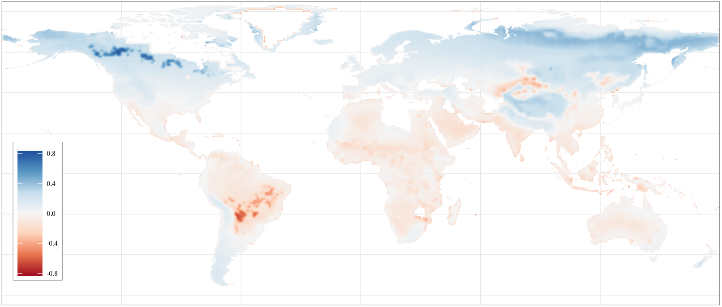
Cost in Real GDP Per Capita



Displaced Population

Implications: Trade as a Form of Adaptation

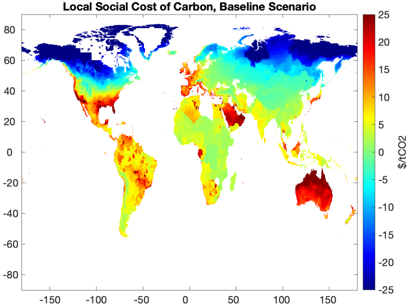
- **Trade is a relevant adaptation mechanism (Conte et al. 2021)**
  - But only if climate change affects local comparative advantage
  - Agricultural productivity is more sensitive to temperature than manufacturing or service productivity
- **Trade and migration are substitutes** as forms of adaptation

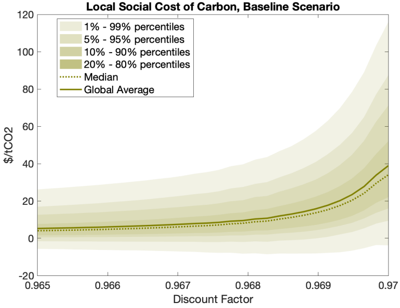


DiD of Population with high (+50%) versus low (-50%) trade costs

Designing Policy: The Local Social Cost of Carbon

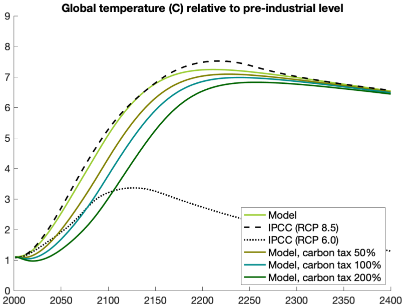
- Model structure facilitates computation of equilibrium but not of optimal allocation
- Optimal policy is likely heterogeneous across time and space
  - Carbon externality interacts with other static and dynamic agglomeration and congestion forces
  - **A price of carbon at its global social cost is not locally optimal** (Cruz and Rossi-Hansberg, 2022)

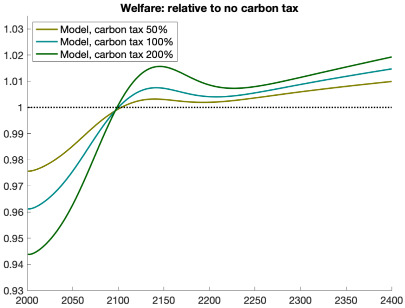




Designing Policy: Carbon Taxes

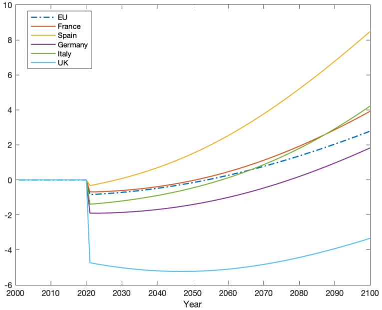
- **Carbon taxes delay carbon use but do not eliminate it**
- "Flatten" the temperature curve
    - Can be **useful if an effective abatement technology is forthcoming**
- Involve large inter-temporal transfers
    - Welfare impact depends heavily on discount factor



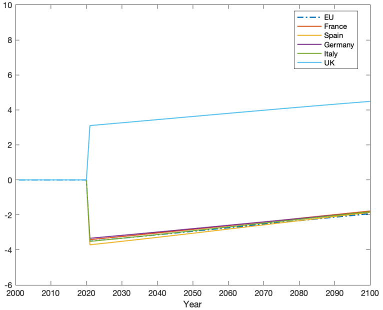


Designing Policy: Production Leakage

- Carbon taxes can **shift economic activity across regions**
- Model agriculture and non-agriculture
  - Since agriculture is less energy intensive, it is less affected by tax
    - Leads to changes in specialization and leakage
- Consider imposing in 2021 a permanent **40$ carbon tax** in the EU, with **no rebating** (Conte et al., 2022)



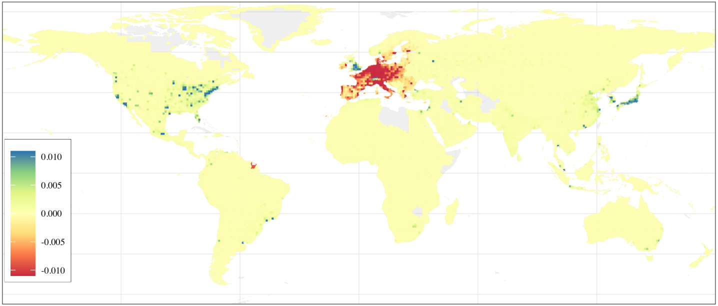
Agriculture output, no rebating (%)



Non–agriculture output, no rebating (%)

Designing Policy: Carbon Leakage

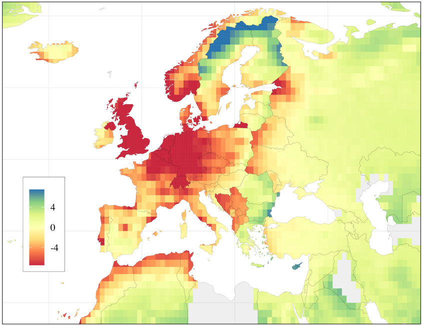
- **Production leakage leads to carbon leakage**
  - Mostly to other developed regions specialized in non-agriculture
  - Europe declines and specializes more in agriculture
  - European emissions fall 40% but world emissions by around 3%



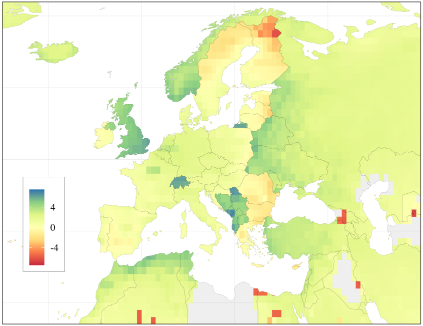
Change in total emissions due to carbon taxes at impact, $GtCO_2$

Designing Policy: Rebating and Spatial Reallocation

- Rebating revenue of the carbon tax affects spatial distribution
  - **Can improve allocation** due to agglomeration and congestion forces
  - Can change overall cost of the tax if it encourages migration to most productive regions



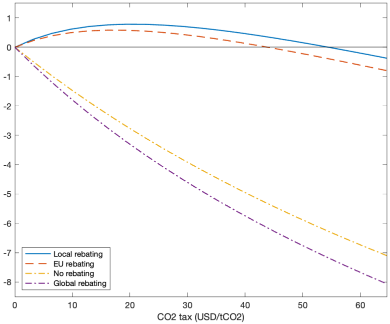
Agriculture output, local rebating (%)



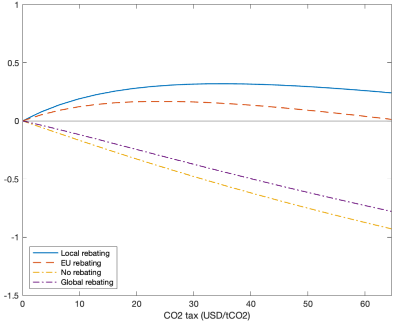
Non–agriculture Output, local rebating (%)

Designing Policy: Rebating and Spatial Reallocation

- Local rebating can be effective in preventing leakage and EU decline
- **Carbon tax with local rebating can generate world welfare gains**, even in the short-run
  - Global rebating is the worst option for global welfare since it prevents people in the developing world from migrating



EU Real GDP, 2021 (%)



World Welfare, 2021 (%)

An Open Agenda

- Many aspects of the analysis are missing or imprecise
- Ample room for many more contributions on the topic
- Enormous needs for detailed economic analysis since policies are being implemented every day
- Analysis requires economic modeling and quantification, but lots of detailed data on climate
- **Where do we need more work?**

An Open Agenda: Green Innovation and the ES

- The discussion above includes innovation that makes firms in a location more productive
- Does not include **directed technical change towards green technologies**
  - Work of Acemoglu, Akcigit, Agion, and others has shown that it can be important
  - So far it has not been combined with spatial frameworks
- Perhaps even more important is that **elasticity of substitution between fossil fuels and other inputs is fixed**
  - Innovation and carbon policy can change this elasticity
  - Depends on characteristics of the stock of capital (e.g. the share of electric cars)
  - Modelling the evolution of the stock of "green capital" and therefore of the ES is essential

An Open Agenda: Risk and Anticipation Effects

- The models we have used **do not feature anticipation effects**
  - Future shocks do not change today's behaviour, only land prices which are not allocative
  - Implies that it is not a good model to think about risk
- But key dimension of climate change is that it will make future climate more volatile and risky
  - Requires a spatial growth model with forward-looking behaviour
  - Hard but feasible using recent macro techniques
  - "Mean Field Games" mathematics as in Alvarez and Bilal's work
    - See ongoing work with Bilal
- Once risk is incorporated, we need to decide how to evaluate policy
  - Incorporate insights of Hansen and Sargent on robust decision making

An Open Agenda: Adding Capital

- The model we have used does not have capital
  - Local growth is the result of cumulative innovations
  - Incorporating a consumption-savings decision in a spatial model is complicated
    - Kleinman, et al. (2021) makes progress but at a smaller scale
    - Work by Krussel and Smith studies climate change in a spatial model with capital accumulation but no trade or migration
    - Work with Bilal adds capital too
- Note that **capital depreciates and climate change is protracted**
  - Buildings depreciate every $\sim$50 years
  - Capital only important through anticipation effects and depreciation or destruction shocks

An Open Agenda: Electricity Market

- In the current model energy is generated locally from fossil fuels and clean energy
  - **Energy is not transported, traded, or stored**
  - Costs of clean and fossil sources vary by location to match use
  - ... but very reduced-form, does not account for local stocks or specific changes and characteristics
- Ideally we want to model energy production, trading, and storage
  - Can use a relatively standard trade model...
    - and iceberg transport cost assumption works well!
  - We could incorporate green innovation in storage and energy transportation too
  - Energy market clearly has a spatial and dynamic component
    - Work by Arkolakis and Walsh is doing some of this

An Open Agenda: Adding Many Sectors

- Incorporating multiple sectors is relevant since climate change and climate policy affects them differently
  - We **need sector specific "damage functions"**
    - Hard to estimate them since time series variation not so large
    - Recent work by Cruz and Rudik et al. estimates them imposing specific functional forms
  - We also need to estimate the energy input share by sector/location
- Incorporating **non-homothetic preferences** is useful too
  - Affects the cost of climate change in the developing world
  - Useful to study the effect of climate change on structural transformation across regions
  - See interesting work by Nath (static) and Cruz (dynamic)

Thank you