On the Geographic Implications of Carbon Taxes

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Environmental policy and carbon taxes

- Environmental policies are needed to mitigate global warming
  - Standard Pigouvian logic says that a carbon tax is first-best
  - Carbon tax can close the gap between social and private cost of carbon
  - Other policies that effectively price carbon are similar (e.g. ETS)

- (Unilateral) carbon taxes are increasingly common
  - France, Canada, Netherlands, Singapore, Sweden, Switzerland, UK, ... 
  - Due to economic and carbon leakage, policy seems ineffective

- This argument ignores some of the spatial effects
  - A carbon tax affects the spatial distribution of economic activity
  - Pre-existing spatial equilibrium need not be efficient
  - Spatial reallocation might improve global efficiency and welfare
The spatial effects of carbon taxes in the EU

- Carbon tax and rebate scheme affects
  - The geography of comparative and absolute advantage
  - The spatial distribution of income, and hence migration flows

- Use two-sector dynamic spatial integrated assessment model (S-IAM) to evaluate the impact of an EU carbon tax rebated locally
  - Non-agricultural EU core gains in relative terms
  - EU economy expands and attracts more immigrants
  - Global efficiency and welfare improve
  - Similar results for a US carbon tax

- Unilateral carbon tax and rebate scheme corrects spatial inefficiency
  - Acts as place-based policy that redistributes income towards high-productivity non-agricultural regions
  - Different results with alternative rebating schemes
Model: Endowments and preferences

- Based on Conte, Desmet, Nagy and Rossi-Hansberg (2021)
- World economy occupies a two-dimensional surface
  - $\bar{L}$ agents, each supplying one unit of labor
- Period utility of agent $j$ residing in location $r$ at time $t$

$$U^j_t (r, r) = \bar{\chi} a_t (r) \prod_{i=1}^{l} \left[ \int_0^1 c_{it}^\omega (r)^\rho \ d\omega \right] ^{\bar{\chi}_i \rho} \epsilon^j_t (r) \prod_{s=1}^{t} m (r_{s-1}, r_s)^{-1}$$

- $\epsilon^j_t (r)$ is location preference shock that acts as a dispersion force
- Amenities are such that $a_t (r) = \bar{a} (r) (\bar{L}_t (r) / H (r))^\lambda$ and so also act as a dispersion force

- Moving costs
  - $m(r, s) = m_1 (r)m_2 (s)$
  - Migrants only pay the flow utility cost while in the host location
  - Simplifies forward-looking migration decision to a static one
Model: Technology

- Firm produces variety $\omega$ in sector $i$ in location $r$ at time $t$ according to
  \[
  q_{it}^\omega (r) = L_{\phi, it} (r)^{\gamma_i} z_{it}^\omega (r) L_{it}^\omega (r)^{\mu_i} E_{it}^\omega (r)^{\sigma_i} H_{it}^\omega (r)^{1-\gamma_i-\mu_i-\sigma_i}
  \]
  - Productivity shifter $z_{it}^\omega (r)$ drawn from Fréchet with average
    \[
    Z_{it} (r) = \tau_{it} (r) g_i (T_t (r)) \left( \frac{L_{it} (r)}{H_{it} (r)} \right)^{\alpha_i}
    \]
    where local density acts as an agglomeration force
  - A location’s fundamental productivity in sector $i$ evolves according to
    \[
    \tau_{it} (r) = L_{\phi, i,t-1} (r)^{\gamma_i} \left[ \int_S e^{-\kappa \text{dist}(r,s)} \tau_{i,t-1} (s) \, ds \right]^{1-\delta} \tau_{i,t-1} (r)^{\delta}
    \]
- Local technology diffuses locally to potential entrants
  - Competition for land implies that firm dynamic innovation decision simplifies to static optimization problem
- Trade cost such that trade flows satisfy standard gravity equation
Model: Global warming

- Bell-shaped sector-specific temperature discount on productivity

\[ g_i(T_t(r)) = \exp \left[ -\frac{1}{2} \left( \frac{T_t(r) - g_{i,\text{opt}}}{g_{i,\text{var}}} \right)^2 \right] \]

- Simple world energy market with constant supply elasticity

- Carbon cycle
  - Energy used in production causes emissions that affect carbon stock

\[ K_t = \varepsilon_1 K_{t-1} + \varepsilon_2 E_{t-1} \]

  - Carbon stock affects global temperature

\[ T_t = T_{t-1} + \nu (K_t - K_{t-1}) \]

- Global temperature affects local temperature

\[ T_t(r) - T_{t-1}(r) = \zeta(r) (T_t - T_{t-1}) \]
Carbon taxes

- Carbon tax increases the energy price $e_t$ by a proportion $\gamma_t(r)$
  - A firm in $r$ producing variety $\omega$ of sector $i$ minimizes
    \[
    p_{it}^\omega(r, r) q_{it}^\omega(r) - w_t(r) \left[ L_{it}^\omega(r) + L_{\phi it}^\omega(r) \right] - (1 + \gamma_t(r)) e_t E_{it}^\omega(r) - R_t(r) H_{it}^\omega(r)
    \]
  - Its marginal cost is
    \[
    mc_{it}(r) = \kappa_i w_t(r)^{\gamma_i + \mu_i} R_t(r)^{1-\gamma_i - \mu_i - \sigma_i} e_t^\sigma_i (1 + \gamma_t(r))^{\sigma_i}
    \]

- Carbon tax affects sectors based on their energy intensity $\sigma_i$

- Carbon tax revenues are either
  - Lost
  - Rebated: locally, EU uniform, developing countries
Local effect of carbon taxes

- How does a carbon tax affect the local economy?
  - It pushes up the marginal cost of local producers
  - This causes a drop in local revenue (and income per capita)
  - Once carbon tax is rebated, income per capita may increase if
    - Trade elasticity, $\theta$, is low enough to limit the initial drop in income
    - Carbon tax is small enough to avoid large distortionary effects
  - If local income per capita increases, immigrants flow in and local economy expands
    - Larger expansion, the lower is locational preference heterogeneity $\Omega$

**Lemma**

*If a small region $r$ imposes a carbon tax $Y_t(r)$ rebated lump-sum to the local population, for $\theta > 1$ and $\alpha_i$ sufficiently small, $\exists Y_t(r) > 0$ that raises local income, and attracts migrants to $r$.***
Local effect of carbon taxes

- Local carbon tax can have positive effects on local output and population
  - Tax incidence falls on trading partners, but rebate benefits only locals
  - Reminiscent of optimal tariff argument
  - Other rebating schemes need not have this effect

- Carbon tax causes larger changes in locations that are more specialized in energy-intensive industries
  - Causes a spatial reallocation of income and economic activity
  - Static and dynamic externalities imply inefficient spatial equilibrium
  - Reallocation has the potential to improve global efficiency and welfare
Quantification: Economics

- Discretize the world into 64,800 $1^\circ \times 1^\circ$ cells

Data
  - Bilateral trade costs
  - Population
  - Total output and agricultural output

Recover
  - Agricultural and non-agricultural productivity
  - Amenities

Moving costs
  - Identified by making local changes in population between first five periods coincide with data
Quantification: Climate

- Parameters of carbon cycle such that
  - 1200 GTC increase in stock of carbon by 2100
  - 3.7°C global temperature increase by 2100
  - Consistent with Representative Concentration Pathway (RCP) 8.5

- Local sensitivity to change in global temperature is heterogeneous
  - Predicted local and global temperatures from 2000 to 2100 to estimate
    \[ T_t(r) - T_{t-1}(r) = \xi(r) (T_t - T_{t-1}) + \nu_t(r) \]

- Temperature discount in agriculture
  - Optimal annual average temperature 19.9°C from agronomy studies
  - Variance parameter so that 0.1% of world agricultural production occurs in locations with a discount factor below 0.01

- Temperature discount in non-agriculture
  - Calibrate to observed relation between temperature and the model-generated non-agricultural productivity across all grid-cells
Quantification: Sectoral temperature discounts

Conte, Desmet, and Rossi-Hansberg
Geographic Implications of Carbon Taxes
March 2023 12 / 41
Quantification: Energy shares and carbon taxes

- Energy shares
  - Agriculture: 0.04 (Schnepf, 2004; Australian Bureau of Statistics, 2021)
  - Non-agriculture: 0.07
    - Energy share in total GDP $\sim 0.056 - 0.08$ (King et al., 2015; Grubb et al., 2018)
    - Combine with energy share in agriculture (0.04) and share of non-agriculture in GDP (0.949)
    - Yields non-agricultural energy share between 0.057 and 0.082

- Carbon taxes
  - Swedish tax $\sim 140$ US$/tCO_2$ (Hassler et al. 2020)
  - Smaller in EU in general: France 48 US$/tCO_2$, Germany 27 US$/tCO_2$, Spain 16 US$/tCO_2$, Italy 0 US$/tCO_2$ (Worldbank)
  - We use a carbon tax of 40 US$/tCO_2$ as our baseline
  - $Y(r) \times e_0 = 40$ USD$/tCO_2 \rightarrow Y(r) = 40/e_0$
  - $Y(r) = 0.8632$ (86.32%)
Carbon taxes *without rebating*
EU output declines in both sectors, but less in agriculture

UK, in comparison, gains comparative advantage in non-agriculture
Sectoral specialization in 2021 without rebating

% Change in sectoral output due to carbon taxes, 2021

A: Agriculture, no rebating, 2021 (%)

B: Non-agriculture, no rebating, 2021 (%)

- EU periphery is gaining comparative advantage in agriculture
- Border effect: negative for agriculture, ambiguous for non-agriculture
Sectoral specialization in 2100 without rebating

% Change in sectoral output due to carbon taxes, 2100

A: Agriculture, no rebating, 2100

B: Non-agriculture, no rebating, 2100

- Effects amplify over time via investments and technological diffusion
- By 2100, effect on climate is present too: positive effect in southern areas, negative effect in northern areas
Effects on the EU of different carbon taxes, 2021

A: % Changes in EU real GDP and population

B: % Changes in EU GDP pc and welfare

- Larger negative effects on real GDP, population, and welfare, the larger the carbon tax
Real GDP and population changes in 2100

A: Real GDP % changes due to carbon taxes, no rebating, 2100

B: Population % changes due to carbon taxes, 2100
Emissions changes in 2021, GtCO₂

World emissions: -2.2% in 2021 and -2.7% in 2100

EU emissions: -43.4% in 2021 and -41.2% in 2100
Aggregate and distributional effects of carbon taxes
% Change in 2021 and 2100 without rebating carbon tax revenues

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Notes: Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar, Malaysia, Philippines, Thailand, and Vietnam.

Δ Real sectoral outputs
Carbon taxes \textit{with local rebating}
Rebating carbon tax

- Carbon tax generates revenue for the government
- Rebate revenues per capita to the local population
- Carbon tax and rebate change spatial distribution of income
  - Migration to places that benefit most from carbon tax and rebate
- Initial spatial distribution of economic activity is inefficient
  - Possibility that carbon tax and rebate improve efficiency
Sectoral specialization over time with local rebating

% Change in sectoral output due to carbon taxes, 2021-2100

A: Agriculture, local rebating (%)

B: Non–agriculture, local rebating (%)

- With local rebating, agriculture falls more in Europe’s core
- Non-agriculture grows everywhere in EU, especially in the core

US case
Core and border regions switch from agriculture to non-agriculture

Border regions’ non-agricultural sector benefits from EU periphery’s change in specialization
Sectoral specialization 2100 with local rebating

% Change in sectoral output due to carbon taxes, 2100

A: Agriculture, local rebating, 2100 (%)

B: Non-agriculture, local rebating, 2100 (%)

- Comparative advantage changes amplify over time
- Border benefits from more investment in non-agriculture
Effects on the EU of different carbon taxes, 2021

**A: % Changes in EU real GDP and population**

- With local rebating, positive effects on real GDP for carbon taxes up to 50 USD/tCO₂

**B: % Changes in EU GDP pc/welfare**

- EU welfare falls for all taxes as migrants move in

US case
With local rebating, world welfare increases due to more efficient distribution of economic activity.

More people live in EU which is relatively more productive.
Real GDP pc and population changes in 2100

**A:** Real GDP pc % Δ due to carbon taxes, local rebating, 2100

**B:** Population % Δ due to carbon taxes, local rebating, 2100
Change in emissions: local rebating vs no rebating

\[ \Delta \text{Emissions (local rebating - no rebating), 2021 (GtCO2)} \]
Effects of trade elasticity and preference heterogeneity

- Lower trade elasticity: smaller negative effect on local revenues
- Lower preference heterogeneity: greater influx of migrants
## Aggregate and distributional effects of carbon taxes

% Changes in 2021 and 2100 when locally rebating carbon tax revenues

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<td>(\Delta) Real GDP pc</td>
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<td>(\Delta) Non-agric. Output</td>
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### Panel A: No rebating

### Panel B: Local rebating

Notes: Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar, Malaysia, Philippines, Thailand, and Vietnam.
Carbon taxes with EU or developing world rebating
EU/developing world rebating

- We consider two additional forms of rebating the revenue of EU carbon taxes
  - **Uniform EU rebating** where we rebate total EU carbon tax revenue equally across the EU population
  - **Developing countries rebating** where we rebate total EU carbon tax revenue equally across the developing world

- Goal is to understand how rebating changes sectoral specialization and population flows
Effects on the EU of different carbon taxes, 2021

- EU rebating: smaller expansion of the EU
- Developing countries rebating: contraction of the EU
Effects on the world of different carbon taxes, 2021

- EU rebating: smaller positive welfare effects
- Developing countries rebating: benefits sub-Saharan Africa and Asia, but hurts the world by keeping people from migrating
Sectoral specialization 2021: EU vs local rebating

A: \( \% \Delta \text{ Agric.}, \text{EU} – \text{local rebating}, 2021 \)

B: \( \% \Delta \text{ Non-agric.}, \text{EU} – \text{local rebating}, 2021 \)

- With EU rebating, more resources flow to EU periphery and so it specializes more in non-agriculture
- Less concentration in the core, which leads to smaller world gains
Sectoral specialization 2021: Developing vs local rebating

\[ \Delta \% \text{ Population, developing – local rebating, 2021} \]
The gains from local rebating (compared to no rebating) does not come at cost of higher emissions.

Developing countries rebating leads to larger reductions in CO₂.
Aggregate and distributional effects of carbon taxes
% Changes in 2021 and 2100: different rebating schemes

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<td><strong>Panel A: Local rebating</strong></td>
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**Notes:** Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar, Malaysia, Philippines, Thailand, and Vietnam.
Concluding remarks

- A unilateral carbon tax in the EU with local rebating
  - Acts as a place-based policy that favors high-productivity core
  - Attracts migrants and expands EU economy
  - Improves global efficiency and welfare
  - Similar findings for US

- More generally, if rebating benefits high-productivity areas, then a unilateral carbon tax may get us closer to efficient spatial equilibrium

- Cost of carbon tax can be avoided with right tax and rebate scheme
  - Local rebating is the most natural way to rebate

- Alternative rebating schemes yield different results
  - Rebating to the developing world keeps people in less productive areas
  - Decreases spatial inequality but worsens global welfare
A: Agriculture, no rebating, 2100 (%)

B: Non-agriculture, no rebating, 2100 (%)
Effects on sectoral output of different carbon taxes, 2021

% Changes in world’s GDP pc/welfare

CO2 tax (USD/tCO2)

Real GDP
Welfare
Effect on GDP per capita

Real GDP pc % changes due to carbon taxes, 2100
Effect on real GDP in Europe

A: Real GDP changes, no rebating, 2021 (%)

B: Real GDP changes, no rebating, 2100 (%)

Conte, Desmet, and Rossi-Hansberg
Geographic Implications of Carbon Taxes
March 2023 47 / 41
Emissions changes in Europe in 2021

Differences in total emissions, 2021 (GTC)
A: Total emissions, % change, by sector

B: EU emissions, % change, by sector

- Agriculture output grows in less efficient areas
- Non-agricultural emissions fall due to decrease in world output
Emissions over time: World vs UK

A: Total emissions, % difference, by sector

B: UK emissions, % difference, by sector
Aggregate and distributional effects of carbon taxes

% Change in 2021 and 2100 without rebating carbon tax revenues

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Notes: Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar, Malaysia, Philippines, Thailand, and Vietnam.
A: Agriculture, local rebating, 2100

B: Non-agriculture, local rebating, 2100
Change in emissions with local rebating

Change in total emissions due to carbon taxes, 2021
Aggregate and distributional effects of carbon taxes
% Change in 2021 and 2100 locally rebating carbon tax revenues

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Panel B: Local rebating

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Notes: Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar, Malaysia, Philippines, Thailand, and Vietnam.
### Global rebating

**Countries benefited by the rebating of CO2 tax revenues**

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Aggregate and distributional effects of carbon taxes

% Changes in 2021 and 2100: different rebating schemes

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</tr>
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</table>

Notes: Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar, Malaysia, Philippines, Thailand, and Vietnam.
US Case: Sectoral specialization

% Change in sectoral output due to carbon taxes, 2021-2100

A: Agriculture, no rebating (%)

B: Non-agriculture, no rebating (%)

- US output declines in both sectors, but less in agriculture
- Canada and Mexico, in comparison, gains comparative advantage in non-agriculture
US Case: Sectoral specialization in 2021 without rebating
% Change in sectoral output due to carbon taxes, 2021

A: Agriculture, no rebating, 2021 (%)
B: Non–agriculture, no rebating, 2021 (%)

- USA periphery is gaining comparative advantage in agriculture
- Border effect: negative for agriculture, ambiguous for non-agriculture
US Case: Effect of different carbon taxes, 2021

A: % Changes in US real GDP and population

B: % Changes in US GDP pc and welfare

- Larger negative effects on real GDP, population, and welfare, the larger the carbon tax
US Case: Sectoral specialization with local rebating

% Change in sectoral output due to carbon taxes, 2021-2100

- With local rebating, agriculture still falls in US, Canada, and Mexico
- Non-agriculture now grows everywhere in the whole region
US Case: Sectoral specialization with local rebating

% Change in sectoral output due to carbon taxes, 2021

A: Agriculture, local rebating, 2021 (%)

B: Non–agriculture, local rebating, 2021 (%)

- Coastal and Midwestern regions non-agricultural production benefit
- Alaska becomes more specialized in agriculture as non-agriculture concentrates in most productive regions
US Case: Effect of different carbon taxes, 2021

With local rebating, positive effects on real GDP for carbon taxes up to 50 USD/tCO$_2$

US welfare falls for all taxes as migrants move in
With local rebating, world welfare increases due to more efficient distribution of economic activity.

More people live in USA which is relatively more productive.
Simulation

- Allocation in $t$ allows deriving fundamental productivities in $t + 1$
- Energy use in $t$ and carbon cycle gives global temperature in $t + 1$
- Determine local temperatures in $t + 1$
- With fundamental productivities and local temperatures in $t + 1$, solve for all other variables in $t + 1$
- Model can be simulated forward for as many periods as needed