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: carbon tax as first-best
  - Other policies that effectively price carbon are similar (e.g. ETS)

- (Unilateral) carbon taxes are increasingly common (e.g. EU and the UK)
  - Issue: economic and carbon leakage, hence often seen as ineffective

- This paper: this argument ignores other spatial effects of CO2 taxes
  - 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 (and the US)

- 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 + rebate scheme corrects pre-tax spatial inefficiencies
  - Acts as place-based policy by redistributing income towards high-productivity non-agricultural regions
  - Different results with alternative rebating schemes

Contribution

1. Climate and welfare effects of CO2 taxes

   Global taxes (Nordhaus, 2010; Golosov et al., 2014; Hassler et al., 2016, 2018) or unilateral taxes in two-country settings (Kortum and Weisbach, 2021; Weisbach et al., 2022)

2. CO2 taxes in a second-best world with other distortinary taxes

   Below-Pigouvian taxes (Bovenberg and van der Ploeg, 1994; Bovenberg and de Mooij, 1994; Barrage, 2020) or the double-dividend hypothesis (Goulder, 1995; Goulder et al., 1997)

3. Redistributive effects of CO2 taxes

   Role of sectoral composition of workforce, relative factor prices, and rebating schemes (Rausch et al., 2011; Fullerton and Monti, 2013; Känzig, 2022); or cross-generational redistribution (Leach, 2009; Fried et al., 2018)

4. Climate change in dynamic spatial (IAM) models

   Focus on global warming (Desmet and Rossi-Hansberg, 2015; Conte et al., 2021; Cruz and Rossi-Hansberg, 2021; Nath, 2020) or coastal flooding (Desmet et al., 2020; Balboni, 2021)

1. Theoretical framework

Framework: a dynamic two-sector S-IAM with carbon taxes

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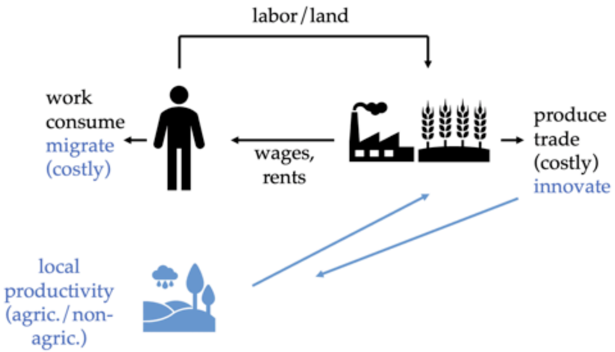

→ Spatial dynamics and growth (Desmet et al., 2018): geography of development

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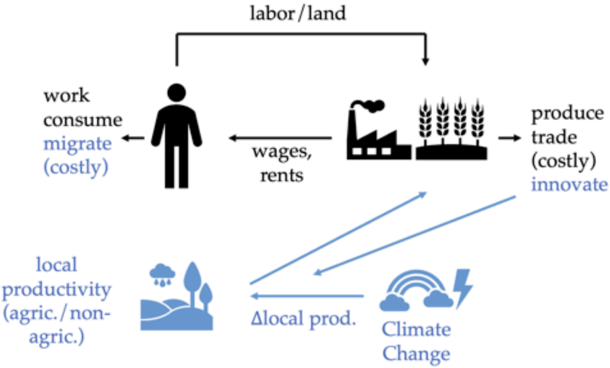

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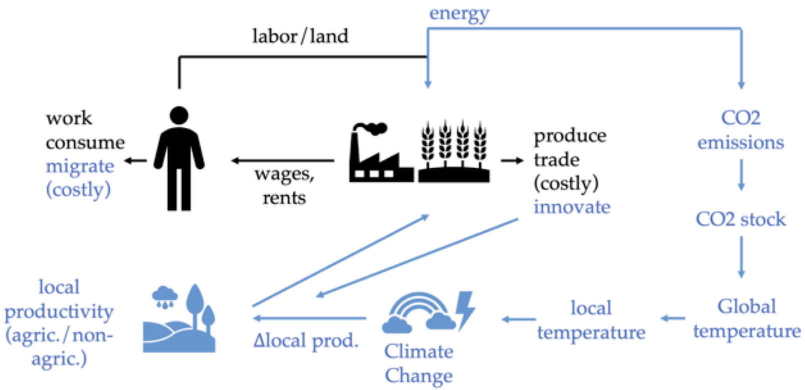

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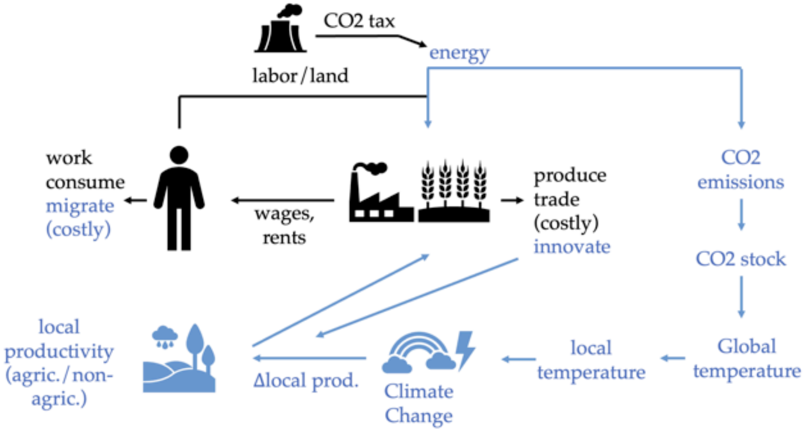

→ Spatial dynamics and growth (Desmet et al., 2018): geography of development

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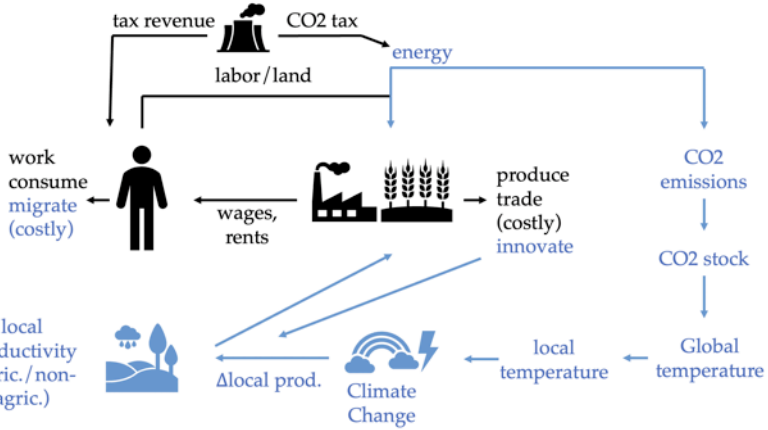
→ Local carbon taxes: trade off between distortion (tax) and income change (transfer)

Framework: a dynamic two-sector S-IAM with carbon taxes ▸ model



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Endowments & preferences

- World economy: two-dimensional surface where $\bar{L}$ agents supply labor

- Period utility of agent j residing in location r at time t

$$U_t^j(r_-, r) = \bar{\chi} a_t(r) \prod_{i=1}^{I} \left[\int_0^1 c_{it}^{\omega}(r)^{\rho} \, d\omega \right]^{\frac{\chi_i}{\rho}} \varepsilon_t^j(r) \prod_{s=1}^{t} m(r_{s-1}, r_s)^{-1}$$

  - $\varepsilon_t^j(r)$ is a location preference shock that acts as a dispersion force and is drawn from Fréchet $\rightarrow \Omega \equiv$ migration elasticity
  - Amenities $a_t(r) = \bar{a}(r) \left(\bar{L}_t(r) / H(r)\right)^{-\lambda}$ also act as a dispersion force

- Moving costs $m(r,s) = m_1(r) m_2(s)$, paid while in the host location
  - Forward-looking migration decision $\rightarrow$ static problem (Desmet et al., 2018)

Technology

- Firm produces variety ω in sector i in location r at time t according to

$$q_{it}^{\omega}(r) = L_{\phi,it}^{\omega}(r)^{\gamma_i} z_{it}^{\omega}(r) L_{it}^{\omega}(r)^{\mu_i} E_{it}^{\omega}(r)^{\sigma_i} H_{it}^{\omega}(r)^{1-\gamma_i-\mu_i-\sigma_i}$$

  - Productivity shifter $z_{it}^{\omega}(r)$ drawn from Fréchet $\sim G(Z_{it}(r), \theta)$

$$Z_{it}(r) = \tau_{it}(r)\, g_i(T_t(r)) \left(\frac{\bar{L}_{it}(r)}{H_{it}(r)}\right)^{\alpha_i}$$

    where local density acts as an agglomeration force

  - A location's fundamental productivity in sector i evolves according to

$$\tau_{it}(r) = L_{\phi,i,t-1}(r)^{\gamma_i} \left[\int_S e^{-\aleph dist(r,s)} \tau_{i,t-1}(s)\, ds\right]^{1-\delta} \tau_{i,t-1}(r)^{\delta}$$

- Local technology diffuses locally to potential entrants
  - Competition for land $\rightarrow$ firm dynamic innovation decisions simplifies to a static optimization problem (Desmet et al., 2018)

- Standard trade costs and Ricardian approach where $\theta \equiv$ elasticity of trade

Global warming

- Bell-shaped sector-specific temperature productivity discount

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

- Simple world energy market with constant supply elasticity

- Carbon cycle:
  - Energy from production ↑ emissions and carbon stock: $K_t = \varepsilon_1 K_{t-1} + \varepsilon_2 E_{t-1}$
  - Carbon stock affects global temperature: $T_t = T_{t-1} + \nu\left(K_t - K_{t-1}\right)$

- Global temperature affects local temperature

$$T_t\left(r\right) - T_{t-1}\left(r\right) = \xi\left(r\right)\left(T_t - T_{t-1}\right)$$

Carbon taxes

- Carbon tax increases the energy price e_t by a proportion $\Upsilon(r)$
  - A firm in r producing variety ω of sector i minimizes

$$p_{it}^{\omega}(r,r)q_{it}^{\omega}(r) - w_t(r)\left[L_{it}^{\omega}(r) + L_{\phi it}^{\omega}(r)\right] - (1+\Upsilon_t(r))e_t E_{it}^{\omega}(r) - R_t(r)H_{it}^{\omega}(r)$$

  - Its marginal cost is

$$mc_{it}(r) = \kappa_i w_t(r)^{\gamma_i+\mu_i} R_t(r)^{1-\gamma_i-\mu_i-\sigma_i} e_t^{\sigma_i}(1+\Upsilon_t(r))^{\sigma_i}$$

- Carbon tax affects sectors based on their energy intensity σ_i
- Carbon tax revenues are either
  - Lost
  - Rebated: locally, EU uniform, developing countries, ...

Local effects of carbon taxes

- Carbon tax: $\uparrow$ marginal cost of local producers, $\downarrow$ local revenue (and income per capita)

- Once carbon tax is rebated, income per capita may increase if
  - Carbon tax is small enough to avoid large distortionary effects
  - Trade elasticity, θ, is low enough to limit initial drop in income

- If local income per capita increases, immigrants flow in and local economy expands
  - Larger expansion, the larger the migration elasticity $(1/\Omega)$

- Larger effects in locations specialized in energy-intensive industries
  - Static and dynamic externalities imply inefficient spatial equilibrium
  - Spatial reallocation: potential to improve global efficiency and welfare

2. Quantification and EU CO2 tax simulations

Quantification: economics, climate, and carbon taxes ‣ details

- Economics: global scale, high-resolution ($1^\circ \times 1^\circ$ cells)
  - Agriculture and non-agriculture; energy shares of 4% and 7% respectively
  - Data: trade costs, population, GDP, sectoral output, well-being
  - Recover: fundamental productivities, amenities, migration costs
- Climate: CO2 cycle parameters that replicates RCP 8.5 ($\uparrow$ 3.7°C by 2100)
  - Damage functions $g_i(T_t(r))$ quantified with agronomy studies + model-implied productivities
- Carbon taxes: 40USD/tCO_2 (Germany = 27, France = 48, Sweden = 140)
  - $Y(r) \times e_0 = 40\text{USD}/tCO_2 \rightarrow Y(r) = 40/e_0 = 0.8632$ (86.32%) ‣ CO2 tax

Simulations: carbon taxes in the EU

- Simulations: evolution the global economy over the 21st century with and without carbon taxes
  - Without taxes: evolution of global economy and climate (RCP 8.5)
  - With taxes: EU sets 40 US$/t$CO_2$ from 2021 onwards

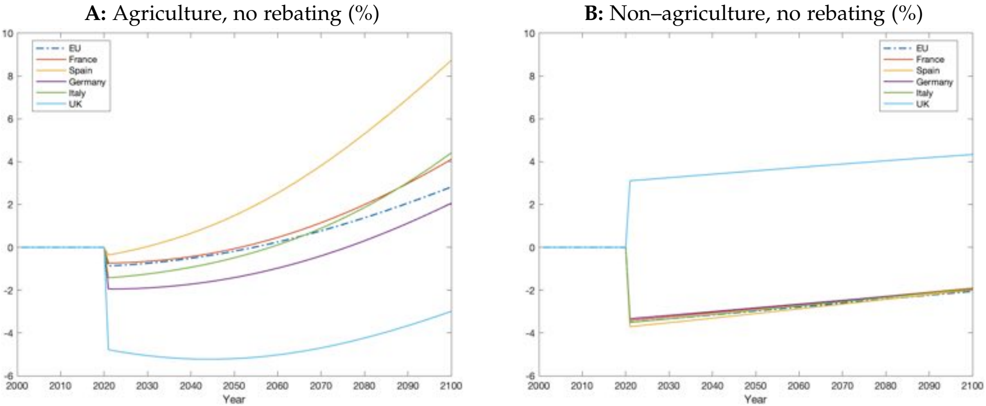
- Carbon tax effects: (dis)aggregate sectoral output, economy size, population, welfare, emissions, ...

- Different tax rebating schemes
  - No rebating: isolates distortive effect of the carbon tax
  - Local rebating: rebate revenues per capita to the local population

3. Carbon taxes without rebating

Sectoral specialization

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

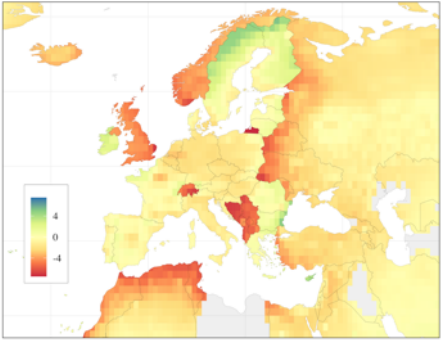


- EU output declines in both sectors, but less in agriculture ‣ US case
- UK, in comparison gains comparative advantage in non-agriculture

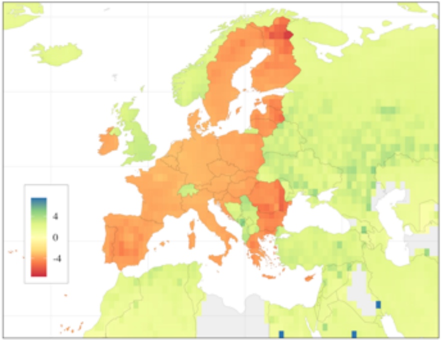
Sectoral specialization in 2021 without rebating

% Change in sectoral output due to carbon taxes, 2021

A: Agriculture, no rebating, 2021 (%)



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



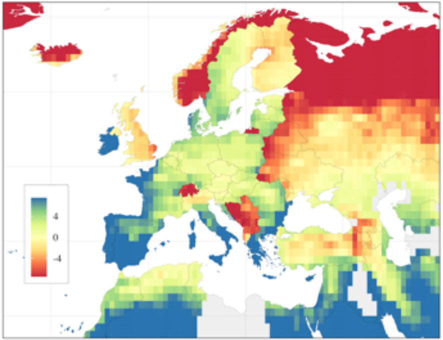
▸ world map ▸ 2100 results ▸ Δ emissions ▸ regional results ▸ US case

- EU periphery is gaining comparative advantage in agriculture
- Border effect: negative for agriculture, ambiguous for non-agriculture
- EU losses (GDP, population and welfare) increase with the tax ▸ details

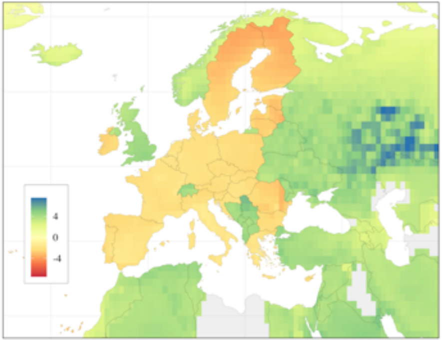
Sectoral specialization in 2100 without rebating

% Change in sectoral output due to carbon taxes, 2100

A: Agriculture, no rebating, 2100 (%)



B: Non–agriculture, no rebating, 2100 (%)

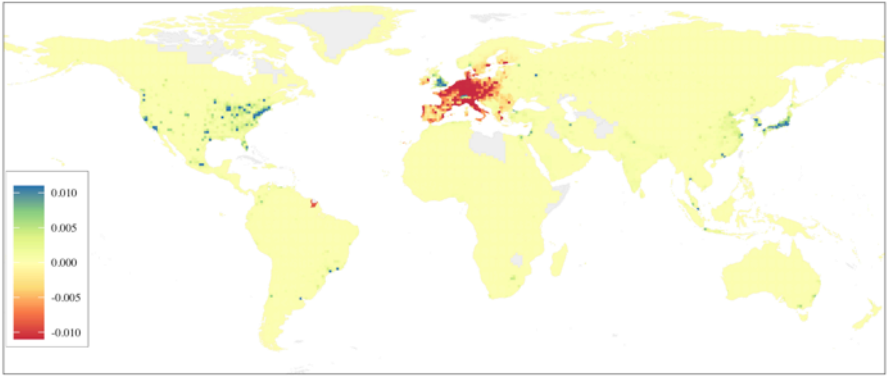


▸ world map ▸ return

- 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

Emissions changes in 2021, GtCO2

Change in total emissions due to carbon taxes, 2021



▸ map Europe ▸ emissions by sector ▸ return

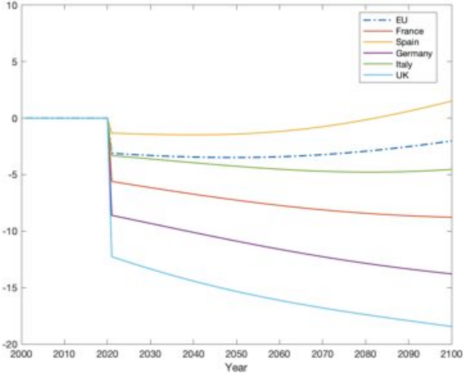
- World emissions: -2.2% in 2021 and -2.7% in 2100
- EU emissions: -43.4% in 2021 and -41.2% in 2100

4. Carbon taxes with local rebating

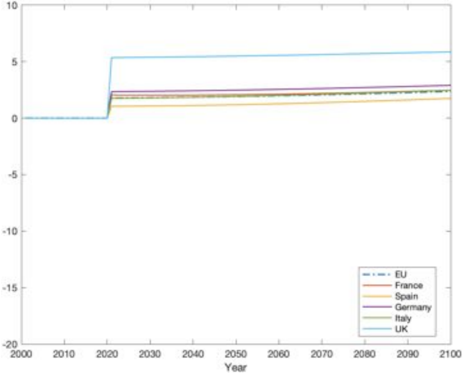
Sectoral specialization over time with local rebating

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

A: Agriculture, local rebating (%)



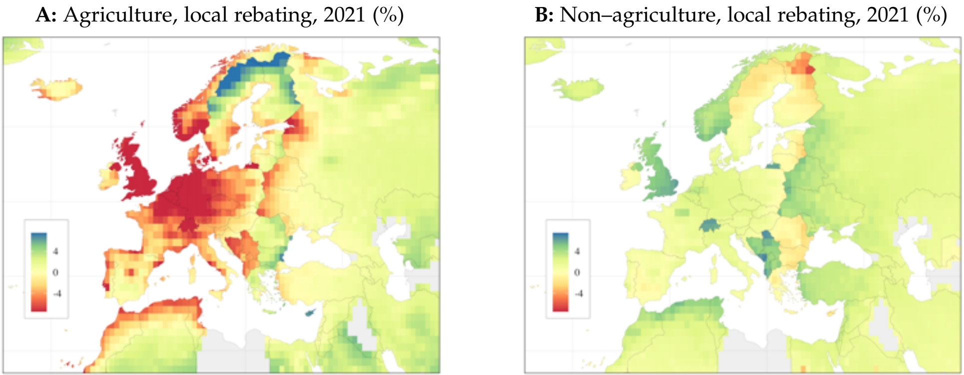
B: Non–agriculture, local rebating (%)



- With local rebating, agriculture falls more in Europe's core
- Non-agriculture grows everywhere in EU, especially in the core ▸ US case

Sectoral specialization 2021 with local rebating

% Change in sectoral output due to carbon taxes, 2021



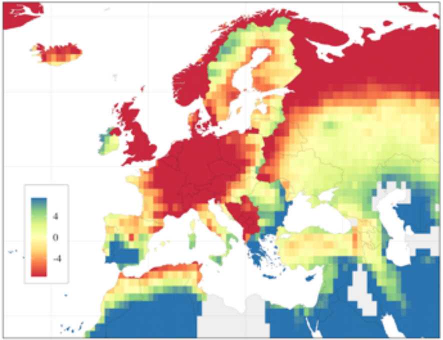
▸ world map ▸ 2100 results ▸ Δ emissions ▸ regional results ▸ US case

- Core and border regions switch from agriculture to non-agriculture
- Border effect: driven by EU periphery's change in specialization
- EU gains (real GDP and population), world is better off

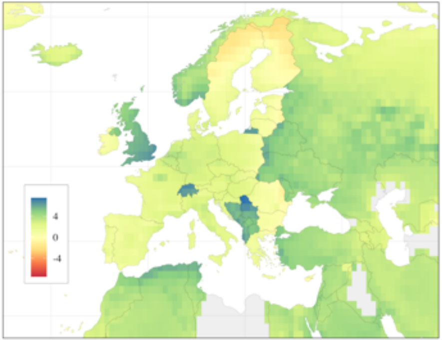
Sectoral specialization 2100 with local rebating

% Change in sectoral output due to carbon taxes, 2100

A: Agriculture, local rebating, 2100 (%)



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

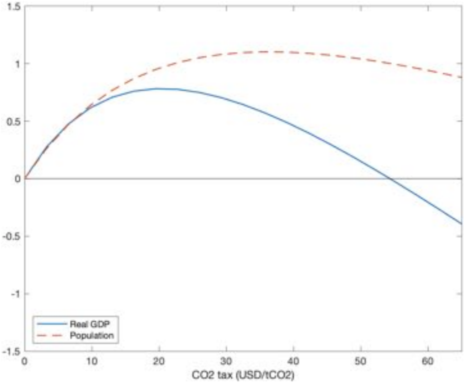


▸ world map ▸ return

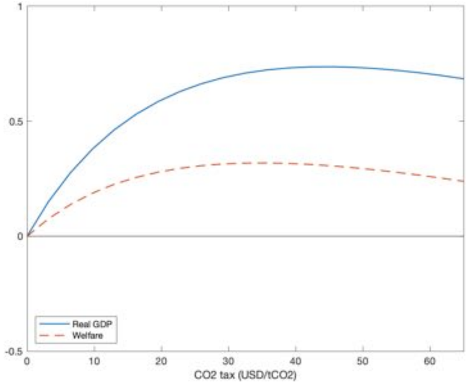
- Comparative advantage changes amplify over time
- Border benefits from more investment in non-agriculture

Effects of different carbon taxes: EU and worldwide (2021)

A: % Changes in EU real GDP and population



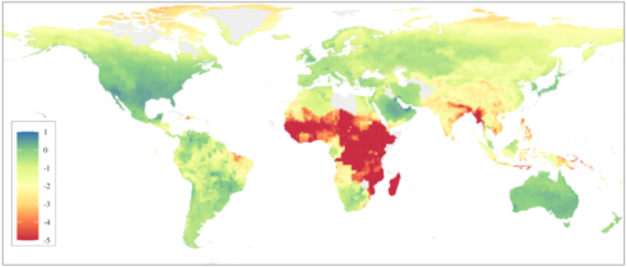
B: % Changes in world's GDP pc/welfare



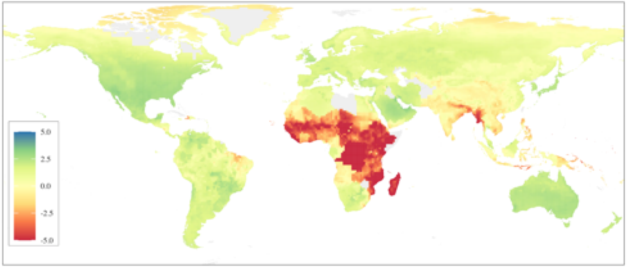
- With local rebating, positive effects on real GDP for carbon taxes up to 50 USD/tCO_2 (EU welfare falls due to migration) ‣ no reb. ‣ θ, Ω
- World welfare increases due to more efficient distribution of economic activity (more people live in more productive regions, like the EU)

Real GDP pc and population changes in 2100

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

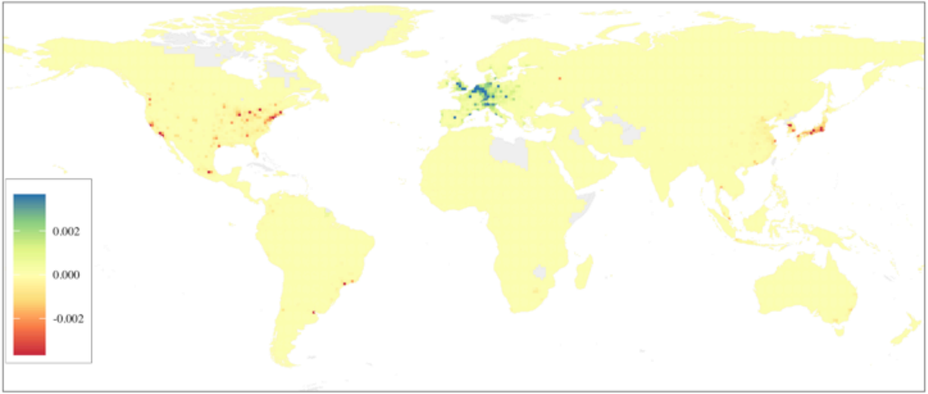


B: Population % Δ due to carbon taxes, local rebating, 2100



Change in emissions: local rebating vs no rebating

Δ Emissions (local rebating - no rebating), 2021 (GtCO2) ▸ emissions levels ▸ return



Aggregate and distributional effects of carbon taxes

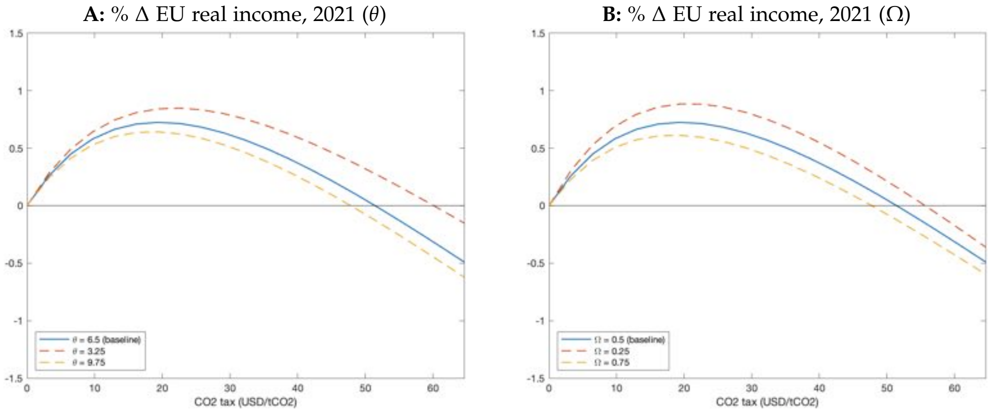
% Changes in 2021 and 2100 when locally rebating carbon tax revenues

Δ Real sectoral outputs return

	World		EU		US		Japan		SSA		Asia	
	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100
Panel A: No rebating												
Δ Real GDP	-0.65	-0.67	-4.95	-4.32	2.03	3.11	1.88	2.91	-3.11	-6.1	-1.34	-1.62
Δ Real GDP pc	-0.65	-0.67	-3.3	-3.18	-0.2	0.1	-0.27	0.03	-0.96	-2.36	-1.2	-1.42
Δ Welfare	-0.62	-0.57	-2.76	-2.86	-0.93	-0.84	-0.97	-0.88	-2.51	-3.53	-1.72	-2.11
Δ Population	0	0	-1.71	-1.17	2.23	3	2.16	2.87	-2.17	-3.83	-0.15	-0.2
Δ Agricultural Output	-0.07	0.86	-0.83	2.83	-0.07	0.63	-0.07	1.93	-0.46	1.56	0.58	1.96
Δ Non-agric. Output	0.74	1.94	-3.44	-1.91	2.75	4.69	2.41	4.11	0.25	0.67	0.63	1.97
Δ Emissions	-2.16	-2.71	-43.42	-41.24	12.13	16.83	11.77	16.19	9.36	12.36	9.83	13.8
Panel B: Local rebating												
Δ Real GDP	0.74	1.25	0.47	1.16	1.72	2.69	1.52	2.48	-3.43	-6.46	-1.46	-1.8
Δ Real GDP pc	0.74	1.25	-0.63	-0.5	-0.22	0.07	-0.31	0	-0.96	-2.37	-1.14	-1.34
Δ Welfare	0.32	0.77	-1.01	-1.08	-0.84	-0.73	-0.89	-0.79	-2.42	-3.41	-1.57	-1.94
Δ Population	0	0	1.1	1.66	1.94	2.61	1.84	2.47	-2.5	-4.19	-0.33	-0.46
Δ Agricultural Output	1.34	2.74	-3.07	-2.21	2.47	5.63	2.96	6.96	1.13	2.86	2.35	4.14
Δ Non-agric. Output	1.37	2.76	1.76	2.5	1.34	2.97	0.46	2.41	-0.46	0.15	-0.64	0.55
Δ Emissions	-2.15	-2.66	-40.46	-38.73	10.55	14.7	9.6	14.08	8.72	11.62	8.76	12.58

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

Effects of trade elasticity and preference heterogeneity ▸ return



- Lower trade elasticity θ: smaller negative effect on local revenues
- Lower preference heterogeneity Ω (higher mig. elasticity): greater influx of migrants

5. Carbon taxes with EU or developing countries rebating

EU or developing countries rebating

▸ regional tables ▸ details

- We consider two additional forms of rebating the revenue of EU CO2 taxes
  - Goal is to understand how rebating changes sectoral specialization and population flows
- Uniform EU rebating where we rebate total EU carbon tax revenue equally across the EU population
  - Smaller expansion of the EU, smaller global efficiency and welfare gains
- Developing countries rebating where we rebate total EU carbon tax revenue equally across the developing world ▸ dev. countries
  - Dilutes efficiency gains from SSA/Asia to the EU and the US (keeps people from migrating)

6. Conclusions

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
- 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 a possible way to rebate
- Alternative rebating schemes yield different results
  - E.g., rebating to developing countries
  - Keeps more people in less productive areas
  - Decreases spatial inequality, but worsens global welfare

Thank you!

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Appendix

Quantification: Economics ▸ back

- Discretize the world into 64,800 $1^\circ \times 1^\circ$ cells
- Data
  - Bilateral trade costs
  - Population
  - Total output and agricultural output
  - Well-being
- 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 ‣ back

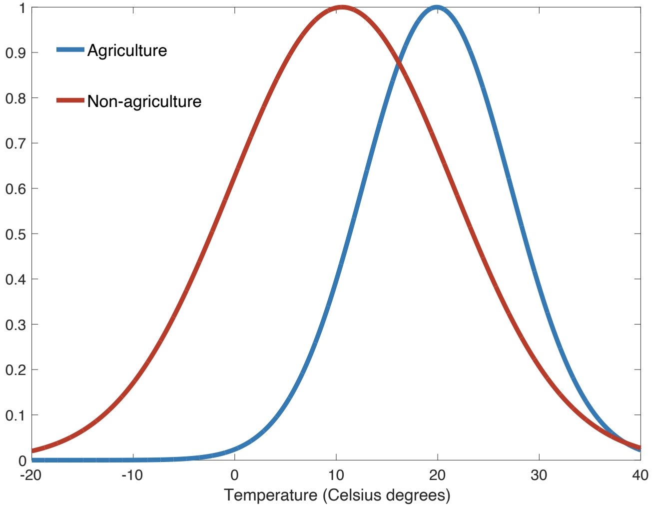
- Parameters of carbon cycle such that
  - 1200 GTC increase in stock of carbon by 2100
  - 3.7°C global temperature increase by 2100
  - Consistent with Representative Concentration Pathway (RCP) 8.5
- Local sensitivity to change in global temperature is heterogeneous
  - Predicted local and global temperatures from 2000 to 2100 to estimate

$$T_t(r) - T_{t-1}(r) = \xi(r)\left(T_t - T_{t-1}\right) + v_t(r)$$

- 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

▸ back



Quantification: Energy shares and CO2 taxes

back

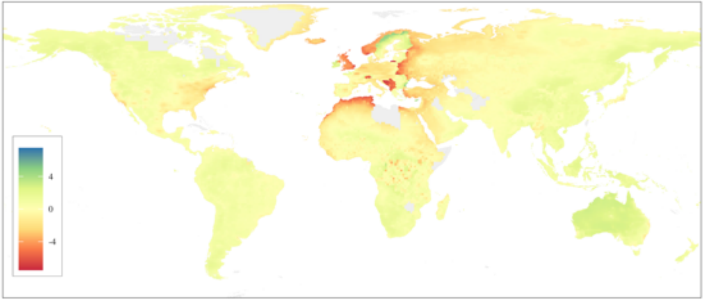
- Energy shares
  - Agriculture: 0.04 (Schnepf, 2004; Australian Bureau of Statistics, 2021)
  - Non-agriculture: 0.07
    - Energy share in total GDP $\sim 0.056 - 0.08$ (King et al., 2015; Grubb et al., 2018)
    - Combine with energy share in agriculture (0.04) and share of non-agriculture in GDP (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
  - $Y(r) \times e_0 = 40 \text{ USD}/tCO_2 \rightarrow Y(r) = 40/e_0$
  - $Y(r) = 0.8632$ (86.32%)

Simulation

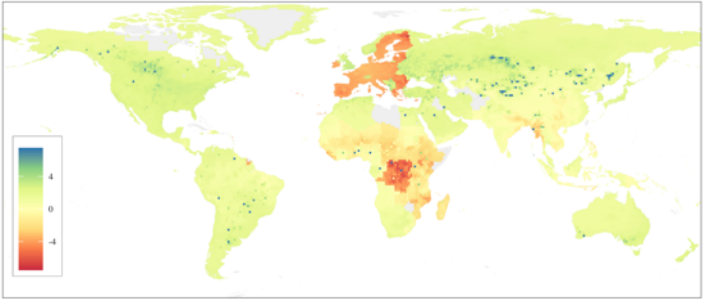
back

- 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

A: Agriculture, no rebating, 2021 (%)

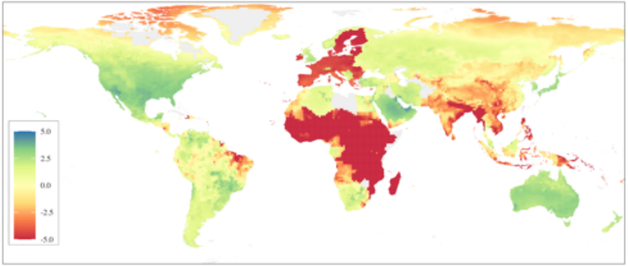


B: Non-agriculture, no rebating, 2021 (%)

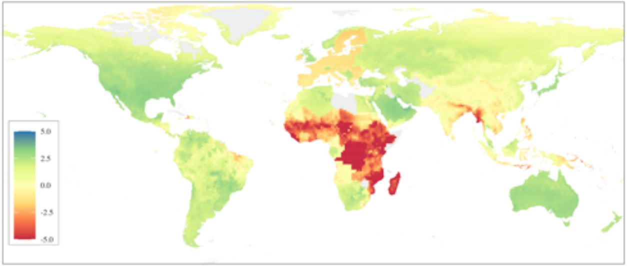


Real GDP and population changes in 2100

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

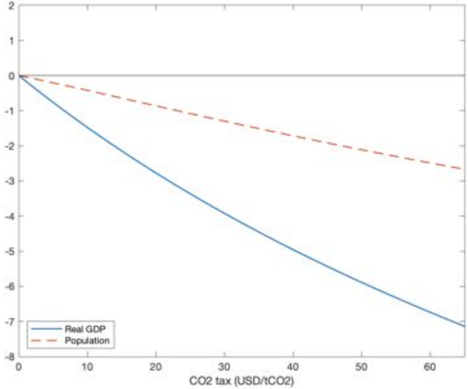


B: Population % changes due to carbon taxes, 2100

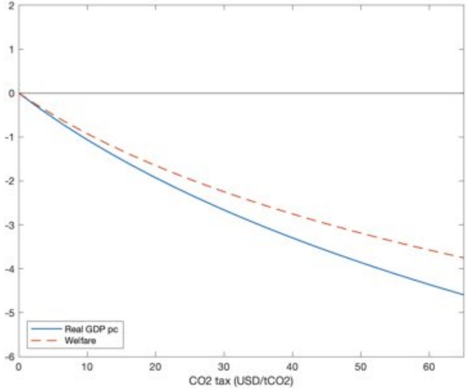


Effects on the EU of different carbon taxes, 2021

A: % Changes in EU real GDP and population



B: % Changes in EU GDP pc and welfare

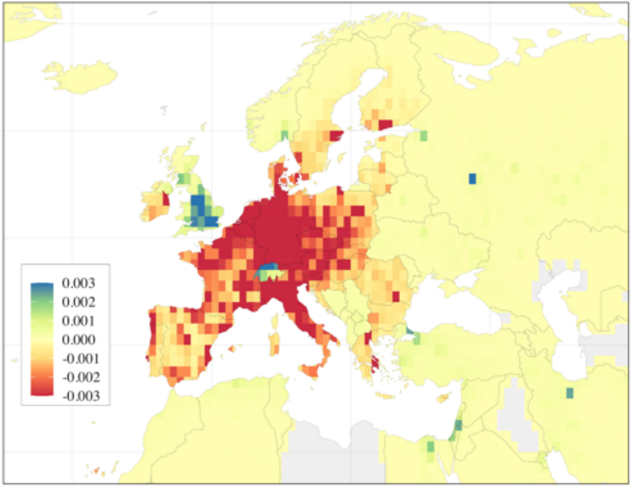


▸ results world ▸ results sectors ▸ US case ▸ return ▸ return loc. reb

- Larger negative effects on real GDP, population and welfare, the larger the carbon tax

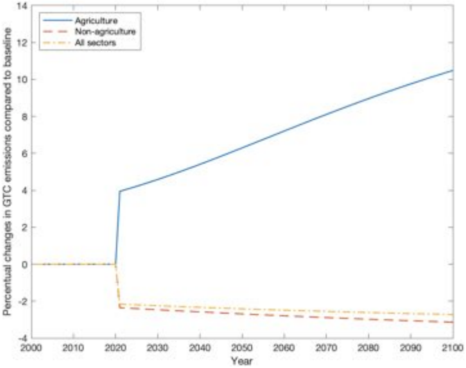
Emissions changes in Europe in 2021

Differences in total emissions, 2021 (GTC) ▸ return

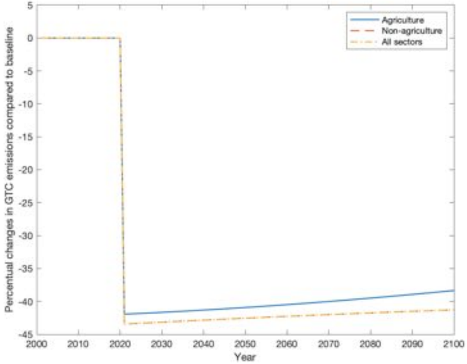


Emissions over time: World vs EU

A: Total emissions, % change, by sector



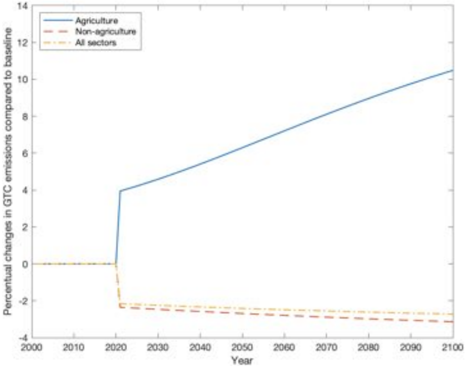
B: EU emissions, % change, by sector



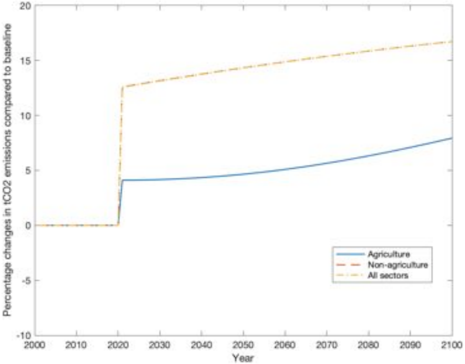
- Agriculture output grows in less efficient areas
- Non-agricultural emissions fall due to decrease in world output

Emissions over time: World vs UK

A: Total emissions, % difference, by sector

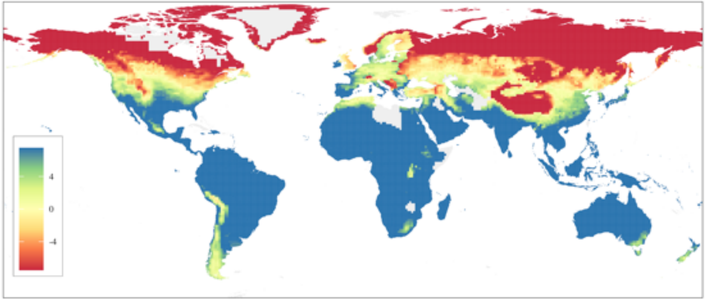


B: UK emissions, % difference, by sector

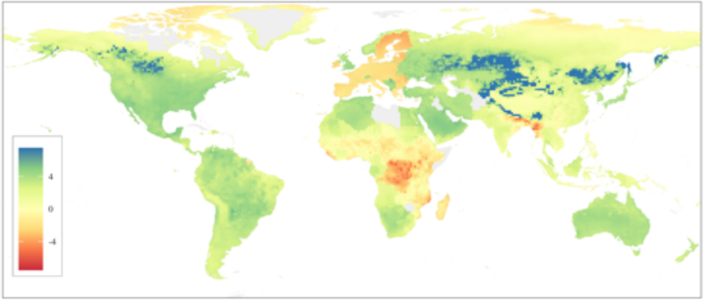


▸ return

A: Agriculture, no rebating, 2100 (%)



B: Non-agriculture, no rebating, 2100 (%)



Aggregate and distributional effects of carbon taxes

% Change in 2021 and 2100 without rebating carbon tax revenues

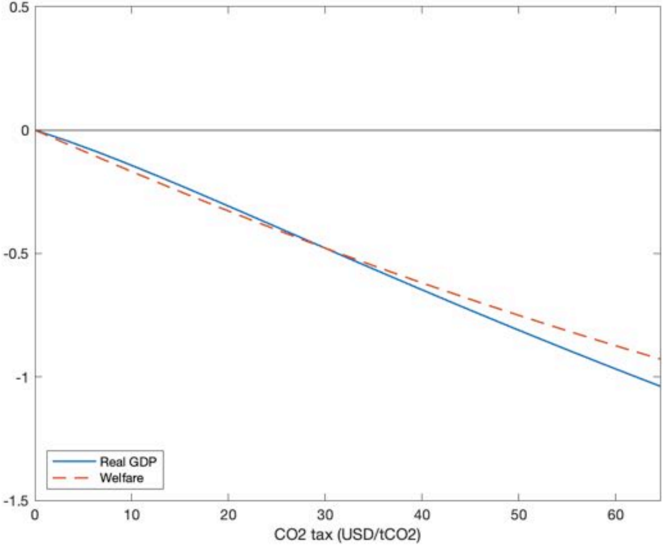
	World		EU		US		Japan		SSA		Asia	
	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100
Δ Real GDP	-0.65	-0.67	-4.95	-4.32	2.03	3.11	1.88	2.91	-3.11	-6.1	-1.34	-1.62
Δ Real GDP pc	-0.65	-0.67	-3.3	-3.18	-0.2	0.1	-0.27	0.03	-0.96	-2.36	-1.2	-1.42
Δ Welfare	-0.62	-0.57	-2.76	-2.86	-0.93	-0.84	-0.97	-0.88	-2.51	-3.53	-1.72	-2.11
Δ Population	0	0	-1.71	-1.17	2.23	3	2.16	2.87	-2.17	-3.83	-0.15	-0.2
Δ Agricultural Output	-0.07	0.86	-0.83	2.83	-0.07	0.63	-0.07	1.93	-0.46	1.56	0.58	1.96
Δ Non-agric. Output	0.74	1.94	-3.44	-1.91	2.75	4.69	2.41	4.11	0.25	0.67	0.63	1.97
Δ Emissions	-2.16	-2.71	-43.42	-41.24	12.13	16.83	11.77	16.19	9.36	12.36	9.83	13.8

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

▸ Δ Real sectoral outputs ▸ return

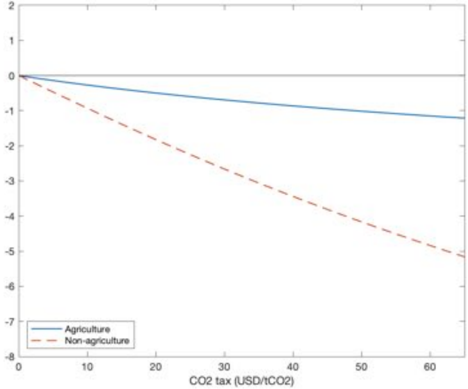
Effects on sectoral output of different carbon taxes, 2021

% Changes in world's GDP pc/welfare ▸ back

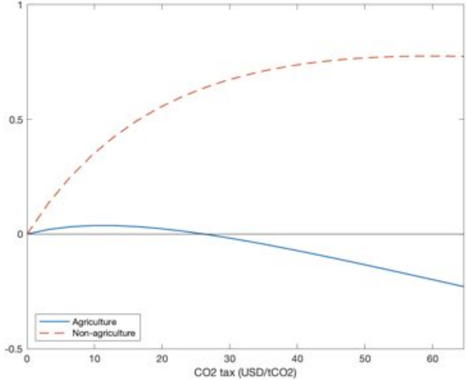


Effects on the World of different carbon taxes, 2021

A: % Changes in EU's sectoral output



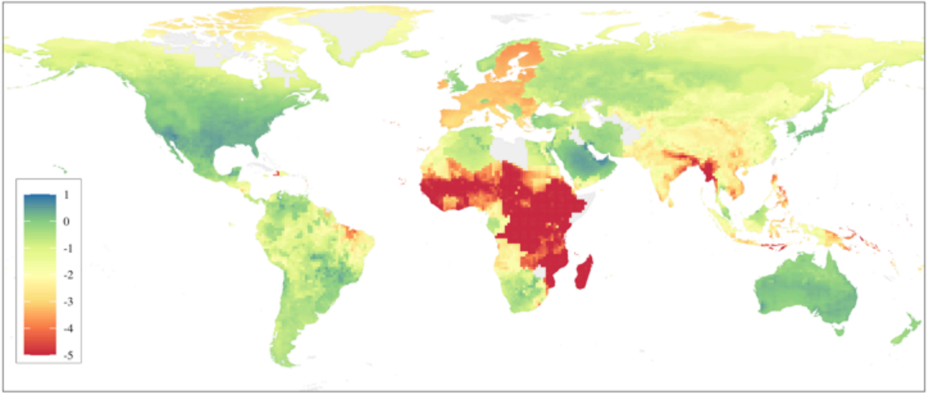
B: % Changes in world's sectoral output



back

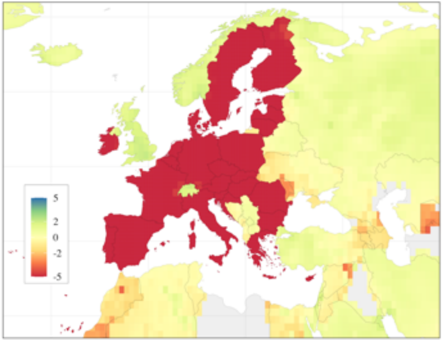
Effect on GDP per capita

Real GDP pc % changes due to carbon taxes, 2100 ▸ return

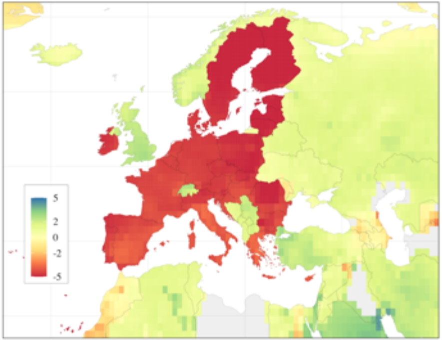


Effect on real GDP in Europe

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



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



return

Aggregate and distributional effects of carbon taxes

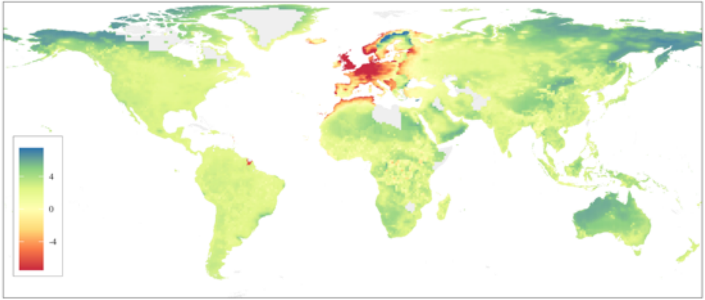
% Change in 2021 and 2100 without rebating carbon tax revenues

	World		EU		US		Japan		SSA		Asia	
	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100
Δ Agricultural output	-0.07	0.86	-0.83	2.83	-0.07	0.63	-0.07	1.93	-0.46	1.56	0.58	1.96
Δ Non-agric. output	0.74	1.94	-3.44	-1.91	2.75	4.69	2.41	4.11	0.25	0.67	0.63	1.97
Δ Agricultural prices	0.18	2.29	0.08	2.25	0.31	2.45	0.2	2.39	0.12	1.99	0.08	1.9
Δ Non-agric. prices	0.42	1.06	1.36	2.06	0.41	1.08	0.18	0.66	0.35	0.93	0.07	0.6
$\Delta P_A/P_M$	-0.24	1.22	-1.26	0.19	-0.1	1.35	0.02	1.72	-0.23	1.05	0.01	1.3
Δ Real agricultural output	-0.08	-1.16	-0.82	0.81	-0.47	-2.26	-0.29	-0.67	-0.56	-0.29	0.49	-0.13
Δ Real non-agric. output	-0.15	0.02	-4.89	-4.1	2.19	3.4	2.12	3.39	0.43	0.34	0.83	1.6

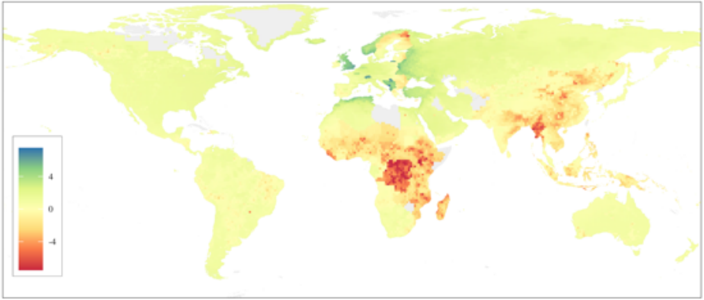
Notes: Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar Malaysia, Philippines, Thailand, and Vietnam.

return

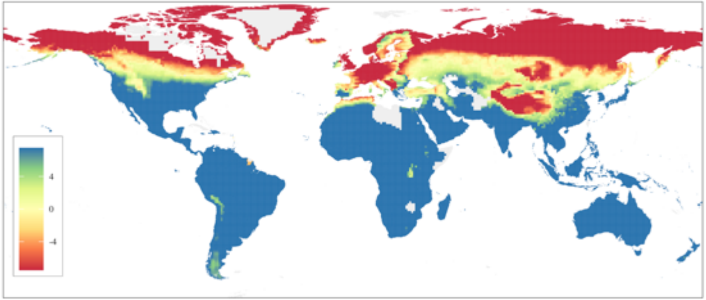
A: Agriculture, local rebating, 2021



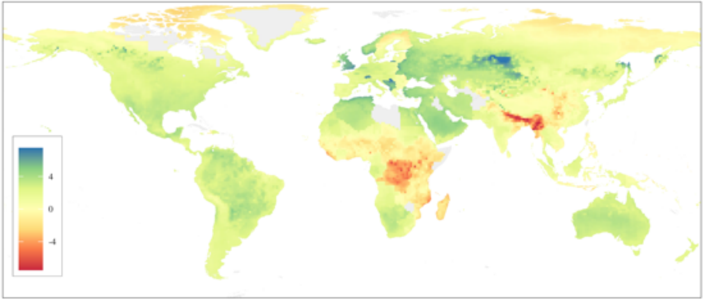
B: Non-agriculture, local rebating, 2021



A: Agriculture, local rebating, 2100

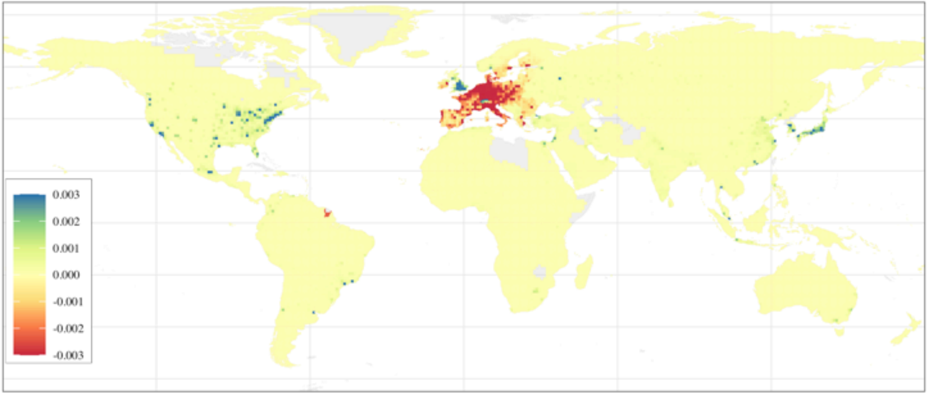


B: Non-agriculture, local rebating, 2100



Change in emissions with local rebating

Change in total emissions due to carbon taxes, 2021 return



Aggregate and distributional effects of carbon taxes

% Change in 2021 and 2100 locally rebating carbon tax revenues

return

	World		EU		US		Japan		SSA		Asia	
	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100
Panel A: No rebating												
Δ Agricultural output	-0.07	0.86	-0.83	2.83	-0.07	0.63	-0.07	1.93	-0.46	1.56	0.58	1.96
Δ Non-agric. output	0.74	1.94	-3.44	-1.91	2.75	4.69	2.41	4.11	0.25	0.67	0.63	1.97
Δ Agricultural prices	0.18	2.29	0.08	2.25	0.31	2.45	0.2	2.39	0.12	1.99	0.08	1.9
Δ Non-agric. prices	0.42	1.06	1.36	2.06	0.41	1.08	0.18	0.66	0.35	0.93	0.07	0.6
$\Delta P_A/P_M$	-0.24	1.22	-1.26	0.19	-0.1	1.35	0.02	1.72	-0.23	1.05	0.01	1.3
Δ Real agricultural output	-0.08	-1.16	-0.82	0.81	-0.47	-2.26	-0.29	-0.67	-0.56	-0.29	0.49	-0.13
Δ Real non-agric. output	-0.15	0.02	-4.89	-4.1	2.19	3.4	2.12	3.39	0.43	0.34	0.83	1.6
Panel B: Local rebating												
Δ Agricultural output	1.34	2.74	-3.07	-2.21	2.47	5.63	2.96	6.96	1.13	2.86	2.35	4.14
Δ Non-agric. output	1.37	2.76	1.76	2.5	1.34	2.97	0.46	2.41	-0.46	0.15	-0.64	0.55
Δ Agricultural prices	0.13	2.12	1.08	2.43	-0.03	2.11	-0.54	1.86	0.2	1.94	-0.17	1.67
Δ Non-agric. prices	0.52	1.1	3.77	3.87	-0.52	0	-1.13	-0.37	0.58	1.14	-0.23	0.44
$\Delta P_A/P_M$	-0.38	1.02	-2.6	-1.38	0.49	2.11	0.6	2.23	-0.37	0.8	0.05	1.23
Δ Real agricultural output	1.47	0.9	-4.09	-4.37	2.49	3.14	3.52	4.87	0.86	0.97	2.51	2.21
Δ Real non-agric. output	0.29	0.62	-2.67	-1.99	1.88	3	1.73	2.95	-0.09	-0.14	0.14	0.63

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

Global rebating

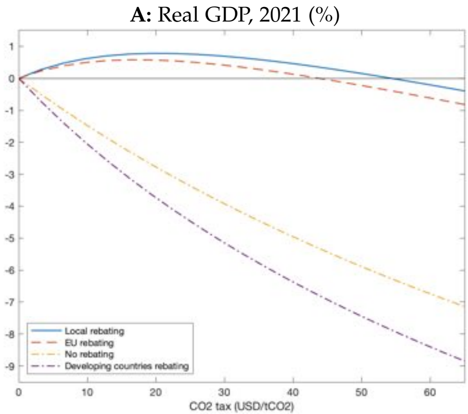
Countries benefited by the rebating of CO2 tax revenues

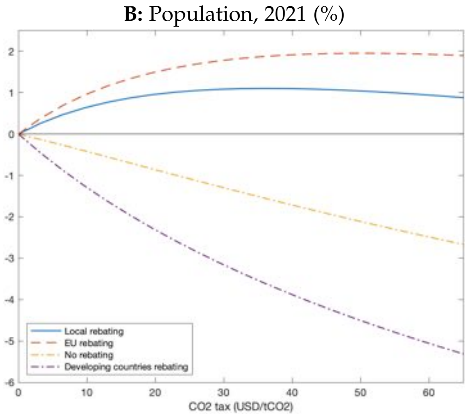
return

Country	Country	Country	Country
Albania	Costa Rica	Korea (North)	Peru
Algeria	Côte d'Ivoire	Kyrgyzstan	Philippines
American Samoa	Djibouti	Laos	Puerto Rico
Angola	Dominican Republic	Lebanon	Réunion
Anguilla	Ecuador	Lesotho	Rwanda
Argentina	Egypt	Liberia	Senegal
Armenia	El Salvador	Madagascar	Serbia
Azerbaijan	Equatorial Guinea	Malawi	Sierra Leone
Bangladesh	Eritrea	Malaysia	Singapore
Belarus	Eswatini	Maldives	Solomon Islands
Belize	Ethiopia	Mali	South Africa
Benin	Fiji	Mauritania	Sri Lanka
Bhutan	Gabon	Mayotte	Sudan
Bolivia, Plurinational State of	Gambia	Mexico	Suriname
Bosnia and Herzegovina	Ghana	Micronesia	Syria
Botswana	Grenada	Moldova	Tanzania
Brazil	Guadeloupe	Mongolia	Thailand
Brunei Darussalam	Guatemala	Morocco	Togo
Burkina Faso	Guinea	Mozambique	Tonga
Burundi	Guinea-Bissau	Myanmar	Tunisia
Cabo Verde	Guyana	Namibia	Turkmenistan
Cambodia	Haiti	Nepal	Uganda
Cameroon	Honduras	Nicaragua	Ukraine
Central African Republic	India	Niger	Uruguay
Chad	Indonesia	Nigeria	Uzbekistan
Chile	Iran	North Macedonia	Vanuatu
China	Jamaica	Pakistan	Venezuela
Colombia	Jordan	Panama	Viet Nam
Congo	Kenya	Papua New Guinea	Yemen
Congo DRC	Kiribati	Paraguay	Zambia

Effects on the EU of different carbon taxes, 2021

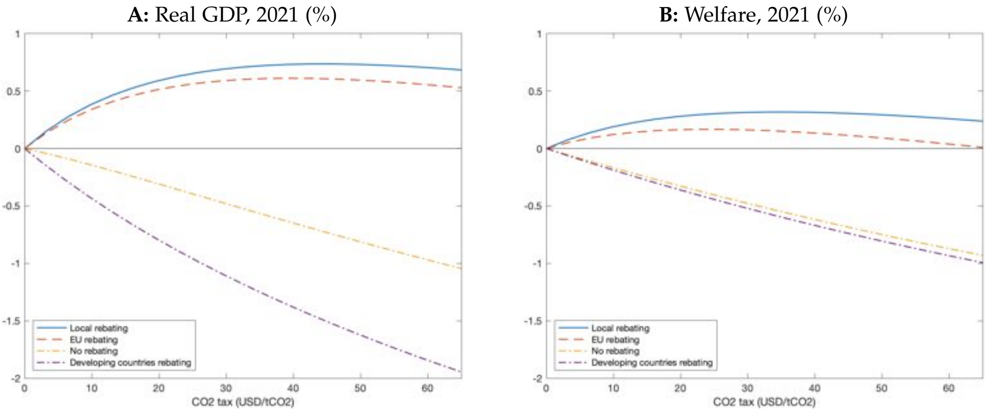
return





- EU rebating: smaller expansion of the EU
- Developing countries rebating: contraction of the EU

Effects on the world of different carbon taxes, 2021 ▸ return

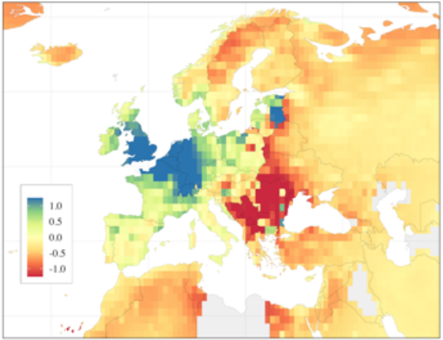


- EU rebating: smaller positive welfare effects
- Developing countries rebating: benefits sub-Saharan Africa and Asia, but hurts the world by keeping people from migrating

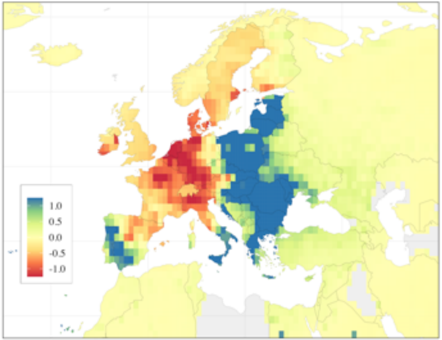
Sectoral specialization 2021: EU vs local rebating

return

A: % Δ Agric., EU – local rebating, 2021



B: % Δ Non-agric., EU – local rebating, 2021

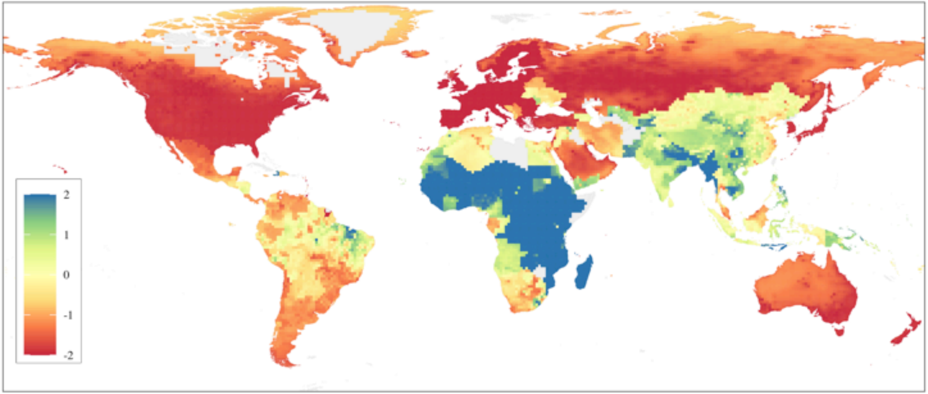


- With EU rebating, more resources flow to EU periphery and so it specializes more in non-agriculture
- Less concentration in the core, which leads to smaller world gains

CO2 tax effects in 2021: Developing vs local rebating

return

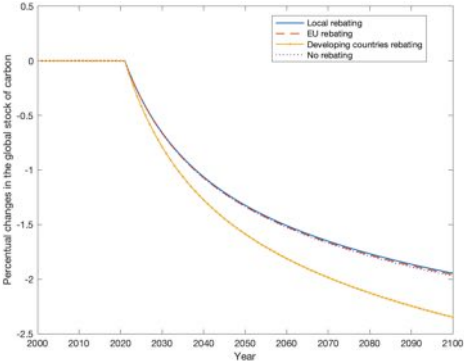
Δ% Population, developing – local rebating, 2021



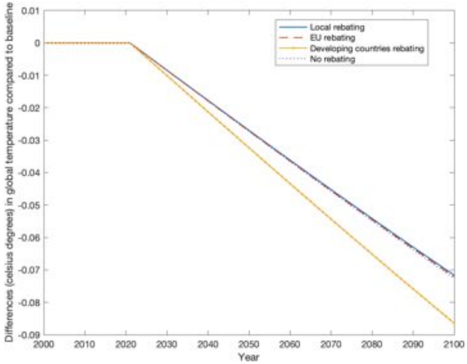
Evolution of global CO_2 stock and temperature

return

A: Change in global CO_2 stock (%)



B: Change in global temperature (°C)



- 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 CO_2

Aggregate and distributional effects of carbon taxes

% Changes in 2021 and 2100: different rebating schemes

▸ Δ Real sectoral outputs ▸ return

	World		EU		US		Japan		SSA		Asia	
	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100
Panel A: Local rebating												
Δ Real GDP	0.74	1.25	0.47	1.16	1.72	2.69	1.52	2.48	-3.43	-6.46	-1.46	-1.8
Δ Real GDP pc	0.74	1.25	-0.63	-0.5	-0.22	0.07	-0.31	0	-0.96	-2.37	-1.14	-1.34
Δ Welfare	0.32	0.77	-1.01	-1.08	-0.84	-0.73	-0.89	-0.79	-2.42	-3.41	-1.57	-1.94
Δ Population	0	0	1.1	1.66	1.94	2.61	1.84	2.47	-2.5	-4.19	-0.33	-0.46
Δ Agricultural Output	1.34	2.74	-3.07	-2.21	2.47	5.63	2.96	6.96	1.13	2.86	2.35	4.14
Δ Non-agric. Output	1.37	2.76	1.76	2.5	1.34	2.97	0.46	2.41	-0.46	0.15	-0.64	0.55
Δ Emissions	-2.15	-2.66	-40.46	-38.73	10.55	14.7	9.6	14.08	8.72	11.62	8.76	12.58
Panel B: EU rebating												
Δ Real GDP	0.62	1.12	0.13	0.87	1.69	2.65	1.49	2.44	-3.49	-6.55	-1.52	-1.86
Δ Real GDP pc	0.62	1.12	-1.75	-1.49	-0.19	0.1	-0.28	0.03	-0.94	-2.36	-1.12	-1.32
Δ Welfare	0.14	0.46	-2.51	-2.67	-0.8	-0.69	-0.85	-0.74	-2.39	-3.38	-1.53	-1.9
Δ Population	0	0	1.92	2.4	1.89	2.55	1.78	2.41	-2.58	-4.3	-0.4	-0.54
Δ Agricultural Output	1.22	2.62	-2.85	-1.97	2.33	5.47	2.81	6.84	1.01	2.78	2.22	4.05
Δ Non-agric. Output	1.25	2.65	1.39	2.24	1.34	2.94	0.45	2.35	-0.51	0.09	-0.68	0.49
Δ Emissions	-2.17	-2.68	-40.63	-38.84	10.62	14.75	9.66	14.1	8.73	11.63	8.77	12.59
Panel C: Developing rebating												
Δ Real GDP	-1.38	-1.85	-6.37	-6.39	0.53	0.97	0.39	0.79	1.44	3.45	1.26	2.29
Δ Real GDP pc	-1.38	-1.85	-2.59	-2.13	0.55	1.24	0.48	1.19	0.78	2.18	0.82	1.61
Δ Welfare	-0.67	-0.76	-1.32	-0.76	0.54	1.35	0.5	1.31	0.8	2.09	0.74	1.75
Δ Population	0	0	-3.88	-4.35	-0.01	-0.26	-0.09	-0.39	0.65	1.25	0.44	0.67
Δ Agricultural Output	-1.46	-1.12	-1.05	2.32	-0.37	-0.91	0.13	-0.13	-1.56	3.92	-1.24	-0.29
Δ Non-agric. Output	-1.44	-1.08	-6.28	-5.66	-0.02	0.97	-0.18	0.85	0.9	2.93	0.76	2.41
Δ Emissions	-2.57	-3.25	-44.14	-42.19	10.95	15.26	10.77	15.12	11.74	17.51	11.56	16.47

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

Aggregate and distributional effects of carbon taxes

% Changes in 2021 and 2100: different rebating schemes ‣ return

	World		EU		US		Japan		SSA		Asia	
	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100	2021	2100
Panel A: Local rebating												
Δ Agricultural output	1.34	2.74	-3.07	-2.21	2.47	5.63	2.96	6.96	1.13	2.86	2.35	4.14
Δ Non-agric. output	1.37	2.76	1.76	2.5	1.34	2.97	0.46	2.41	-0.46	0.15	-0.64	0.55
Δ Agricultural prices	0.13	2.12	1.08	2.43	-0.03	2.11	-0.54	1.86	0.2	1.94	-0.17	1.67
Δ Non-agric. prices	0.52	1.1	3.77	3.87	-0.52	0	-1.13	-0.37	0.58	1.14	-0.23	0.44
$\Delta P_A/P_M$	-0.38	1.02	-2.6	-1.38	0.49	2.11	0.6	2.23	-0.37	0.8	0.05	1.23
Δ Real agricultural output	1.47	0.9	-4.09	-4.37	2.49	3.14	3.52	4.87	0.86	0.97	2.51	2.21
Δ Real non-agric. output	0.29	0.62	-2.67	-1.99	1.88	3	1.73	2.95	-0.09	-0.14	0.14	0.63
Panel B: EU rebating												
Δ Agricultural output	1.22	2.62	-2.85	-1.97	2.33	5.47	2.81	6.84	1.01	2.78	2.22	4.05
Δ Non-agric. output	1.25	2.65	1.39	2.24	1.34	2.94	0.45	2.35	-0.51	0.09	-0.68	0.49
Δ Agricultural prices	0.12	2.14	1.18	2.52	-0.03	2.12	-0.55	1.85	0.18	1.95	-0.19	1.67
Δ Non-agric. prices	0.5	1.09	3.73	3.89	-0.5	0	-1.13	-0.38	0.55	1.13	-0.24	0.43
$\Delta P_A/P_M$	-0.36	1.04	-2.45	-1.32	0.47	2.12	0.58	2.25	-0.36	0.81	0.05	1.24
Δ Real agricultural output	1.34	0.78	-4.12	-4.5	2.35	2.98	3.38	4.74	0.76	0.9	2.41	2.13
Δ Real non-agric. output	0.21	0.55	-2.85	-2.14	1.85	2.97	1.7	2.91	-0.13	-0.18	0.11	0.59
Panel C: Global rebating												
Δ Agricultural output	-1.46	-1.12	-1.05	2.32	-0.37	-0.91	0.13	-0.13	-1.56	3.92	-1.24	-0.29
Δ Non-agric. output	-1.44	-1.08	-6.28	-5.66	-0.02	0.97	-0.18	0.85	0.9	2.93	0.76	2.41
Δ Agricultural prices	-0.46	1.54	-0.85	1.36	-0.42	1.68	-0.39	1.89	-0.42	1.23	-0.38	1.36
Δ Non-agric. prices	-0.53	-0.06	0.02	0.46	-0.71	-0.33	-0.78	-0.41	-0.46	0.03	-0.57	-0.07
$\Delta P_A/P_M$	0.07	1.6	-0.87	0.9	0.29	2.02	0.39	2.31	0.04	1.19	0.19	1.43
Δ Real agricultural output	-0.99	-2.34	-0.1	1.21	0.05	-3.03	0.54	-2.11	-1.11	2.83	-0.87	-1.68
Δ Real non-agric. output	-1.36	-1.75	-6.31	-6.11	0.73	1.33	0.66	1.37	1.28	2.8	1.29	2.46

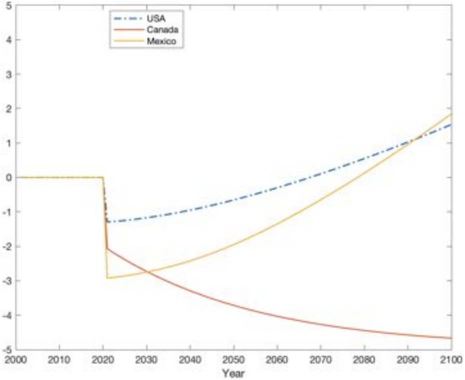
Notes: Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar Malaysia, Philippines, Thailand, and Vietnam.

7. US Carbon taxes without rebating

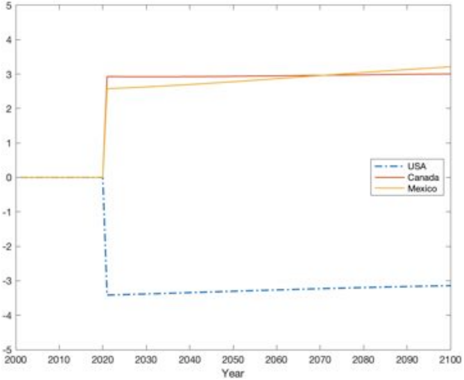
US Case: Sectoral specialization

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

A: Agriculture, no rebating (%)



B: Non–agriculture, no rebating (%)

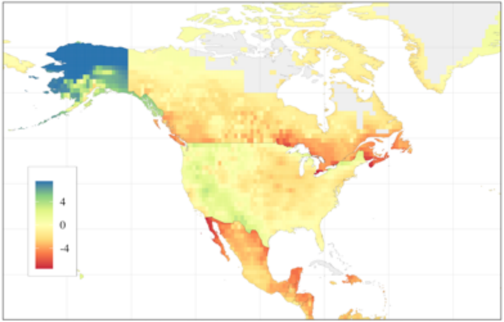


- US output declines in both sectors, but less in agriculture
- Canada and Mexico, in comparison, gains comparative advantage in non-agriculture ▸ return

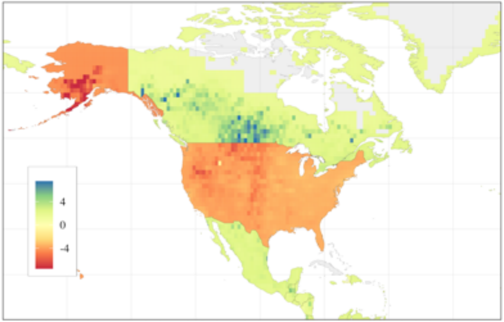
US Case: Sectoral specialization in 2021 without rebating

% Change in sectoral output due to carbon taxes, 2021

A: Agriculture, no rebating, 2021 (%)



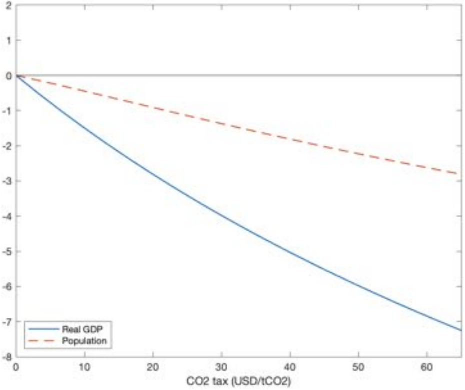
B: Non–agriculture, no rebating, 2021 (%)



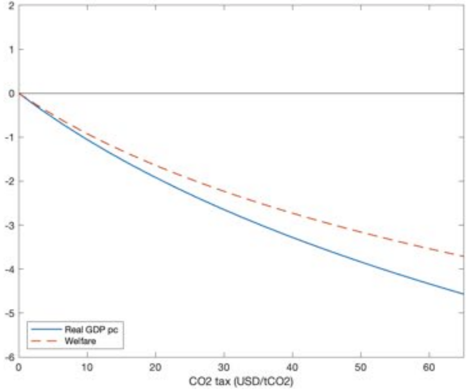
- USA periphery is gaining comparative advantage in agriculture return
- Border effect: negative for agriculture, ambiguous for non-agriculture

US Case: Effect of different carbon taxes, no rebating, 2021

A: % Changes in US real GDP and population



B: % Changes in US GDP pc and welfare



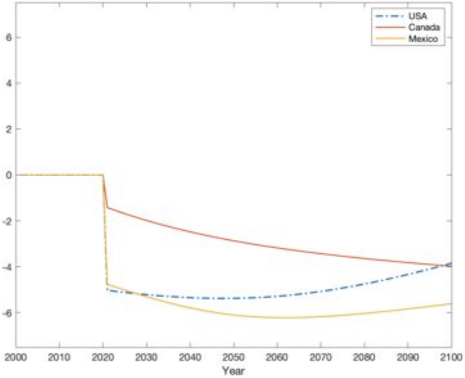
- Larger negative effects on real GDP, population, and welfare, the larger the carbon tax return

8. US Carbon taxes with local rebating

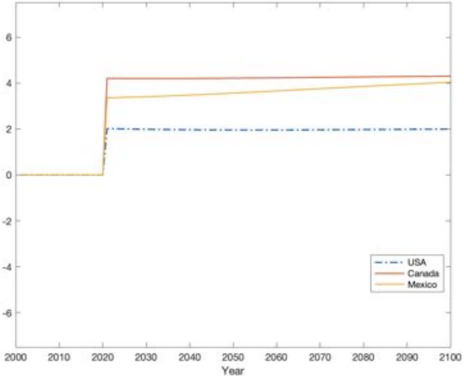
US Case: Sectoral specialization with local rebating

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

A: Agriculture, local rebating (%)



B: Non–agriculture, local rebating (%)

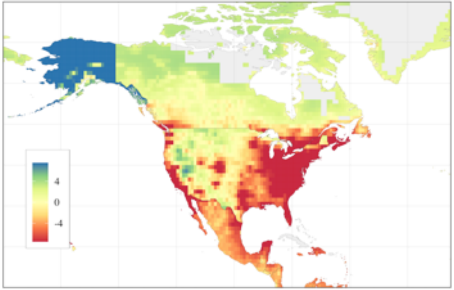


- With local rebating, agriculture still falls in US, Canada, and Mexico
- Non-agriculture now grows everywhere in the whole region ▸ return

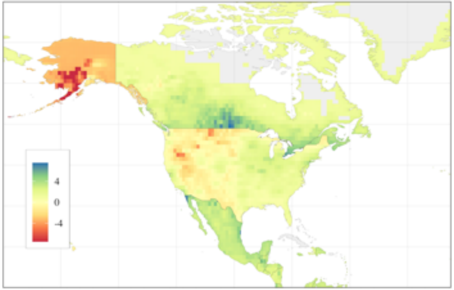
US Case: Sectoral specialization with local rebating

% Change in sectoral output due to carbon taxes, 2021

A: Agriculture, local rebating, 2021 (%)

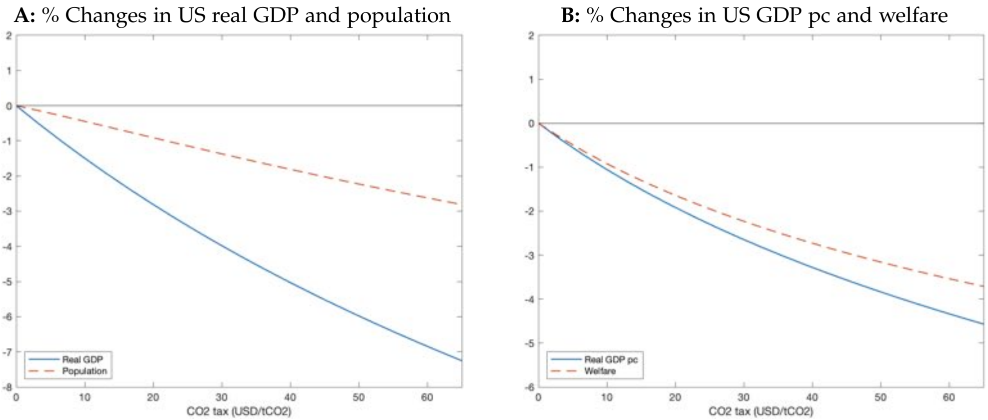


B: Non–agriculture, local rebating, 2021 (%)



- Coastal and Midwestern regions non-agricultural production benefit ▸ return
- Alaska becomes more specialized in agriculture as non-agriculture concentrates in most productive regions

US Case: Effect of different carbon taxes, no rebating, 2021



- Larger negative effects on real GDP, population, and welfare, the larger the carbon tax return