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

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

  - $\varepsilon_t^j(r)$ is location preference shock that acts as a *dispersion force*
  - Amenities are such that $a_t(r) = \bar{a}(r) \left(\bar{L}_t(r) / H(r) \right)^{-\lambda}$ 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 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 with average

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

    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 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

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

- Simple world energy market with constant supply elasticity
- Carbon cycle
  - Energy 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

$$T_t = T_{t-1} + \nu\left(K_t - K_{t-1}\right)$$

- 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 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, θ, 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 Ω

Lemma

If a small region r imposes a carbon tax $\Upsilon_t(r)$ rebated lump-sum to the local population, for $\theta > 1$ and α_i sufficiently small, $\exists \Upsilon_t(r) > 0$ 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

simulation

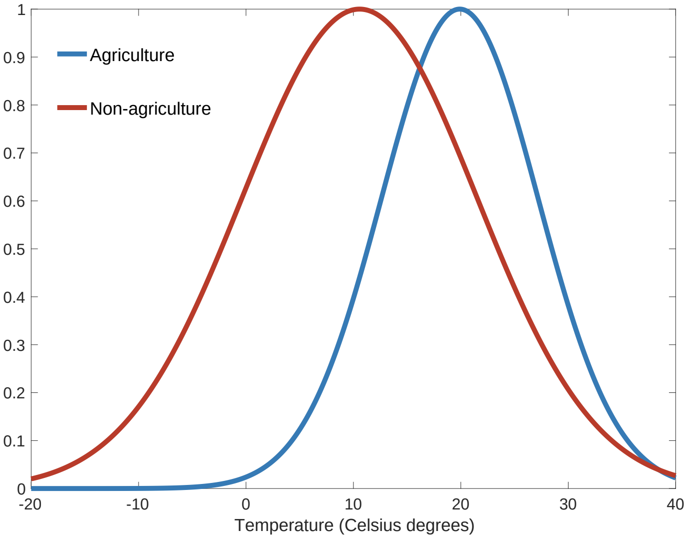
Quantification: Climate

- 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

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

- 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



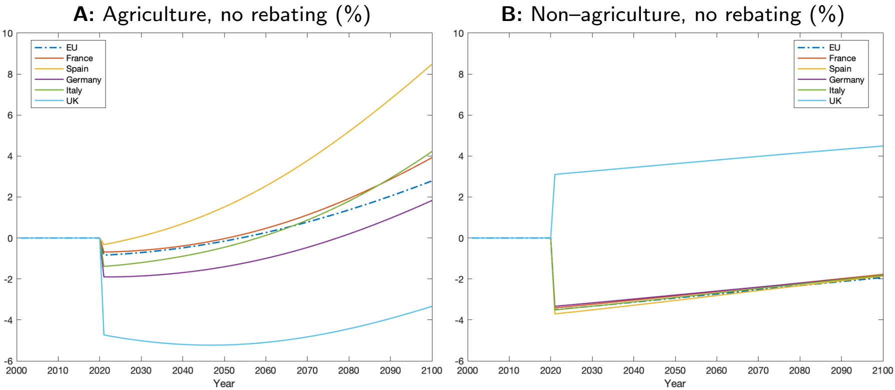
Quantification: Energy shares and carbon taxes

- 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
  - $\Upsilon(r) \times e_0 = 40 \text{ USD/tCO}_2 \rightarrow \Upsilon(r) = 40/e_0$
  - $\Upsilon(r) = 0.8632$ (86.32%)

Carbon taxes without rebating

Sectoral specialization

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



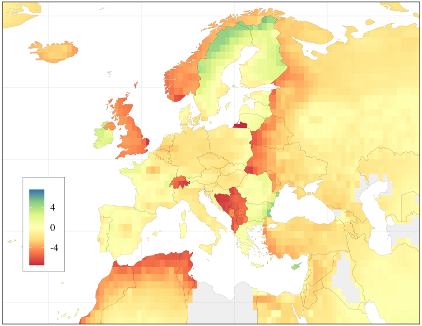
- EU output declines in both sectors, but less in agriculture
- UK, in comparison, gains comparative advantage in non-agriculture

US case

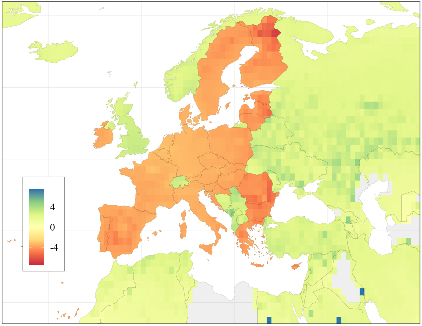
Sectoral specialization in 2021 without rebating

% Change in sectoral output due to carbon taxes, 2021

A: Agriculture, no rebating, 2021 (%)



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



▸ world map

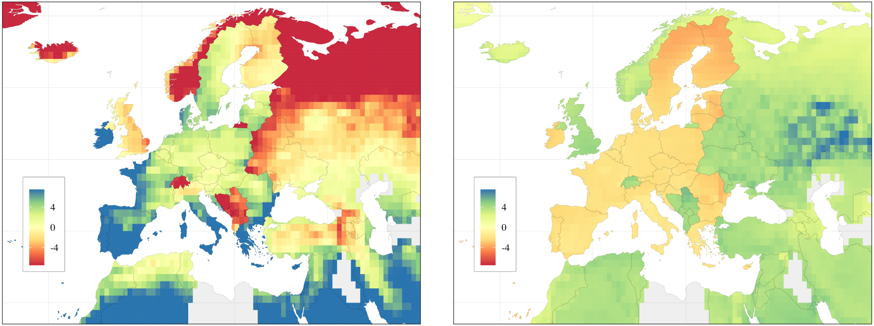
- EU periphery is gaining comparative advantage in agriculture
- Border effect: negative for agriculture, ambiguous for non-agriculture

▸ US case

Sectoral specialization in 2100 without rebating

% Change in sectoral output due to carbon taxes, 2100

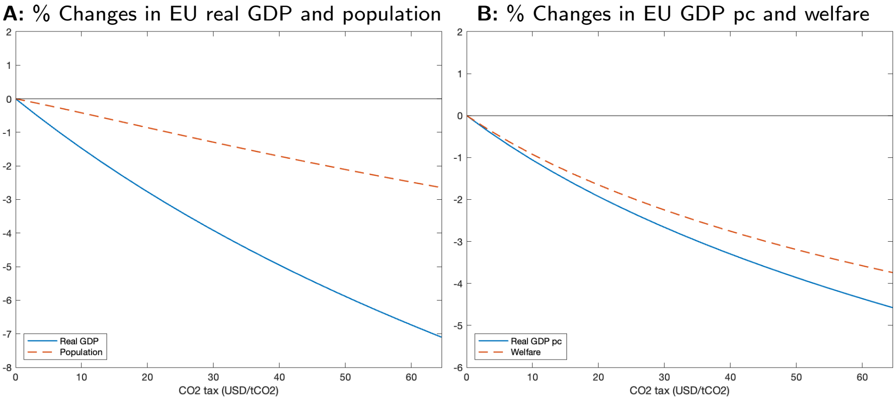
A: Agriculture, no rebating, 2100 **B:** Non–agriculture, no rebating, 2100



‣ world map

- 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



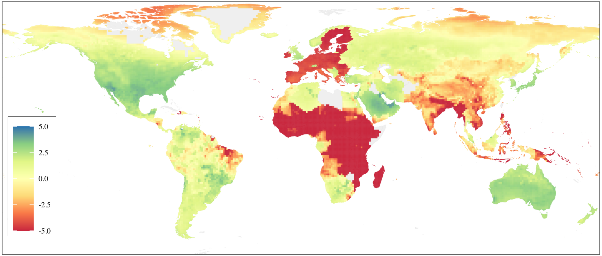
results world

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

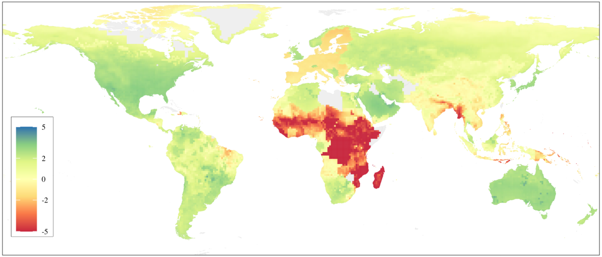
US case

Real GDP and population changes in 2100

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



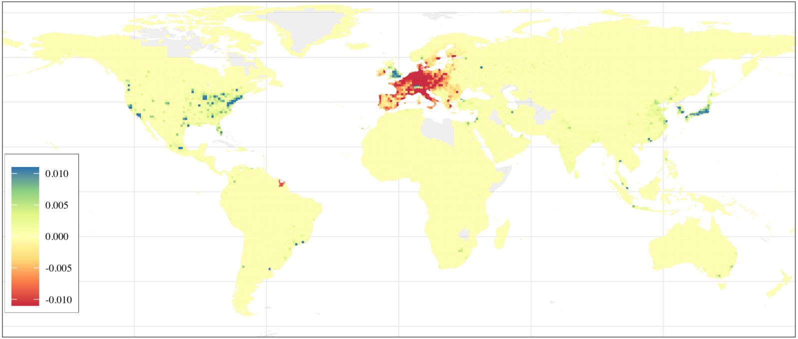
B: Population % changes due to carbon taxes, 2100



▸ map GDP per capita ▸ map Europe

Emissions changes in 2021, GtCO2

Change in total emissions due to carbon taxes, 2021



▸ map Europe ▸ emissions by sector

- 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

	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

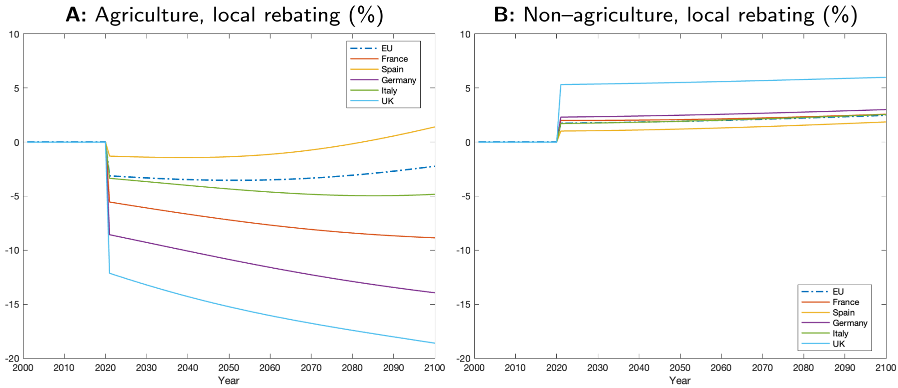
Carbon taxes with local rebating

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



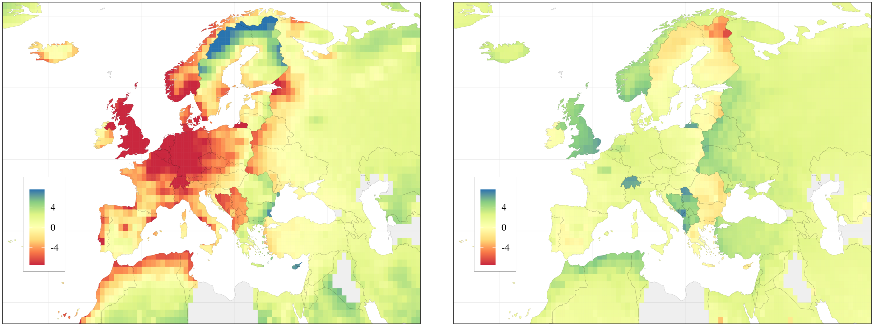
- With local rebating, agriculture falls more in Europe's core
- Non-agriculture grows everywhere in EU, especially in the core

US case

Sectoral specialization 2021 with local rebating

% Change in sectoral output due to carbon taxes, 2021

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



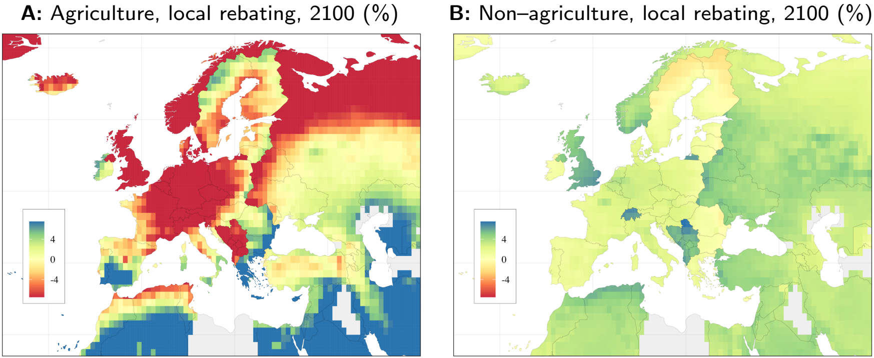
▸ world map

- Core and border regions switch from agriculture to non-agriculture
- Border regions' non-agricultural sector benefits from EU periphery's change in specialization

▸ US case

Sectoral specialization 2100 with local rebating

% Change in sectoral output due to carbon taxes, 2100



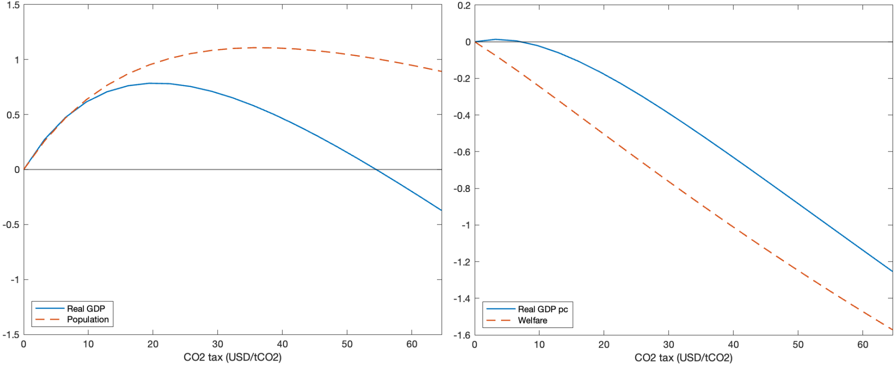
world map

- 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

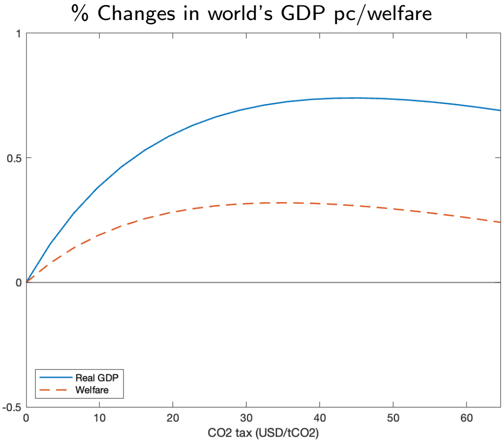
B: % Changes in EU GDP pc/welfare



- With local rebating, positive effects on real GDP for carbon taxes up to 50 USD/tCO_2
- EU welfare falls for all taxes as migrants move in

US case

Effects on the World of different carbon taxes, 2021

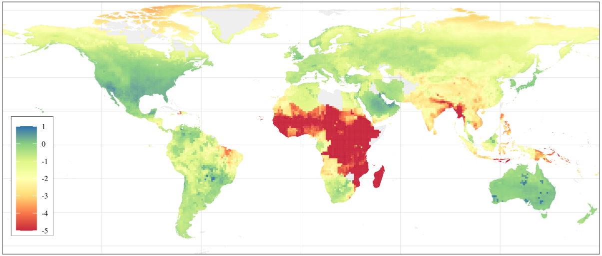


- With local rebating, world welfare increases due to more efficient distribution of economic activity
- More people live in EU which is relatively more productive

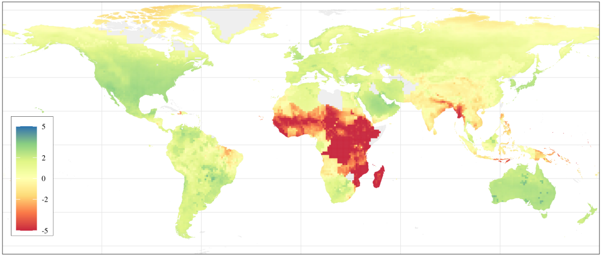
▸ US case

Real GDP pc and population changes in 2100

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

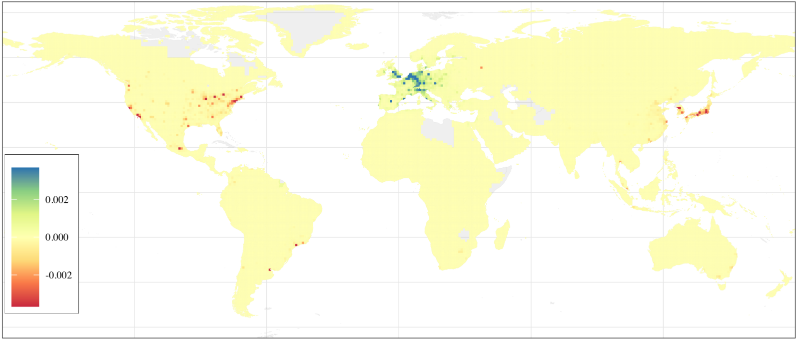


B: Population % Δ due to carbon taxes, local rebating, 2100



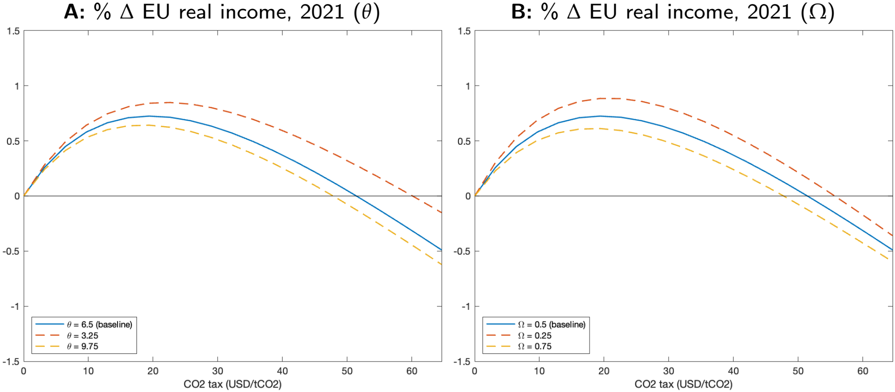
Change in emissions: local rebating vs no rebating

Δ Emissions (local rebating - no rebating), 2021 (GtCO2)



▸ emissions levels

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

	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.

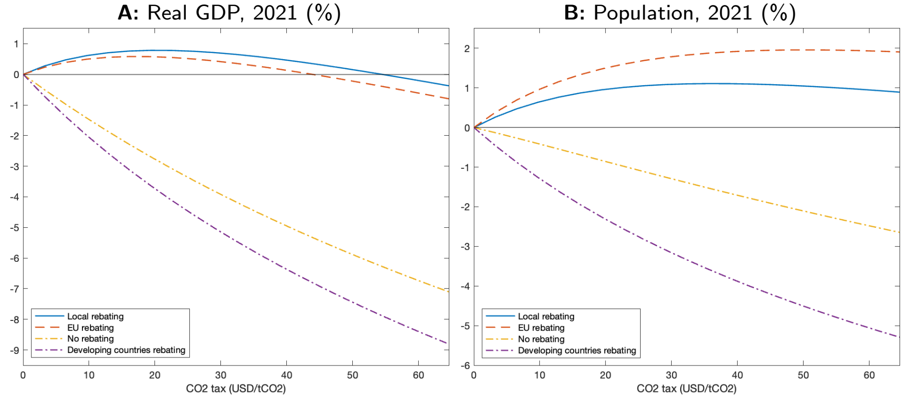
▸ Δ Real sectoral outputs

Carbon taxes with EU or developing world rebating

EU/developing world rebating

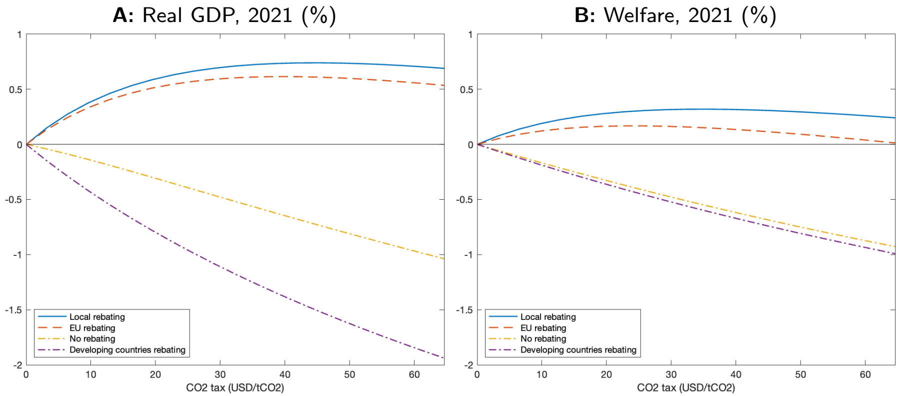
- We consider two additional forms of rebating the revenue of EU carbon taxes
  - Uniform EU rebating where we rebate total EU carbon tax revenue equally across the EU population
  - Developing countries rebating where we rebate total EU carbon tax revenue equally across the developing world ▸ details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

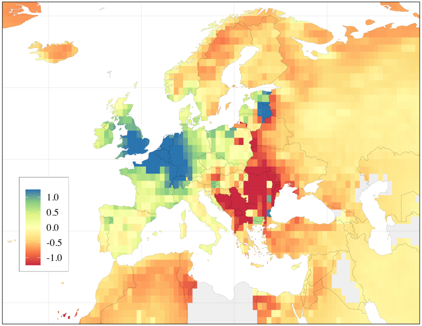
Effects on the world of different carbon taxes, 2021



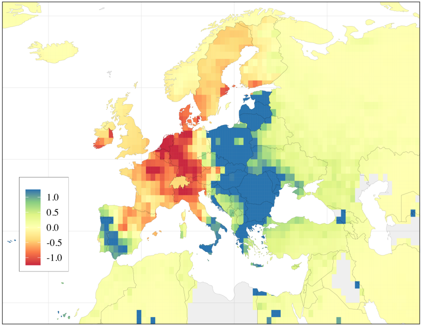
- EU rebating: smaller positive welfare effects
- Developing countries rebating: benefits sub-Saharan Africa and Asia, but hurts the world by keeping people from migrating

Sectoral specialization 2021: EU vs local rebating

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



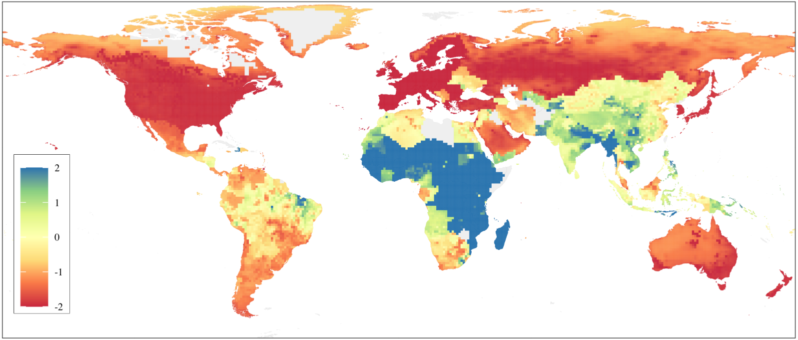
B: % Δ Non-agric., EU – local rebating, 2021



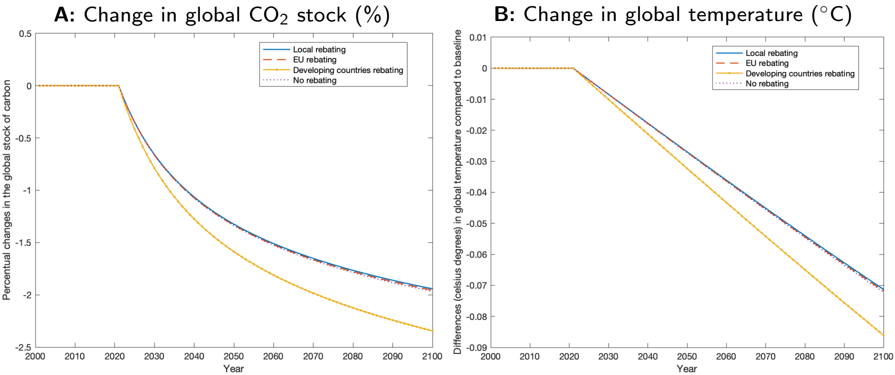
- With EU rebating, more resources flow to EU periphery and so it specializes more in non-agriculture
- Less concentration in the core, which leads to smaller world gains

Sectoral specialization 2021: Developing vs local rebating

Δ% Population, developing – local rebating, 2021



Evolution of global CO_2 stock and temperature



- 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

	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

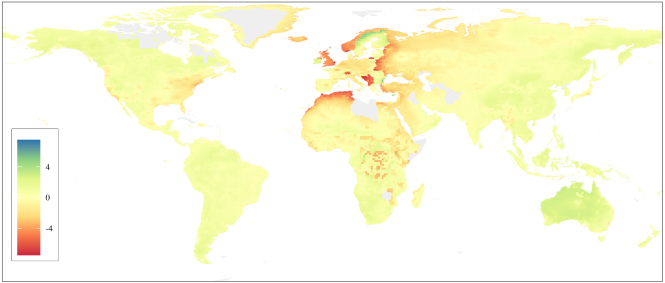
Notes: Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar Malaysia, Philippines, Thailand, and Vietnam.

Concluding remarks

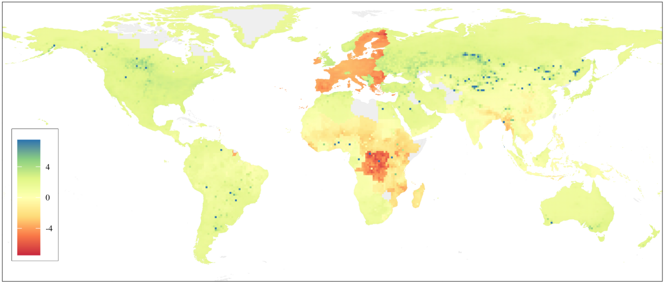
- A unilateral carbon tax in the EU with local rebating
  - Acts as a place-based policy that favors high-productivity core
  - Attracts migrants and expands EU economy
  - Improves global efficiency and welfare
  - Similar findings for US
- More generally, if rebating benefits high-productivity areas,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

Appendix

A: Agriculture, no rebating, 2021 (%)

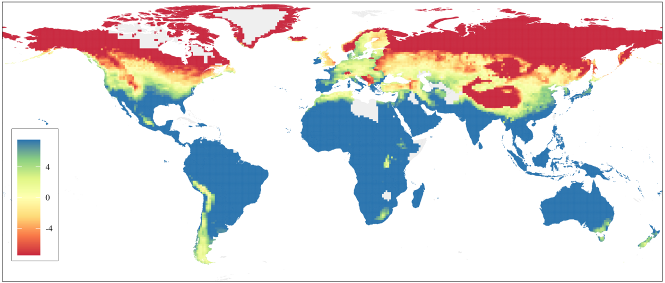


B: Non-agriculture, no rebating, 2021 (%)

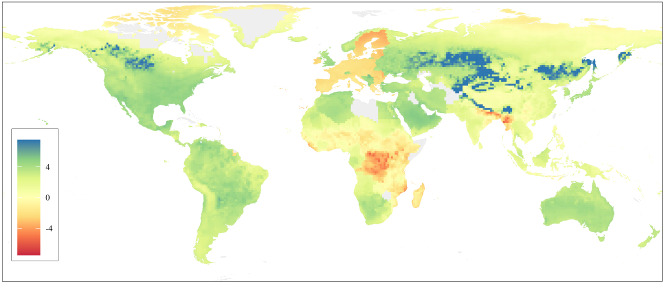


return

A: Agriculture, no rebating, 2100 (%)

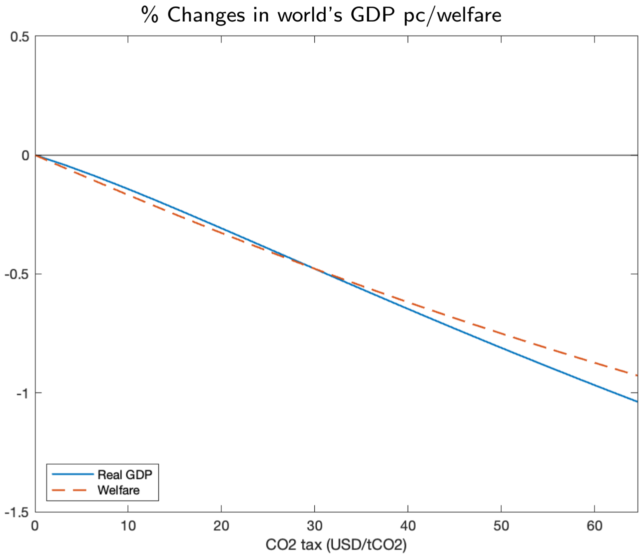


B: Non-agriculture, no rebating, 2100 (%)



▸ return

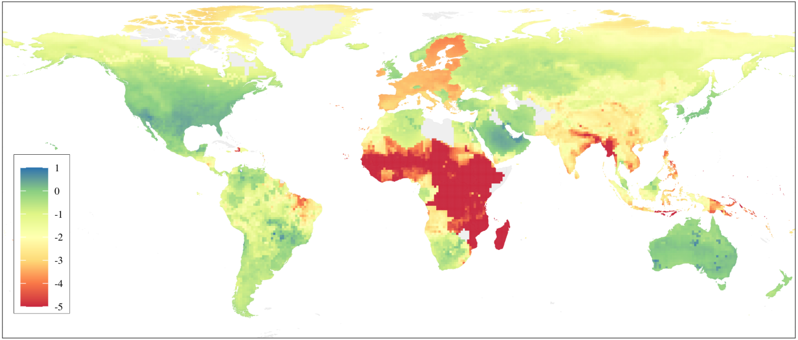
Effects on sectoral output of different carbon taxes, 2021



▸ back

Effect on GDP per capita

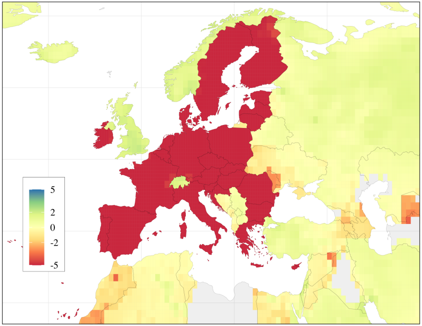
Real GDP pc % changes due to carbon taxes, 2100



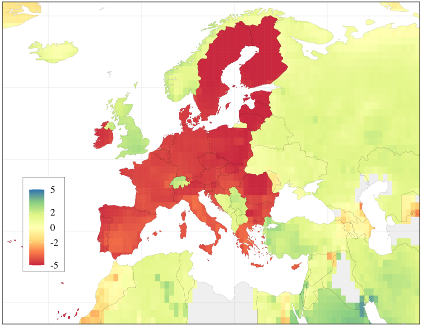
▸ return

Effect on real GDP in Europe

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



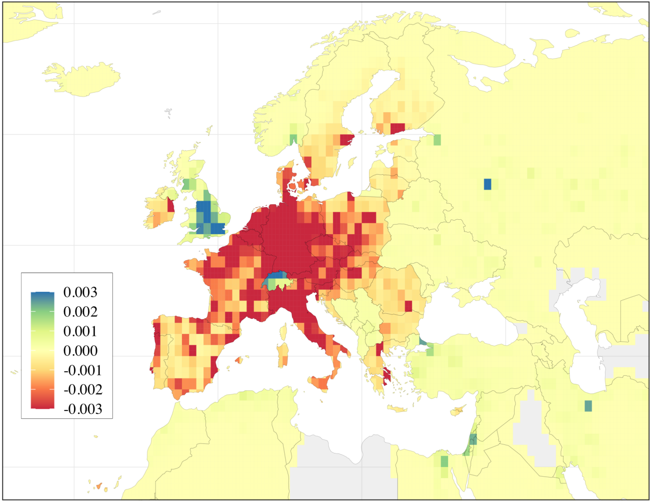
B: Real GDP changes, no rebating, 2100 (%)



▸ return

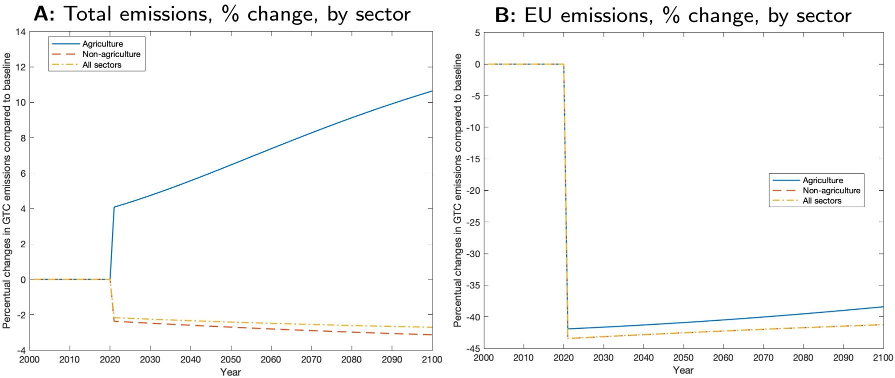
Emissions changes in Europe in 2021

Differences in total emissions, 2021 (GTC)



▸ return

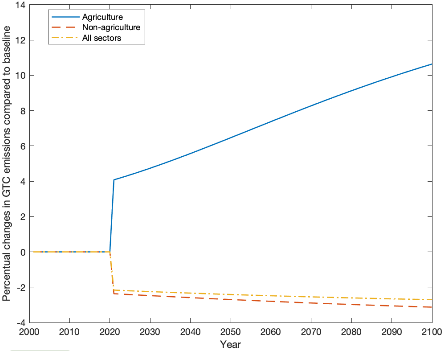
Emissions over time: World vs EU



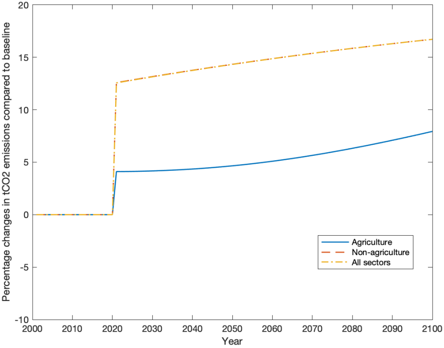
- Agriculture output grows in less efficient areas
- Non-agricultural emissions fall due to decrease in world output

Emissions over time: World vs UK

A: Total emissions, % difference, by sector



B: UK emissions, % difference, by sector



return

Aggregate and distributional effects of carbon taxes

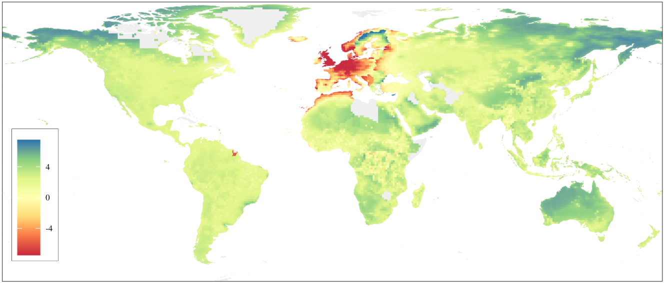
% Change in 2021 and 2100 without rebating carbon tax revenues

	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

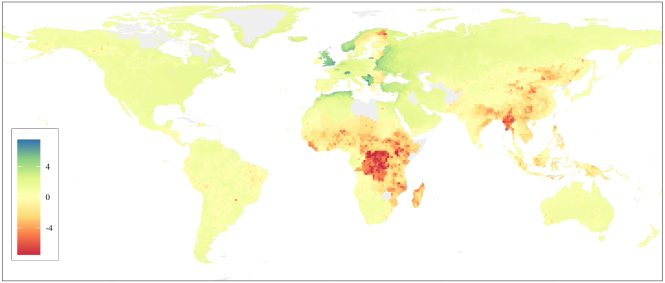
Notes: Asia includes Bangladesh, Brunei, China, Indonesia, India, Cambodia, Laos, Sri Lanka, Myanmar Malaysia, Philippines, Thailand, and Vietnam.

return

A: Agriculture, local rebating, 2021

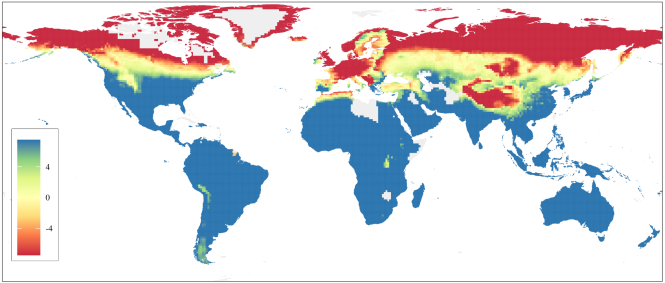


B: Non-agriculture, local rebating, 2021

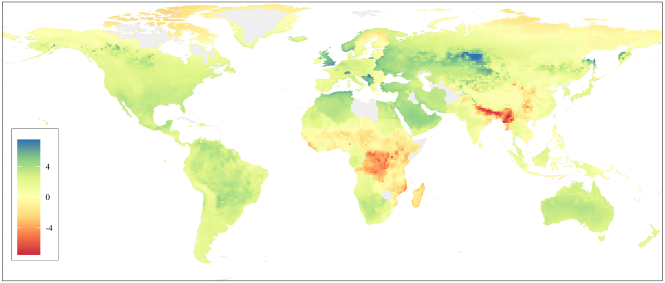


▸ return

A: Agriculture, local rebating, 2100



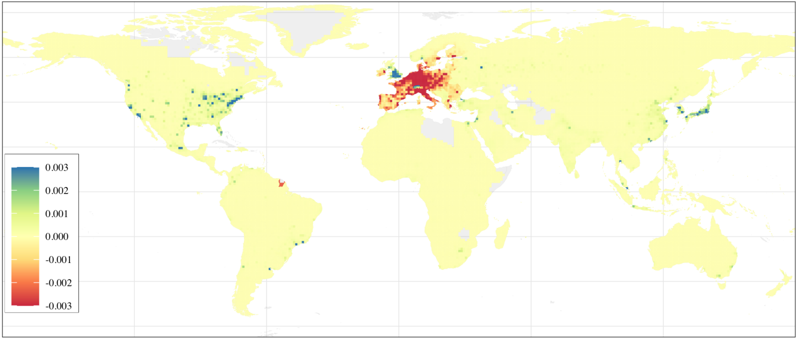
B: Non-agriculture, local rebating, 2100



▸ return

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

	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.

return

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

Aggregate and distributional effects of carbon taxes

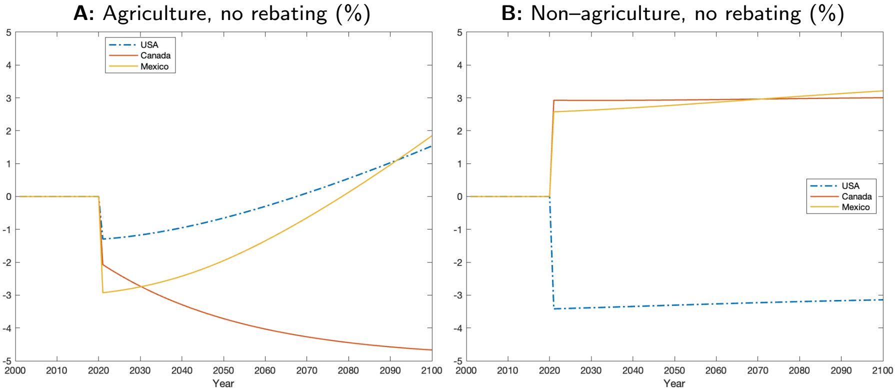
% Changes in 2021 and 2100: different rebating schemes ▸ return

	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.

US Case: Sectoral specialization

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



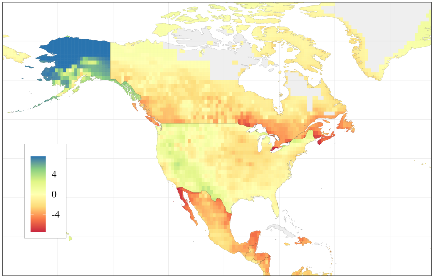
- US output declines in both sectors, but less in agriculture
- Canada and Mexico, in comparison, gains comparative advantage in non-agriculture

▸ return

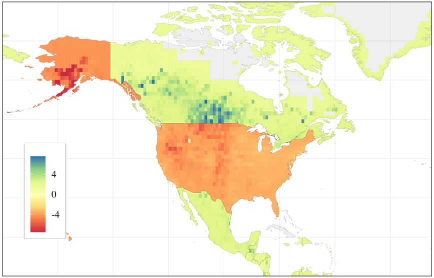
US Case: Sectoral specialization in 2021 without rebating

% Change in sectoral output due to carbon taxes, 2021

A: Agriculture, no rebating, 2021 (%)



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



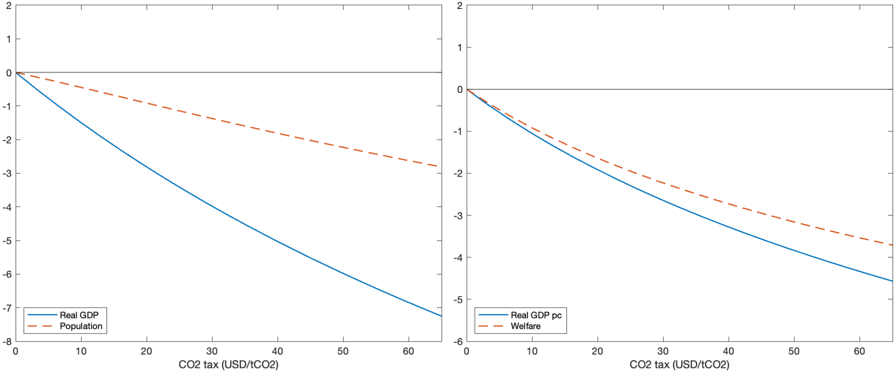
- USA periphery is gaining comparative advantage in agriculture
- Border effect: negative for agriculture, ambiguous for non-agriculture

▸ return

US Case: Effect of different carbon taxes, 2021

A: % Changes in US real GDP and population

B: % Changes in US GDP pc and welfare

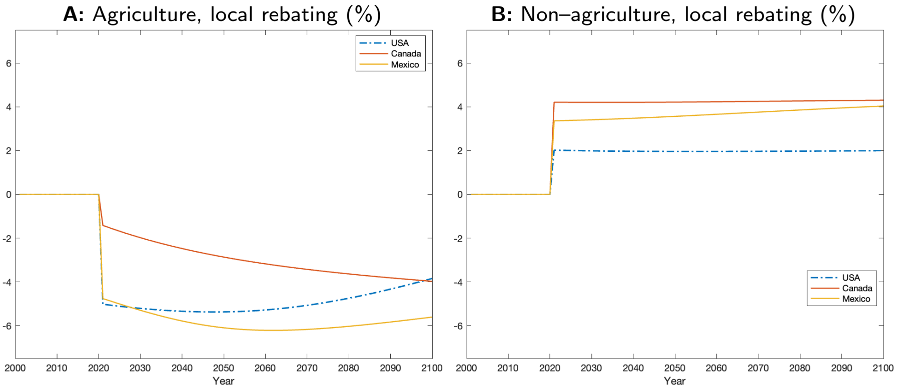


- Larger negative effects on real GDP, population, and welfare, the larger the carbon tax

▸ return

US Case: Sectoral specialization with local rebating

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



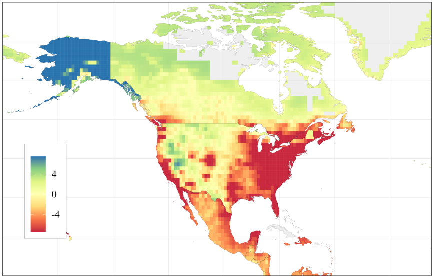
- With local rebating, agriculture still falls in US, Canada, and Mexico
- Non-agriculture now grows everywhere in the whole region

return

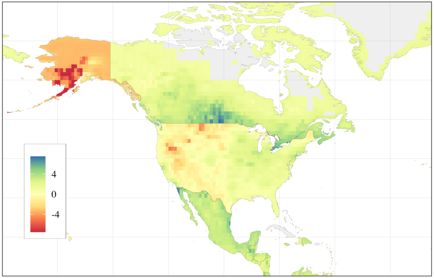
US Case: Sectoral specialization with local rebating

% Change in sectoral output due to carbon taxes, 2021

A: Agriculture, local rebating, 2021 (%)



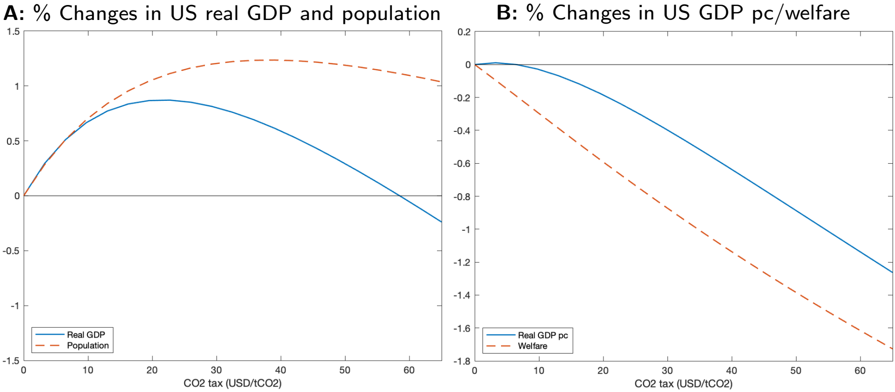
B: Non–agriculture, local rebating, 2021 (%)



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

▸ return

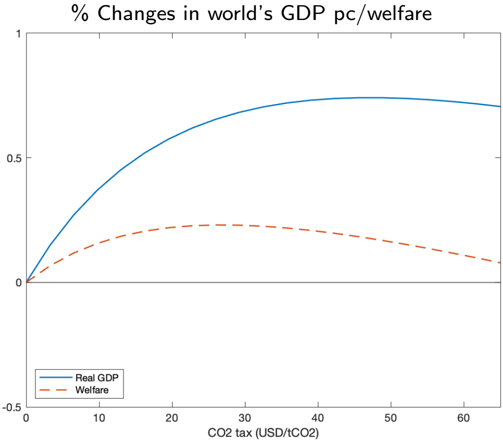
US Case: Effect of different carbon taxes, 2021



- 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

▸ return

US Case: Effects on the World, 2021



- With local rebating, world welfare increases due to more efficient distribution of economic activity
- More people live in USA which is relatively more productive

return

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

▸ return