The Distributional Costs of Net-Zero: A Heterogeneous Agent Perspective

G. Benmir and J. Roman

IMSI – Workshop on Climate, Macroeconomic Uncertainty and Policy

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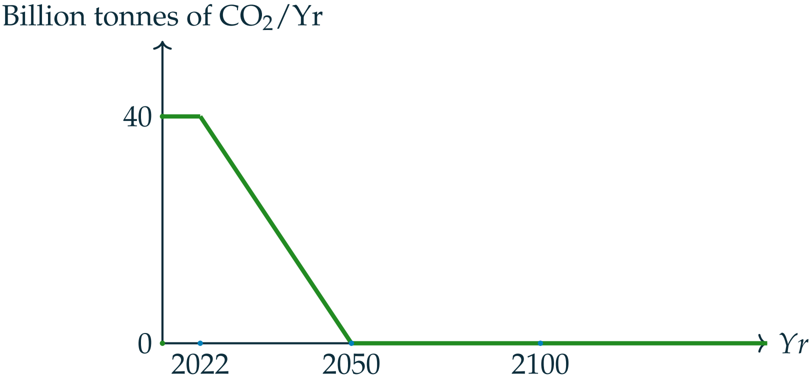
Main question:

What are the distributional impacts of implementing the 2050 fiscal net-zero emissions target in the U.S?

Motivation

Temperature < 1.5^oC and Net-Zero Emissions

- Keeping temperature below 1.5^oC in the long-run requires a net-zero emission target by 2050



Adapted from the IPCC Special Report on Global Warming of 1.5^oC

Implicit Carbon Price: Main Mitigation Tool

1. **Carbon pricing** is gaining momentum world wide

Source: International Carbon Action Partnership

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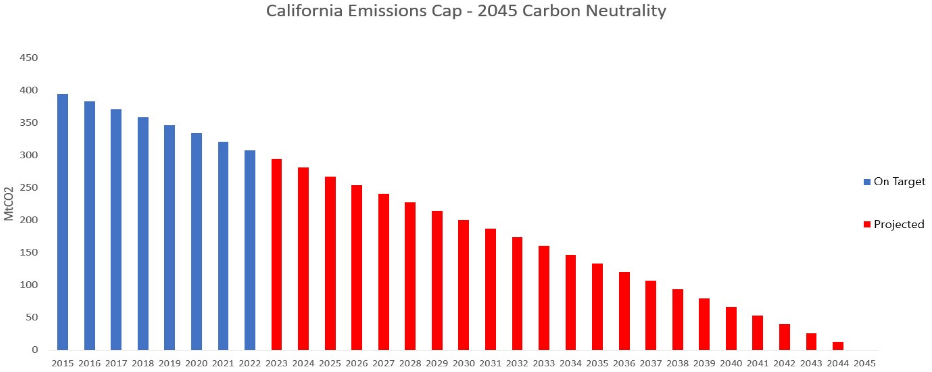
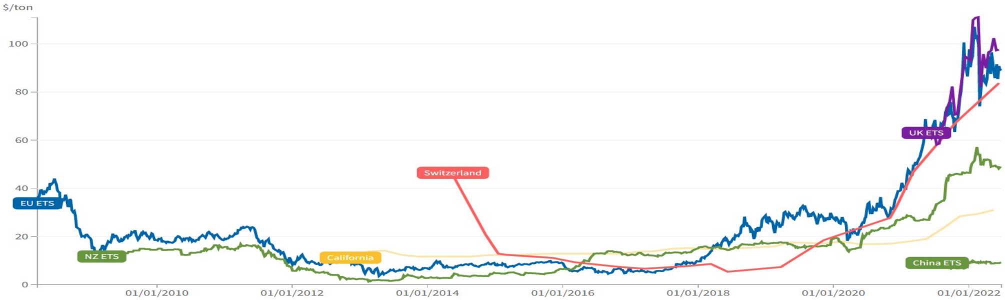


Constructed using International Carbon Action Partnership

Implicit Carbon Price: Main Mitigation Tool

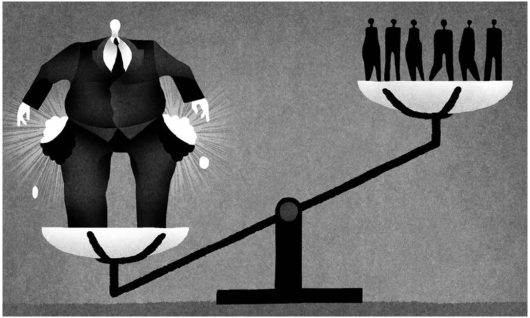
1. **Carbon pricing** is gaining momentum world wide
2. **Cap-and-Trade Market** is the major tool used in climate change mitigation
3. The inherent **carbon price** is expected to increase to meet net-zero by 2050



World Cap and Trade System Carbon Prices (in USD)
Source: International Carbon Action Partnership

Distributional Impacts of Carbon Pricing

- **Increasingly higher** carbon prices could induce:
  - “Distributional Macroeconomic” costs



Political Feasibility?

Yellow Vests Protests [2018]

Chileans Protest Consequences of "Green" Energy [2019]

Where We Stand

- Need for **aggressive environmental policy** to meet climate goals

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$\Downarrow$

Need for a Distributional Macro Framework:

- i) Heterogeneity
- ii) Transition Dynamics
- and iii) General Equilibrium Effects

Paper Objectives and Main Results

What We Do

In this paper, we provide a new: i) **empirical** and ii) **theoretical** framework and evidence on

i) **Empirical:**

- How carbon pricing impacts macroeconomic aggregates and the distribution of household income/wealth in the case of California and the U.S.

ii) **Theoretical:**

- Distributional impacts of meeting the net-zero target for the U.S. and the role of redistribution according to a Heterogeneous Agents New-Keynesian (HANK) framework

Main Paper Message

- The net-zero transition is **necessary** **(0.54% welfare gain – CE)**
- However, it is **costly in the medium run** **(6-10% increase in financially constrained household)**

Main Takeaways

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1. Over the long-run, the net-zero target is welfare enhancing, however over the short/medium run increasing carbon mitigation cost leads to an increase in wealth disparities over the transition

2. **Income-based redistribution** allows for an offset of most negative impacts on consumption, and thus on welfare, with no major distortion (as seen in the case of uniform transfers)

3. Costly abatement and raising carbon prices generate high levels of inflation over the long-run. These effects and those on inequalities could be eased by green innovation

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3. We do not compare or assess the efficiency of cap versus tax policies
4. We consider the U.S. as a closed economy (i.e. the rest of the world follows the US policy)

Relevant Literature: Empirical

- **Carbon pricing and inequality:** Fullerton et al. [2011], Sager [2019], Metcalf [2019], Shapiro and Metcalf [2021], and Bernard and Kichian [2021], Kanzig [2021], among others

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  ⇒ **How we differ**: We use a **full-fledged** macro-climate with heterogeneous agents and **inflation dynamics** and investigate **long-run transition**

Climate-HANK

Heterogeneous Households
à la Achdou et al. (2020)

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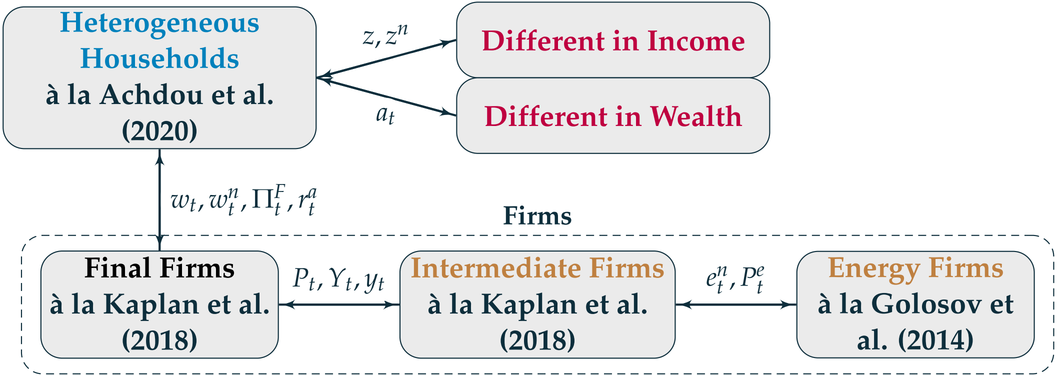
z, z^n

Different in Income

a_t

Different in Wealth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à la Kaplan et al. (2018)
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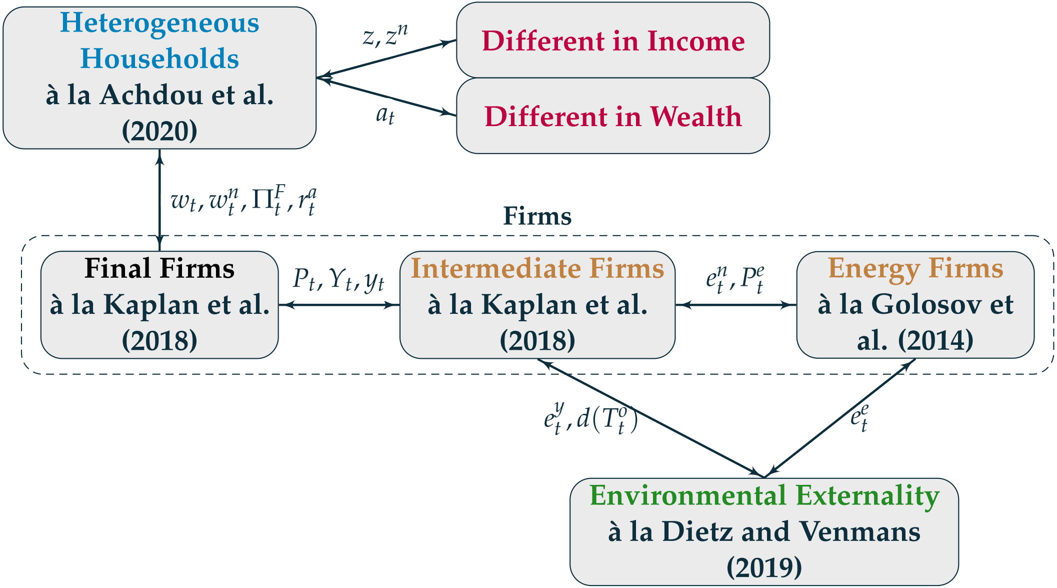
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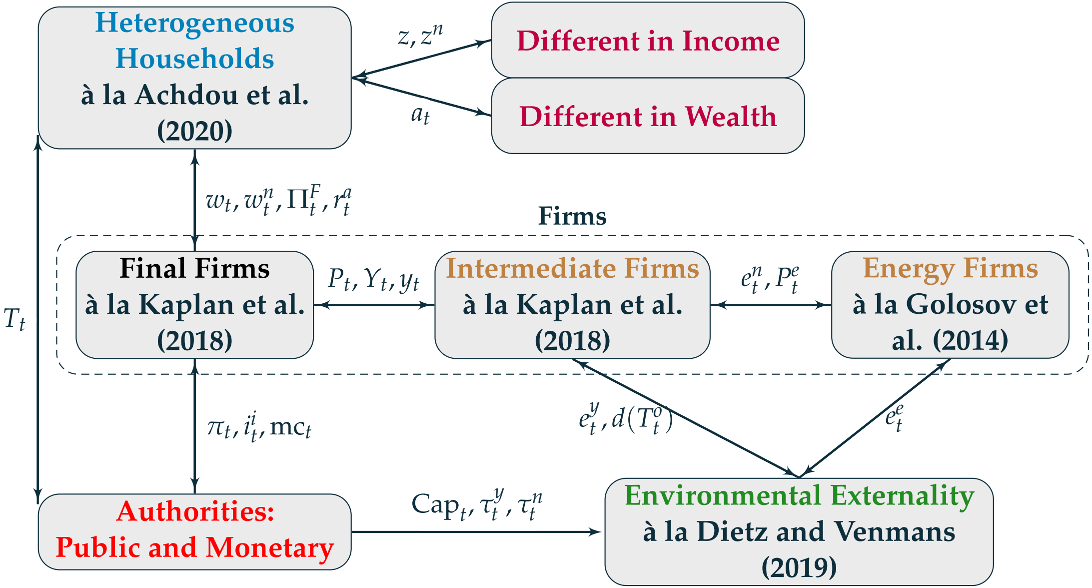
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T_t
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Authorities:
Public and Monetary
$\mathrm{Cap}_t, \tau_t^y, \tau_t^n$
Environmental Externality
à la Dietz and Venmans (2019)

Full Model

- Environmental Externality: more
- Energy Firms: more
- Intermediate Firms: more
- Final Firms: more
- Households: more
- Fiscal Authority: more
- Monetary Authority: more

Environmental Externality: Climate Dynamics

- Following **Dietz and Venmans (2019)**, CO_2 cumulative emissions X_t in the atmosphere is the sum of domestic E_t and international E_t^{Row} emission flows:

$$\dot{X}_t = E_t + E_t^{Row} \tag{1}$$

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In our framework, the total emissions flow reads as:

$$E_t = \int_0^1 e_{j,t}^y dj + \int_0^1 e_{j,t}^e dj \tag{2}$$

$e_{j,t}^y$ are emissions from non-energy firms and $e_{j,t}^e$ are emissions from energy firms.

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- Temperature T_t^o reads as:

$$\dot{T}_t^o = \phi_1(\phi_2 X_t - T_t^o) \tag{3}$$

Energy and Non-Energy Firms: Production

Our economy is comprised of two sectors: $\{e^n, y\}$

- The energy firms employ capital and labour to produce energy, which is then supplied to the intermediate non-energy firms (all other sectors):

$$e^n_{j,t} = A^n_t {k^n_{j,t}}^{\alpha_n} {l^n_{j,t}}^{1-\alpha_n} \tag{4}$$

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- Intermediate non-energy firms produce goods using energy, capital and labour as follows:

$$y_{j,t} = A_t \underbrace{d(T^o_t)}_{\text{Convex Damages}} {k^y_{j,t}}^{\alpha_1} {e^n_{j,t}}^{\alpha_2} {l^y_{j,t}}^{1-\alpha_1-\alpha_2} \tag{5}$$

Energy and Non-Energy Firms: Emissions and Abatement Investment

- Both energy and non-energy firms emit CO_2 emissions $e^e_{j,t}$ and $e^y_{j,t}$ when they produce goods:

$$e^e_{j,t} = \underbrace{(1-\mu^n_{j,t})}_{\text{Abatement efforts}} \varphi^n_t e^n_{j,t} \tag{6}$$

$$e^y_{j,t} = (1-\mu^y_{j,t}) \underbrace{\varphi^y_t}_{CO_2 \text{ intensity} \downarrow \text{ trend}} y_{j,t} \tag{7}$$

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- Abatement technology is costly for firms and is assumed to be a fraction of their total production:

$$\underbrace{F(\mu^k_{j,t})}_{\text{Convex cost function}} = \theta_1 {\mu^k_{j,t}}^{\theta_2} \tag{8}$$

Energy and Non-Energy: Profit and Aggregate Firms

- The energy producers' profit reads as follows: more

$$\Pi^E_{j,t} = \underbrace{p^e_t e^n_{j,t}}_{\text{energy price and output}} - \underbrace{w^n_t l^n_{j,t}}_{\text{labour wages}} - \underbrace{i^n_{j,t}}_{\text{capital investment}} - \underbrace{f(\mu^n_{j,t}) e^n_{j,t}}_{\text{abatement cost}} - \underbrace{\tau^n_t e^n_{j,t}}_{\text{carbon price}} \tag{9}$$

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- The non-energy firms' profit reads as: more

$$\Pi^F_{j,t} = \frac{p_{j,t}}{P_t} y_{j,t} - w^y_t l^y_{j,t} - i^y_{j,t} - \underbrace{p^e_t e^n_{j,t}}_{\text{energy cost}} - f(\mu^y_{j,t}) y_{j,t} - \tau^y_t e^y_{j,t} \quad (10)$$

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- The final firms are a standard aggregate of intermediate firms more

Final Firms: The Climate Externality and Price Setting

Case of Flexible Prices (i.e. Real Business Cycles)

- When prices are flexible, the firm's marginal cost is constant:

$$mc_t = \frac{\theta - 1}{\theta} \tag{11}$$

$$\tag{12}$$

Case of Sticky Prices (i.e. New-Keynesian)

- When prices are sticky (à la Rotemberg), the New Philips Curve under the presence of the climate externality reads as:

$$\left(r_t^a - \frac{\dot{Y}_t}{Y_t}\right)\pi_t = \frac{\theta}{\theta^P}\Big(\underbrace{mc_t}_{\uparrow \text{ with env tax}} - \frac{\theta - 1}{\theta}\Big) + \dot{\pi}_t \tag{13}$$

more

Households: Heterogeneity

- The households are heterogeneous in their wealth a and income y (with two different states $z_t^s \in \{z_1, z_2\}$ for each sector s), and choose consumption expenditures c_t:

$$\max_{\{c_t\}} E_0 \int_0^\infty e^{-\rho t} u(c_t) dt$$

where $\rho \geq 0$ is the time discount factor and $u(c_t)$ is CRRA.

- The representative household budget constraint reads:

$$\dot{a}_t = r_t^a a_t + w_t^y z_t^y + w_t^n z_t^n + \frac{z_t^y}{\bar{z}} \Pi_t^F + T_t - c_t$$

Individuals also face a borrowing limit:

$$a_t \geq \underline{a} \tag{14}$$

where $-\infty < \underline{a} < 0$ more

Fiscal Authorities

- The public authority sets an emissions cap as follows:

$$E_t = \text{Carbon Cap}_t \tag{15}$$

- The government uses the environmental policy revenues $\tau_t E_t$ to finance exogenous expenditures G_t and transfers to households T_t:

$$G_t + T_t = \sum_s \tau_t^s E_t^s \tag{16}$$

with $\sum_s \tau_t^s E_t^s = \int_0^1 (\tau_t^e e_{j,t}^y + \tau_t^n e_{j,t}^e) dj$

MONETARY AUTHORITIES

- The monetary authority follows a standard Taylor rule to set the nominal interest rate i_t^i:

$$i_t^i = \bar{r}^a + \phi_\pi(\pi_t - \bar{\pi}) + \phi_Y(Y_t - \bar{Y}) \tag{17}$$

where $\bar{\pi}$ and $\bar{Y}$ are the steady state levels.

- In addition, the relationship between the nominal and the real interest rate is modeled through the Fisherian equation:

$$i_t^i = r_t^a + \pi_t \tag{18}$$

Model Intuition Summary

- **Wages** and **returns** will play a central role:

$$r_t^y = (\underbrace{mc_t}_{\text{Total Marginal Cost}} - \underbrace{\underbrace{f(\mu_t^y)}_{\text{Abatement Investment}} - \underbrace{\tau_t^y(e_t^y/y_t)}_{\text{Emission Intensity Carbon Price}}}_{\text{Total Environmental Costs}})\alpha_1 y_t/k_t^y - \delta \tag{19}$$

$$w_t^y = \left(mc_t - f(\mu_t^y) - \tau_t^y(e_t^y/y_t)\right)(1 - \alpha_1 - \alpha_2)y_t/l_t^y \tag{20}$$

Note: The total marginal cost is constant in the case of flexible prices.

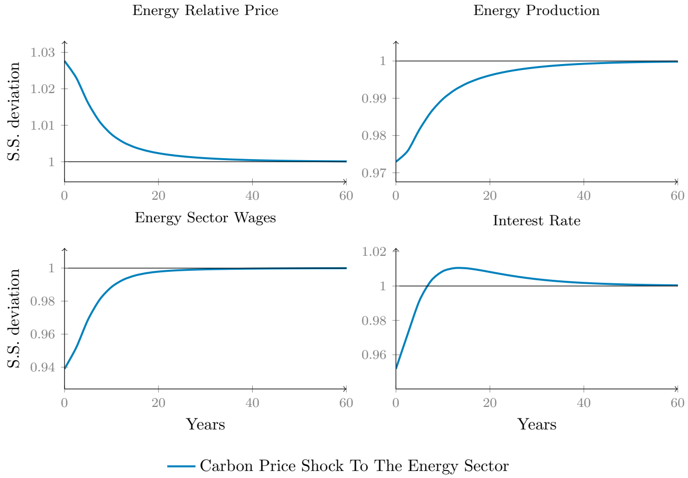
CALIBRATION

- **Macro parameters:** Standard values from the literature more

- **Environment parameters:** Damage function from Dietz (2015) and temperature parameters from Dietz & Venmans (2019) more

Target	Model	Data	Source
Macro Aggregates:			
Labor Share	0.567	0.597	FRED (2019)
Capital Share	0.260	0.311	BEA (2020)
Environmental Aggregates:			
Global Level of Carbon Stock (GtC)	840	840	USDA (2020)
Temperature °C (in excess to pre-industrial level)	1.15	1.19	NOAA (2020)
Share of Emissions from Energy	0.25	0.25	EIA (2020)
Share of Emissions from Non-Energy	0.75	0.75	EIA (2020)
Emissions Decoupling Rate	0.01	0.01	EIA

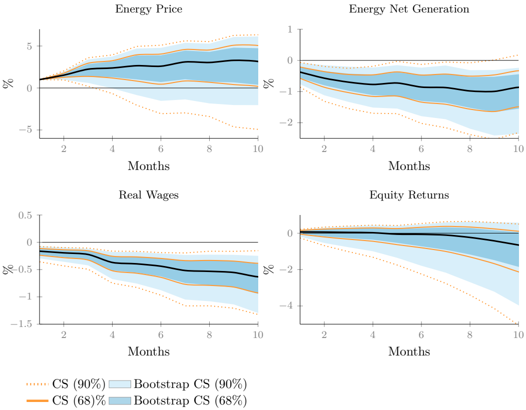
Results 1a: Carbon Price and Macroeconomic Dynamics

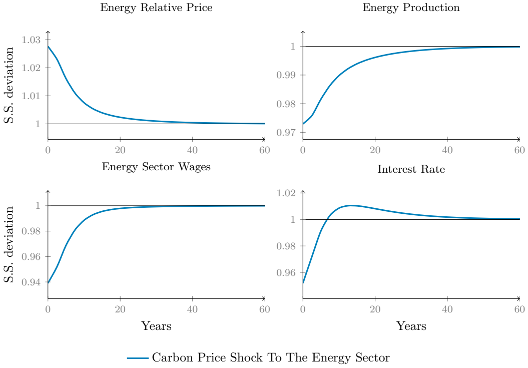


Note: The figure plots the responses to a carbon price shock leading to a 25% reduction in total emissions.

Results

- First Stage: we conduct weak instrument inference following Montiel et al. (2021) as the heteroskedastcitity-robust F-statistic: 8.41 < 10 but > 4





Empirical Strategy Details Cholesky IRF

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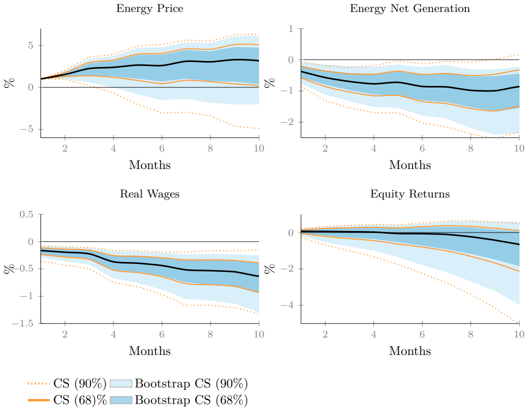

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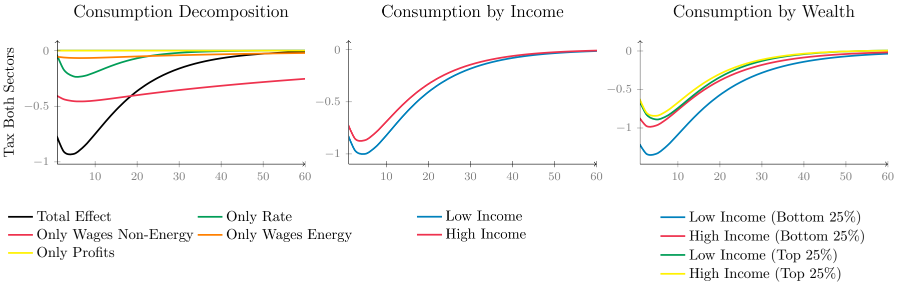
Results 1b: Carbon Price Transmission Mechanism

- Following Kaplan et al. (2018), we can decompose the consumption response at t = 0 as:

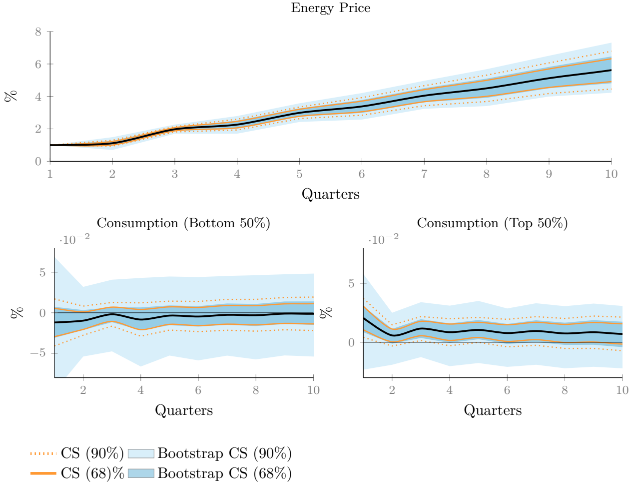
$$dC0 = \int_0^\infty \left(\underbrace{\frac{\partial C0}{\partial r_t^a} dr_t^a}_{\text{asset returns}} + \underbrace{\frac{\partial C0}{\partial w_t^n} dw_t^n}_{\text{energy wages}} + \underbrace{\frac{\partial C0}{\partial w_t^y} dw_t^y}_{\text{non-energy wages}} + \underbrace{\frac{\partial C0}{\partial \Pi_t^F} d\Pi_t^F}_{\text{profits}} + \underbrace{\frac{\partial C0}{\partial T_t} dT_t}_{\text{fiscal transfers}} \right) dt \tag{21}$$

Results 1b: Carbon Price Transmission Mechanism



Note: We show consumption following a carbon price shock on both sectors leading to an initial 25% emissions reduction. All Sectors Details

Results: Distributional Impacts



Data Details

Model With Climate Dynamics Solution Details

- Laissez-faire: **We first compute a synthetic path for emissions consistent with the laissez-faire RCP 8.5 scenario** and then find the terminal value of emission stock and temperature

- Net-zero: **We feed a cap trajectory that is consistent with zero emissions by 2050** and find the terminal value of emissions stock and temperature

- Thereafter, we retrieve the remaining values within the inner loop used to find the level of capital in each sector

Solution Details

Results 2: Welfare

- Net-zero policy is welfare enhancing compared to the case of the laissez-faire

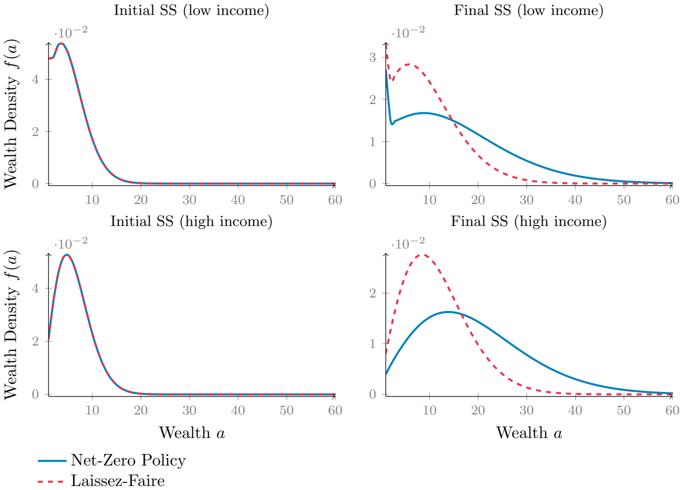
Table: Welfare: Net-zero versus Laissez-faire

		HA-Climate	RA-Climate
	Low Abatement Cost	0.84%	1.05%
Welfare gains (in CE)	Moderate Abatement Cost (baseline case)	0.54%	0.72%
	High Abatement Cost	0.13%	0.26%

Note: This table compares the welfare gains in consumption equivalent terms (CE) from a 2050 net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 to 2100. For climate and no climate damages distr

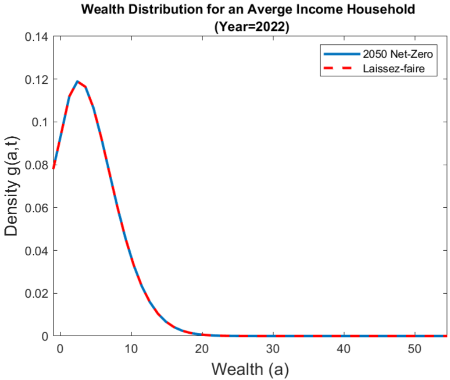
$$Welfare = \int v^{final}(a, z_j^y, z_j^n) g^{final}(a, z_j^y, z_j^n) d\mu \tag{22}$$

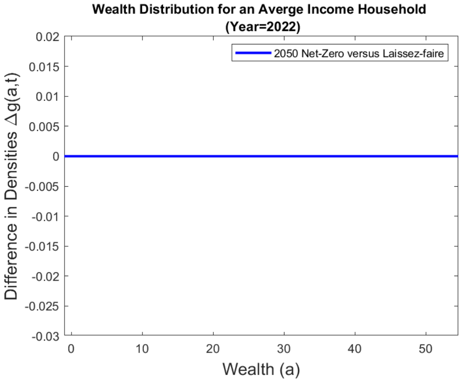
Results 2a: Net-zero long-run distributional impacts



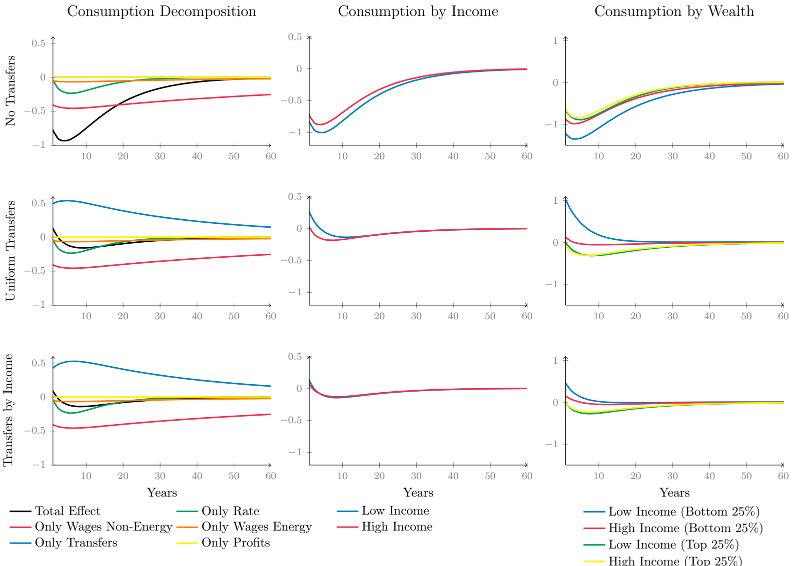
For net-zero long-run transitions please see here Income Gini over the transition here

Results 2b: Net-zero versus laissez-faire medium-run distributional impacts





Results 3a: Carbon Policy and Transfers



Results 3b: Learning By Doing and Abatement Cost

- The abatement cost function $f(\mu_t^s)$ (for each sector s and firm j) is now steered by endogenous green innovations A_t^g:

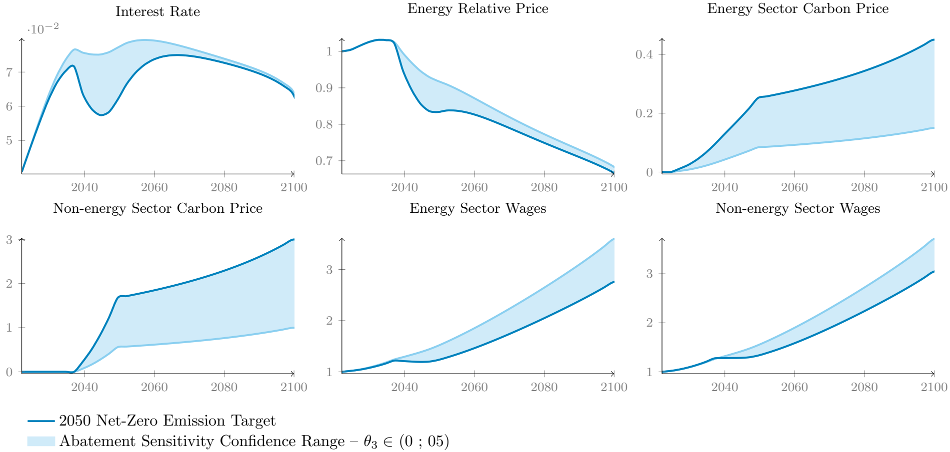
$$f(\mu_t^s) = \left(\int_0^{A_t^g} f(\mu_{j,t}^s)^{\frac{1}{\theta_3}} dj \right)^{\theta_3} \tag{23}$$

where $\theta_3 > 0$ is the elasticity of green innovations

- We use abatement level μ_t as a learning indicator for green innovation A_t^g (i.e. $A_t^g = \mu_t$):

$$f(\mu_t^s) = \theta_1 (\mu_t^s)^{\theta_2 - \theta_3} \tag{24}$$

Results 4b: Learning By Doing and Abatement Cost



here

Main Takeaways

Main Takeaways 1/2

1. Carbon policy shock leads to a persistent increase in energy prices, triggering a **persistent decrease in net energy, wages, and returns**

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2. Carbon policy shock leads to an **asymmetric consumption reaction** among the top and bottom 50 percent income distribution

Main Takeaways

1. A wide scale carbon pricing program generates a **consumption loss twice as high** for bottom wealth/income households than for top wealth/income households

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3. Carbon revenue redistribution—following an **income-based approach**—allows for an offset of most negative impacts on consumption

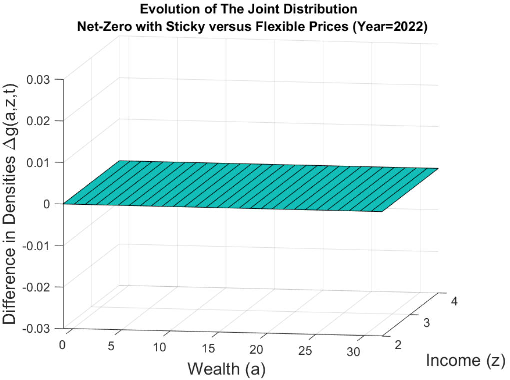
4. Costly abatement and raising carbon prices could generate high levels of **inflation** over the long-run. These effects and those on inequalities could be **eased by green innovation**

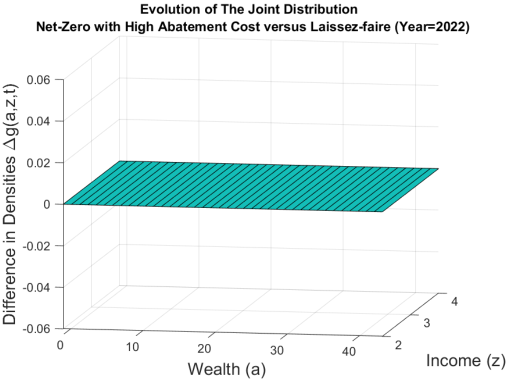
THANK YOU!

Annex

IMPACTS OF INFLATION AND ABATEMENT COST ON THE JOINT DISTRIBUTION

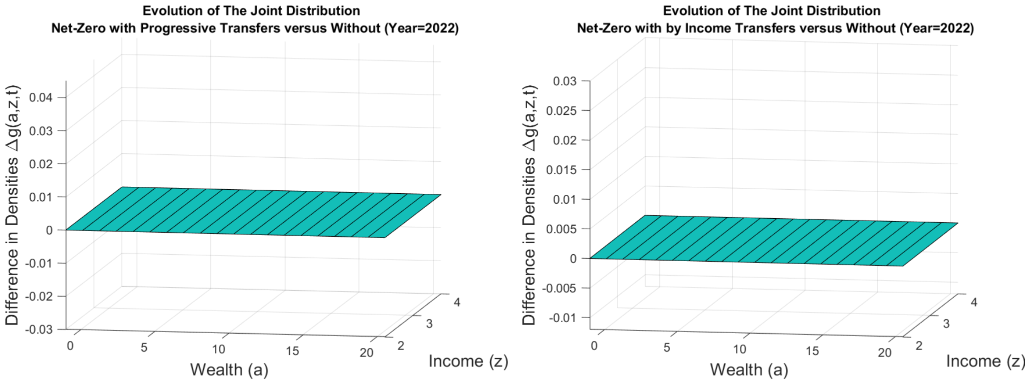
BACK





THE ROLE OF REDISTRIBUTION

BACK



- Following Pastor et al. (2019), we could fit an AR(1) process to the carbon surprise series $\tau_t^C = \phi\tau_{t-1}^C + \epsilon_t$, where shocks to carbon prices is a change market price around the shocks to climate news events ϵ_t:

$$\tau_t^{\text{Shock}} = \begin{cases} \tau_t^C - \tau_{t-1}^C & \text{If } |\text{day}_t(\epsilon_t)| \geq \bar{\sigma}, \\ 0 & \text{otherwise.} \end{cases} \tag{25}$$

where $\bar{\sigma}$ is the average standard deviation of the shock $\epsilon_{\text{Carbon Index}}$

Back to the main specification here

SVAR-IV MODEL

- Let Y_t, be a 4 x 1 vector of observables (energy prices, net energy generation, wages, equity index returns):

$$Y_t = \sum_{j=1}^{p} A_j Y_{t-j} + \eta_t \tag{26}$$

where $\eta_t = \Gamma \epsilon_t$ is a vector of reduced-form VAR innovations.

- The carbon surprise shock series z_t is correlated with the shock of interest but not with the other shocks:

$$E(z_t \epsilon_{1,t}) \neq 0 \text{ (Relevance)} \tag{27}$$

$$E(z_t \epsilon_{j,t}) = 0 \text{with j} \neq 1 \text{ (Exogenity)} \tag{28}$$

back

SVAR Model

- Let Y'_t, be a 5 x 1 vector of observables (carbon price shock series, energy prices, net energy generation, wages, equity index returns):

$$Y'_t = \sum_{j=1}^{p} A_j Y'_{t-j} + \eta_t \tag{29}$$

where $\eta_t = \Gamma \epsilon_t$ is a vector of reduced-form VAR innovations.

- The instrument has to be orthogonal to leads and lags of structural shocks (robust to non-invertibility):

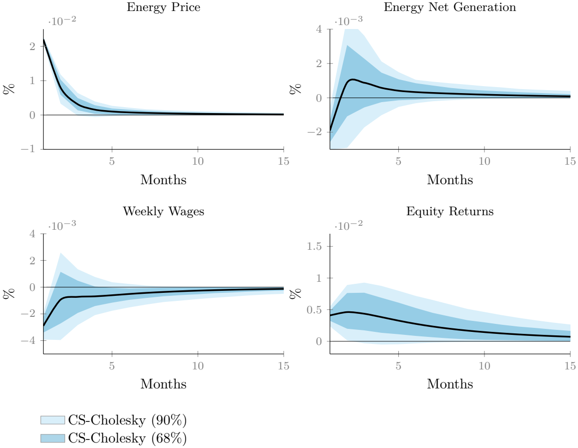
$$E(z_t \epsilon_{1,t}) \neq 0 \text{ (Relevance)} \tag{30}$$

$$E(z_t \epsilon_{j,t}) = 0 \text{with j} \neq 1 \text{ (Exogenity)} \tag{31}$$

$$E(z_t \epsilon_{t+j}) = 0 \text{for j} \neq 0 \text{ (Lead-lag exogenity)} \tag{32}$$

back

Cholesky IRF



back

Energy Firms Problem

- The energy producers maximize their profit subject to:

$$\dot{k}^n_{j,t} = i^n_{j,t} - \delta k^n_{j,t} \tag{33}$$

$$e^n_{j,t} = A^n_t {k^n_{j,t}}^{\alpha_n} {l^n_{j,t}}^{1-\alpha_n} \tag{34}$$

- The first order conditions read as:

$$p^e_t = \varrho^e_t + f(\mu^n_t) + \varphi^n_t \tau^n_t (1 - \mu^n_t) \tag{35}$$

$$r^e_t = \varrho^e_t \alpha_n e^n_t / k^n_t - \delta \tag{36}$$

$$\tau^n_t = f(\mu^n_{j,t})' / \varphi^n_t \tag{37}$$

$$w^n_t = \varrho^e_t (1 - \alpha_n) e^n_t / l^n_t \tag{38}$$

where $\varrho^e_{j,t} = \varrho^e_t$ is the input shadow cost.

back

Non-Energy Firms Problem

- The non-energy firms maximize their profit subject to:

$$\dot{k}^y_{j,t} = i^y_{j,t} - \delta k^y_{j,t} \tag{39}$$

$$y_{j,t} = A_t d(T^o_t) {k^y_{j,t}}^{\alpha_1} {e^n_{j,t}}^{\alpha_2} {l^y_{j,t}}^{1-\alpha_1-\alpha_2} \tag{40}$$

- The first order conditions read as:

$$p^e_t = \varrho^y_t \alpha_2 y_t / e^n_t \tag{41}$$

$$r^y_t = \varrho^y_t \alpha_1 y_t / k^y_t - \delta \tag{42}$$

$$w^y_t = \varrho^y_t (1 - \alpha_1 - \alpha_2) y_t / l^y_t \tag{43}$$

$$\tau^y_t = f(\mu^y_t)' / \varphi^y_t \tag{44}$$

where $\varrho^y_{j,t} = \varrho^y_t$ is the input shadow cost.

back

Final Firms: Aggregation and Prices

- Final good Y_t is an aggregation of intermediate goods $y_{j,t}$:

$$Y_t = \int_0^1 \left(y_{j,t}^{1-\frac{1}{\theta}} \right)^{\frac{1}{1-\frac{1}{\theta}}} \tag{45}$$

where $\theta \in (1, \infty)$ is the elasticity of substitution between the intermediate goods.

- The final firms in the model are looking for profit maximization (in nominal terms), at a given price P_t subject to the intermediate goods j prices $p_{j,t}$ yields:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t} \right)^{-\theta} Y_t \tag{46}$$

- Under perfect competition and free entry, the price of the final good denoted as P_t reads:

$$P_t = \left(\int_0^1 p_{j,t}^{1-\theta} dj \right)^{\frac{1}{1-\theta}} \tag{47}$$

back

Firms Marginal Cost and Environmental Cost

- Firms are subject to higher marginal cost under the presence of the environmental externality:

$$\underbrace{mc_t}_{\text{Total Marginal Cost}} = \underbrace{\varrho_t^y}_{\text{Firms' Input Shadow Cost}} + \underbrace{\underbrace{f(\mu_t^y)}_{\text{Abatement Investment}} + \underbrace{\tau_t^y(e_t^y/y_t)}_{\text{Emission Intensity Carbon Price}}}_{\text{Total Environmental Costs}} \tag{48}$$

back

Households: Problem

- Individuals' consumption–saving decision and the evolution of the joint distribution of their income and wealth can be summarized in two differential equations:

back

Households: Problem

- Individuals' consumption–saving decision and the evolution of the joint distribution of their income and wealth can be summarized in two differential equations:
- i) A Hamilton-Jacobi-Bellman (HJB) equation:

$$
\begin{aligned}
\rho v(a, z_j^y, z_j^n, t) = \max_c u(c) + \partial_a v(a, z_j^y, z_j^n, t)\left(r(t)^a a + w(t)^n z_j^n + w(t)^y z_j^y + \frac{z_j^y}{\bar{\bar{z}}}\Pi_t^F + T_t - c\right) \\
+ \sum_{j'} \lambda_{jj'} v(a, z_{j'}^y, z_{j'}^n, t) + \partial_t v(a, z_j^y, z_j^n, t) \qquad (49)
\end{aligned}
$$

back

Households: Problem

- Individuals' consumption–saving decision and the evolution of the joint distribution of their income and wealth can be summarized in two differential equations:
- i) A Hamilton-Jacobi-Bellman (HJB) equation:

$$\rho v(a, z_j^y, z_j^n, t) = \max_c u(c) + \partial_a v(a, z_j^y, z_j^n, t)(r(t)^a a + w(t)^n z_j^n + w(t)^y z_j^y + \frac{z_j^y}{\bar{\bar{z}}}\Pi_t^F + T_t - c) \\ + \sum_{j'} \lambda_{jj'} v(a, z_{j'}^y, z_{j'}^n, t) + \partial_t v(a, z_j^y, z_j^n, t) \tag{49}$$

- ii) A Kolmogorov Forward equation:

$$\partial_t g(a, z_j^y, z_j^n, t) = -\partial_a [s(a, z_j^y, z_j^n, t) g(a, z_j^y, z_j^n, t)] + \sum_{j'} \lambda_{j'j} g(a, z_j^y, z_j^n, t) \tag{50}$$

back

Calibration: Macroeconomic Block

	Calibrated parameters (annually)	Values
Standard Macro Parameters		
α^1	Capital intensity for non-energy firms	0.19
α^2	Elasticity of energy to non-energy production	0.15
α^n	Capital intensity for energy firms	2/3
δ	Depreciation rate of capital	0.05
σ	Risk aversion	2
ρ	Discount rate	5%
θ	Price elasticity	6
$\bar{L}$	Labor supply	1/3
NK Parameters		
θ^P	Rotemberg quadratic cost parameter	100
ϕ^π	Inflation stance	1.25
ϕ_Y	Output gap reaction parameter	0.1

back

Calibration: Environmental Block

	Calibrated parameters (annually)	Values
Environmental Parameters		
$\bar{e^n}/\bar{e^e} = \varphi^n$	Emissions-to-output ratio in energy sectors	0.3
$\bar{e^y}/\bar{y} = \varphi^y$	Emissions-to-output ratio in non-energy sectors	2
θ_1	Abatement cost parameter	0.1
θ_2	Abatement cost parameter	2.7
θ_3	Abatement learning elasticity	$\in (0,1)$
ϕ_1^o	Temperature parameter	0.5
ϕ_2^o	Temperature parameter	0.00125
a	Damage function parameter	1.004
b	Damage function parameter	0.02

back

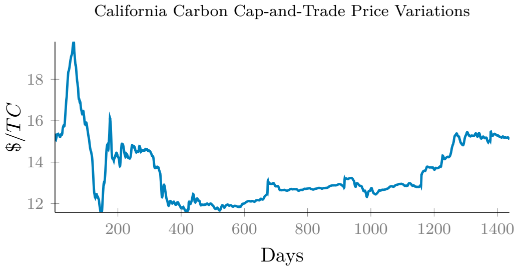
California Carbon Market At A Glance

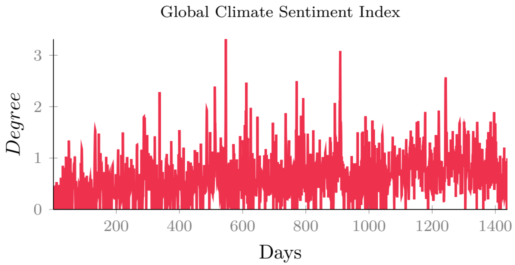
- One of the largest multi-sectoral **emissions trading systems** in the world along with the EU ETS
- Aims at reaching **carbon neutrality** by 2045
- The allowances are traded on secondary markets (spot and futures markets)
- Revenue from **carbon pricing** is used (5 billion USD of total revenue since its beginning):
  - On one hand for a **Greenhouse Gas Reduction Fund** (65 percent)
  - On the other hand as a **redistribution tool** for environmentally disadvantaged and low-income communities (35 percent)

Climate Sentometric Index

- Climate Sentometric index by Ardia et al. (2020) lists all **daily news on climate sentiment** in the U.S. from 2003 to 2018
- The climate sentiment index is constructed based on 8 major newspapers in the U.S. and includes a risk measure
- The index reflects a movement in the sentiment and/or the regulatory constraints, which we use as an event news shock to the California carbon price

CARBON PRICE CHANGES AND CLIMATE SENTIMENT INDEX





Sources: ISO California and Ardia et al. (2020)

Carbon Surprise Series BACK

- Carbon surprise series τ_t^C reads as changes in California futures market price in a tight window around climate news events:

$$\tau_t^{\text{Shock}} = \begin{cases} \tau_t^C - \tau_{t-1}^C & \text{If } \text{day}_t(\text{Carbon Index}) \geq \frac{1}{T}\sum_{i=1}^{T} \text{Carbon Index}_i, \\ 0 & \text{otherwise.} \end{cases} \tag{51}$$

For the AR(1) specification please see here

Distributional Impacts

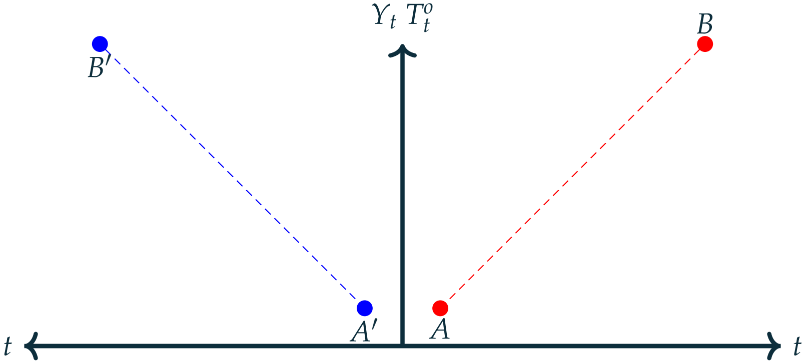
BACK

We use quarterly data from Q1 2006 to Q4 2019 for Californian households (CES surveys):

- We classify households according to their **income level** and, thus, follow the quantiles over the studied period
- Then we investigate the impacts of carbon price shock series on these quantiles

Solution Method: With Climate Feedback (Long-run)

- With no climate feedback (i.e. damages), the final steady state output B' at $t = T$ coincides with the exact transition final value of output
- Temperature value at the final state B and its transition value C at $t = T$, however do not coincide



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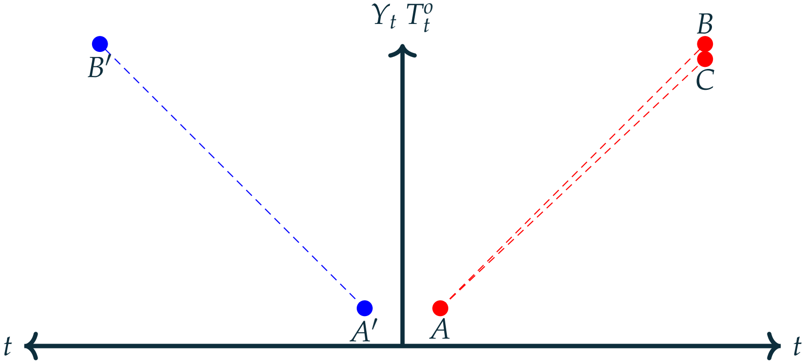
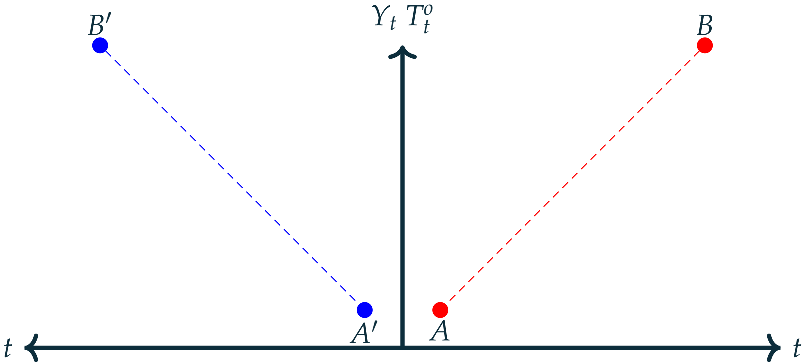


Solution Method: With Climate Feedback (Long-run)

- Contrary to the non-climate feedback case, **climate dynamics** in our model imply adjustments to the standard method for finding the transition pathways



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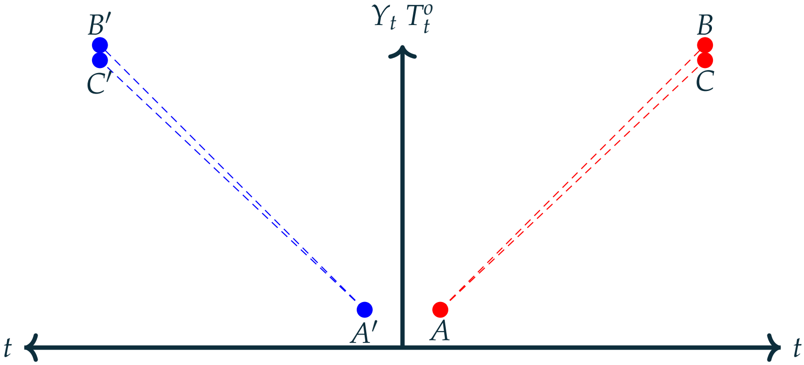


Solution Method: With Climate Feedback (Long-run)

- Laissez-faire: **We first compute a synthetic path for emissions consistent with the laissez-faire RCP 8.5 scenario** and then find the terminal value of emission stock and temperature
- Net-zero: **We feed a cap trajectory that is consistent with zero emissions by 2050** and find the terminal value of emissions stock and temperature
- Thereafter, we retrieve the remaining values within the inner loop used to find the level of capital in each sector

Solution Method: With Climate Feedback (Long-run) BACK

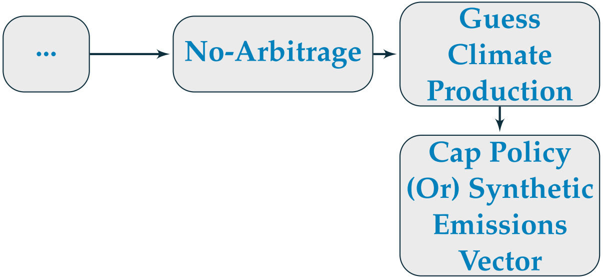
... → **No-Arbitrage**

Solution Method: With Climate Feedback (Long-run) ⏩ BACK

... → No-Arbitrage → Guess Climate Production

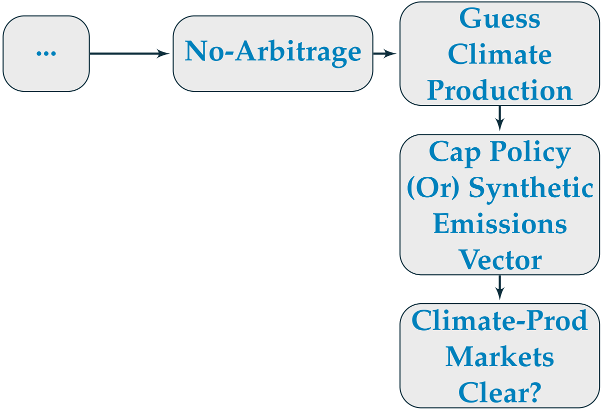
Solution Method: With Climate Feedback (Long-run)

BACK

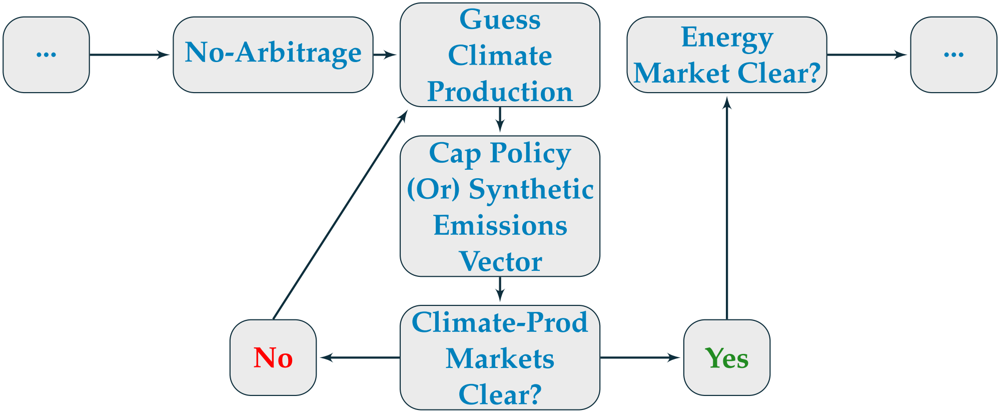


Solution Method: With Climate Feedback (Long-run)

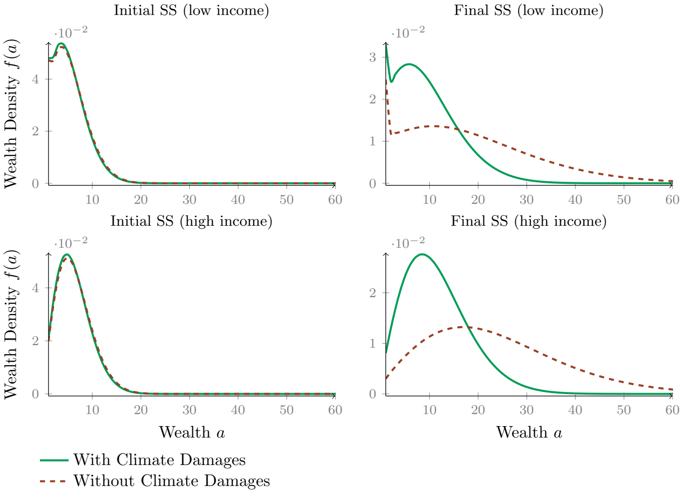
BACK



Solution Method: With Climate Feedback (Long-run) ▸▸ BACK

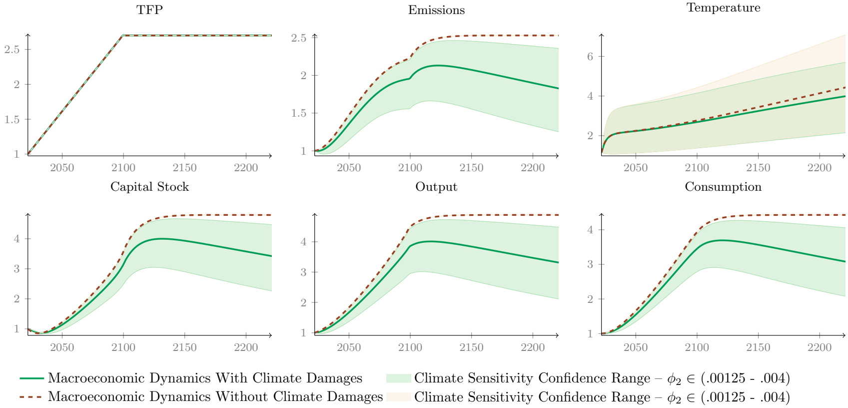


Results 2a: Climate implications for wealth distribution



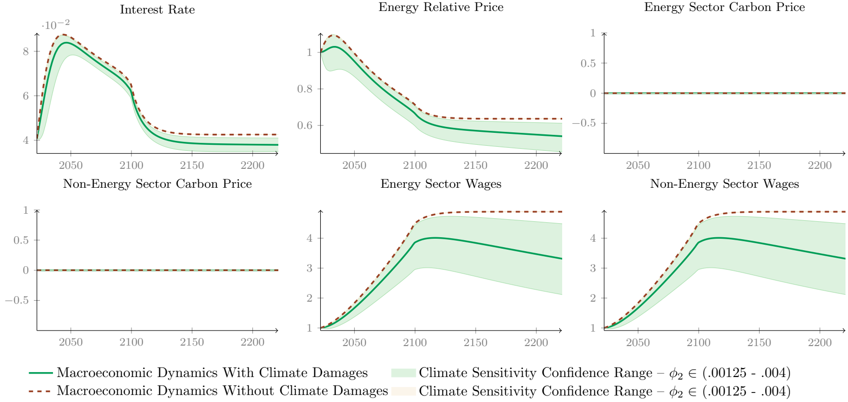
For long-run transitions please see here

Results 2a: Climate damages, climate uncertainty, and laissez-faire transition pathways–Macro Aggregates



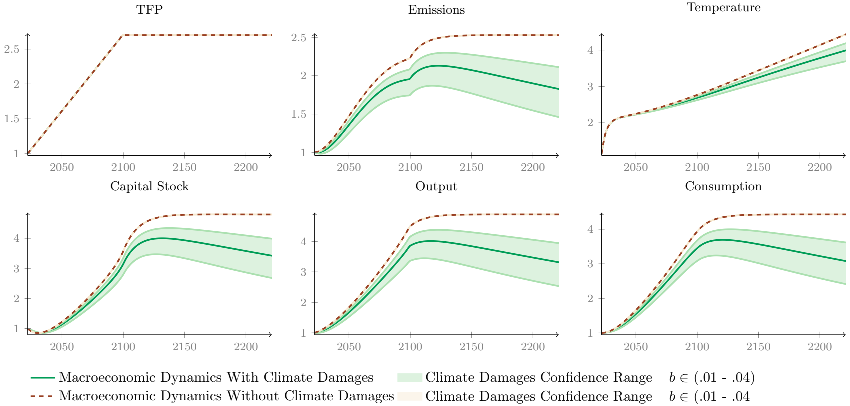
Note: Brown and green confidence ranges represent confidence range for values of ϕ_2 in line with IPCC scenarios. For damages uncertainty please see here back

Results 2a: Climate damages, climate uncertainty, and laissez-faire transition pathways–Price Aggregates



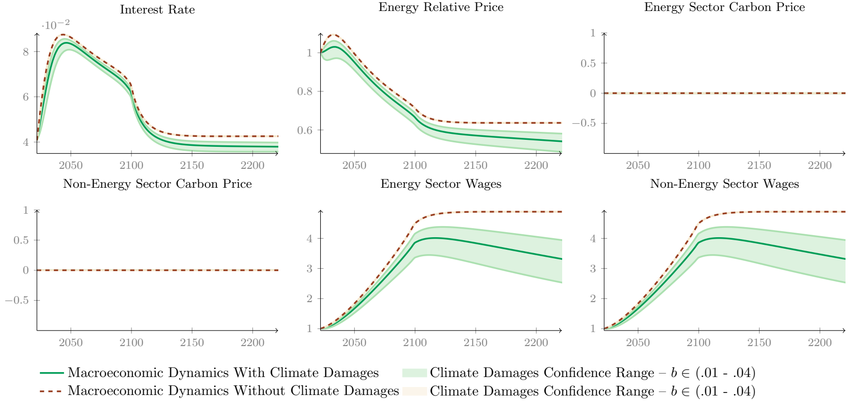
Note: Brown and green confidence ranges represent confidence range for values of ϕ_2 in line with IPCC scenarios. For damages uncertainty please see here back

Results 2a(bis): Climate dynamics, damages uncertainty, and laissez-faire transition pathways–Macro Aggregates



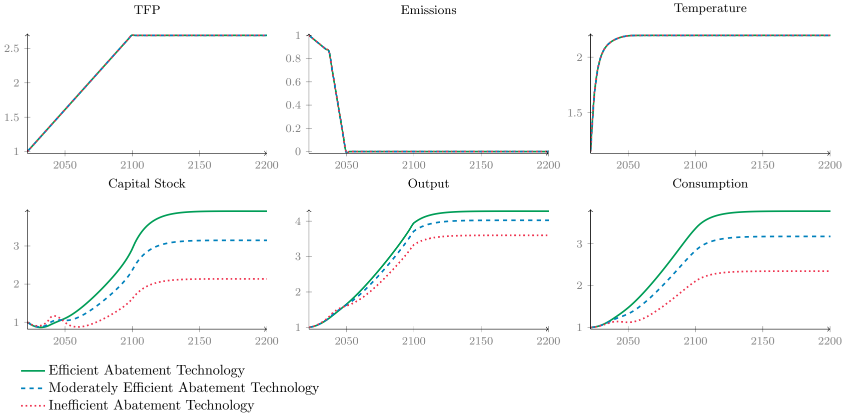
Note: Brown and green confidence ranges represent confidence ranges for values of the climate damages parameter. back

Results 2a(bis): Climate dynamics, damages uncertainty, and laissez-faire transition pathways–Price Aggregates



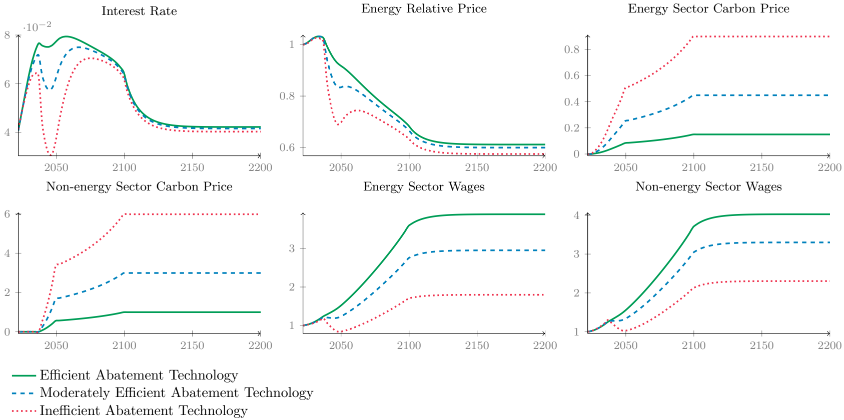
Note: Brown and green confidence ranges represent confidence ranges for values of the climate damages parameter. back

Results 2b: Meeting Net-Zero–Macro Aggregates



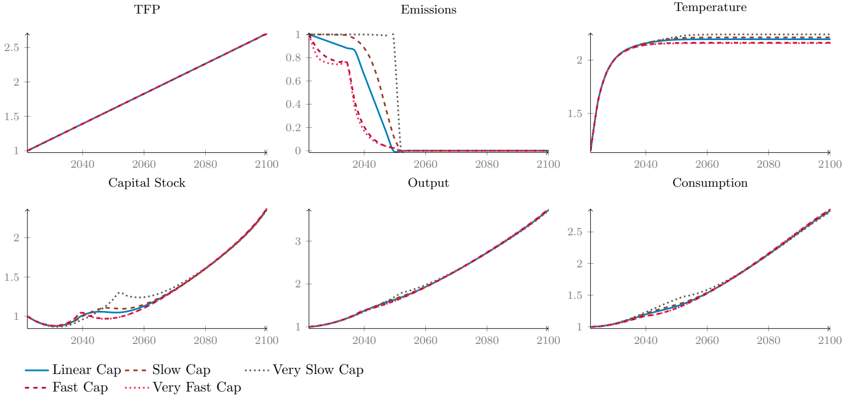
Note: This figure compares the net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 t0 2100. For trajectory uncertainty please see here back

Results 2b: Meeting Net-Zero–Prices Aggregates



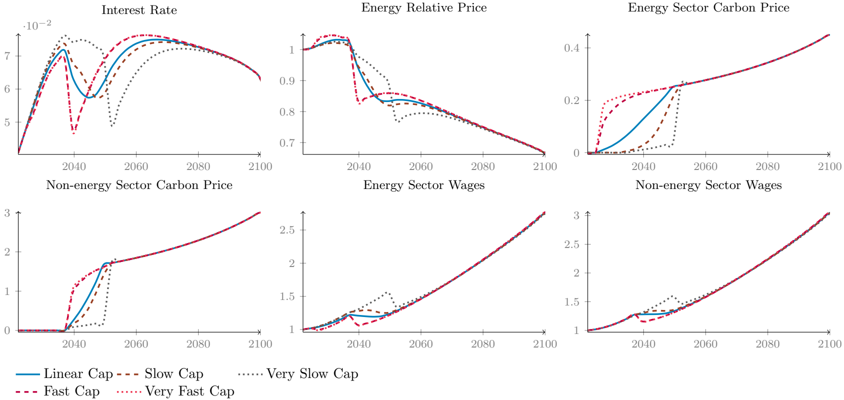
Note: This figure compares the net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 t0 2100. For trajectory uncertainty please see here back

Results 2b(bis): Meeting Net-Zero Following Different Trajectories–Macro Aggregates



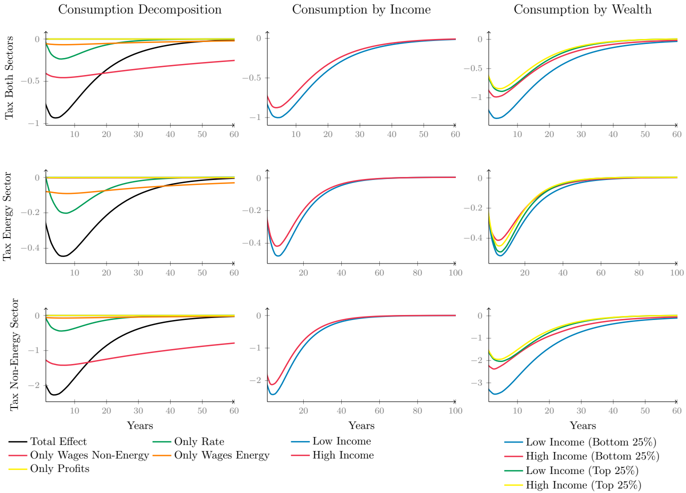
Note: This figure compares the net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 t0 2100. back

Results 2b(bis): Meeting Net-Zero Following Different Trajectories–Prices Aggregates



Note: This figure compares the net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 to 2100. back

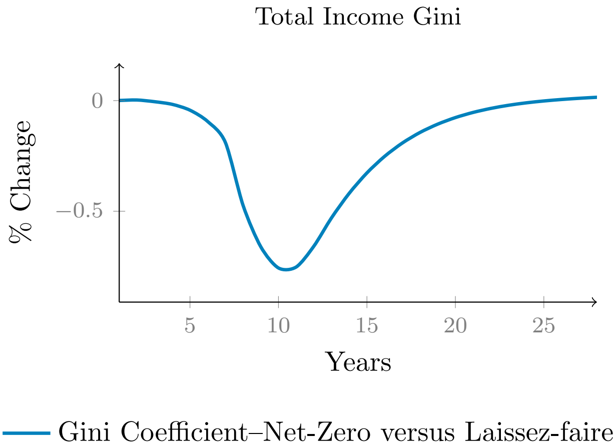
Results 1b: Carbon Price Transmission Mechanism



Note: We show consumption according to 3 different scenarios leading to an initial 25% emissions reduction.

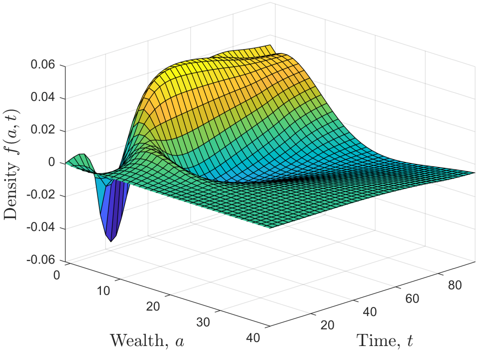
back

Results 2b(bis): Total Income Gini

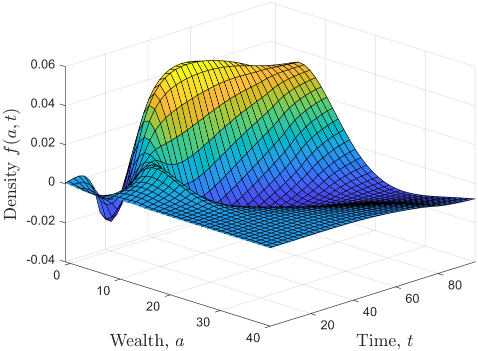


Note: This figure compares the 2050 net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 to 2100. back

Results 2c: Net-zero versus laissez-faire medium-run distributional impacts



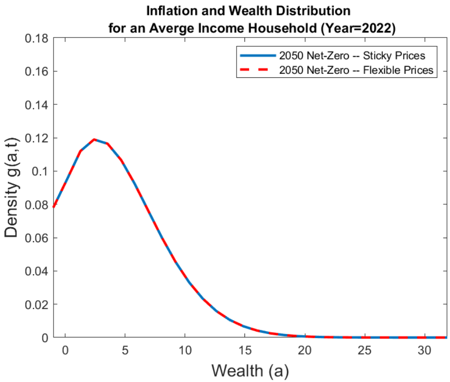
Low Income Households

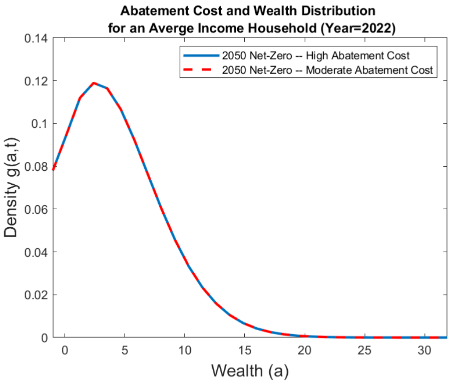


High Income Households

Wealth distribution along the net-zero transition with inefficient abatement. back

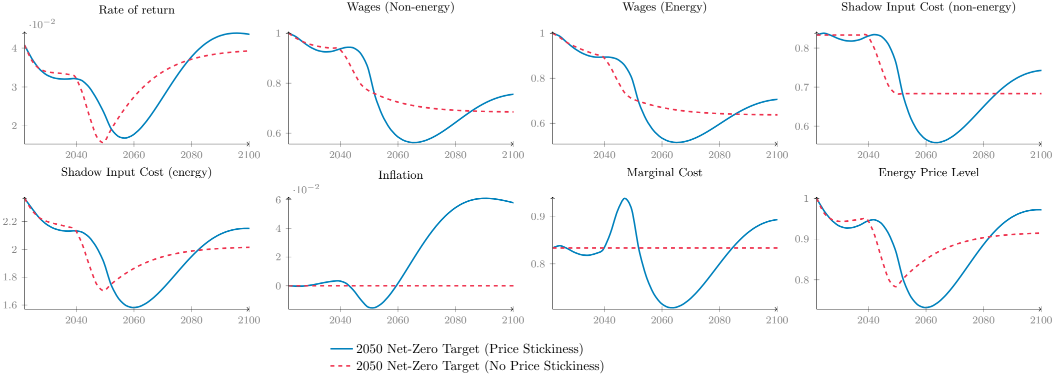
Results 4a: The Role of Inflation and Abatement Cost





back

Results 4b: The Role of Inflation and Abatement Cost



Note: The figure plots the reaction of relevant macro-aggregates and prices according to two modeling choices: i) in blue the presence of price stickiness, and ii) in red under the assumption of flexible prices. In both cases, we plot the net-zero trajectory under no TFP growth. back