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

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QCGBF Conference

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The views and opinions expressed in this article are those of the authors and do not necessarily reflect the views or positions of any entities they represent

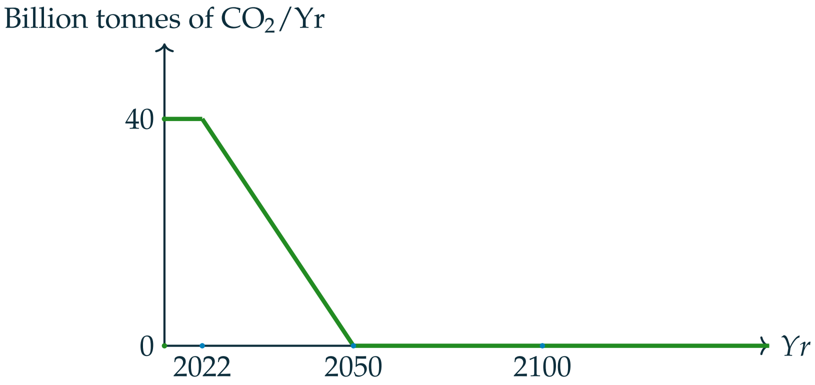
Main question:

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

Motivation

Temperature < 1.5^{o}C and Net-Zero Emissions

- Keeping temperature below 1.5^{o}C in the long-run requires a net-zero emission target by 2050



Adapted from the IPCC Special Report on Global Warming of 1.5^{o}C

Implicit Carbon Price: Main Mitigation Tool

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

Source: International Carbon Action Partnership

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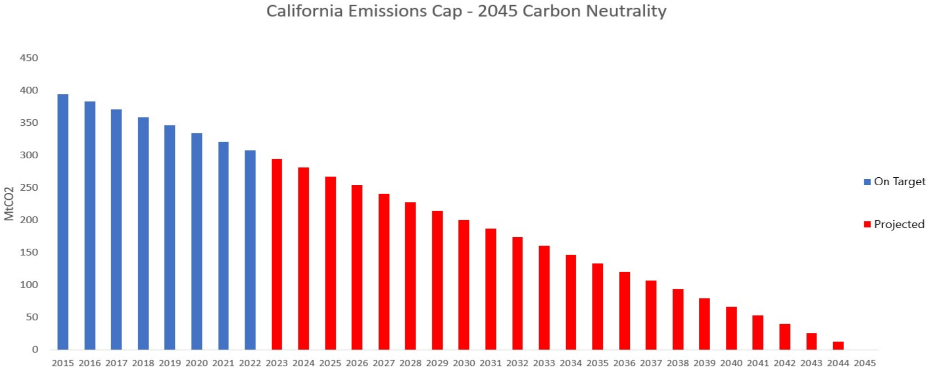
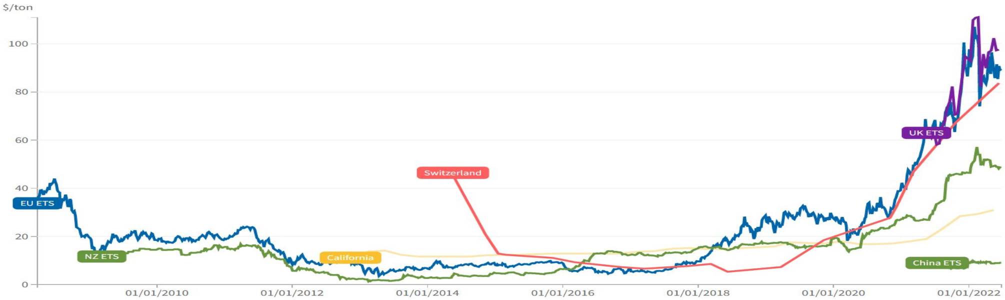


Constructed using International Carbon Action Partnership

Implicit Carbon Price: Main Mitigation Tool

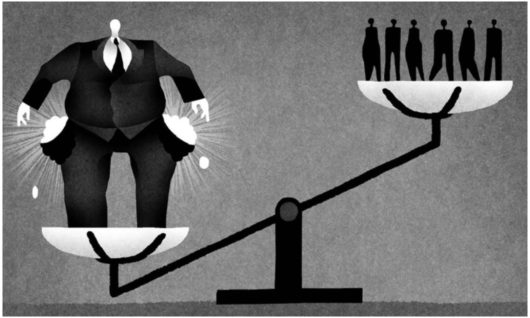
1. **Carbon pricing** is gaining momentum world wide
2. **Cap-and-Trade Market** is the major tool used in climate change mitigation
3. The inherent **carbon price** is expected to increase to meet net-zero by 2050



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

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

Main Takeaways

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

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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)

Disclaimer!

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2. We focus on the net-zero cap trajectory(ies) and not the social cost of carbon
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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Relevant Literature: Theoretical

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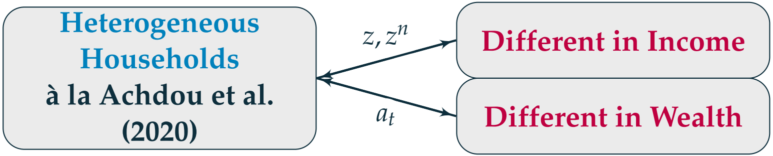
  ⇒ **How we differ**: We use a **full-fledged** macro-climate with heterogeneous agents and **inflation dynamics** and investigate **long-run transition**

Climate-HANK

Heterogeneous Households
à la Achdou et al. (2020)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à la Achdou et al. (2020)
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a_t
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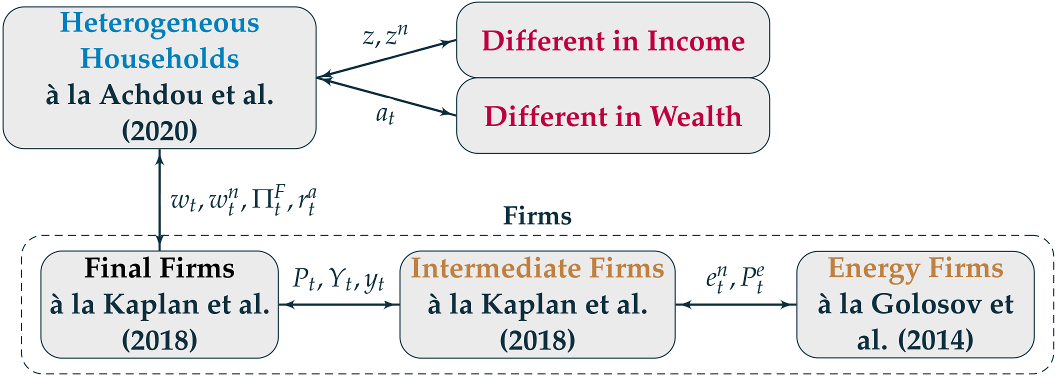
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à la Kaplan et al. (2018)
P_t, Y_t, y_t
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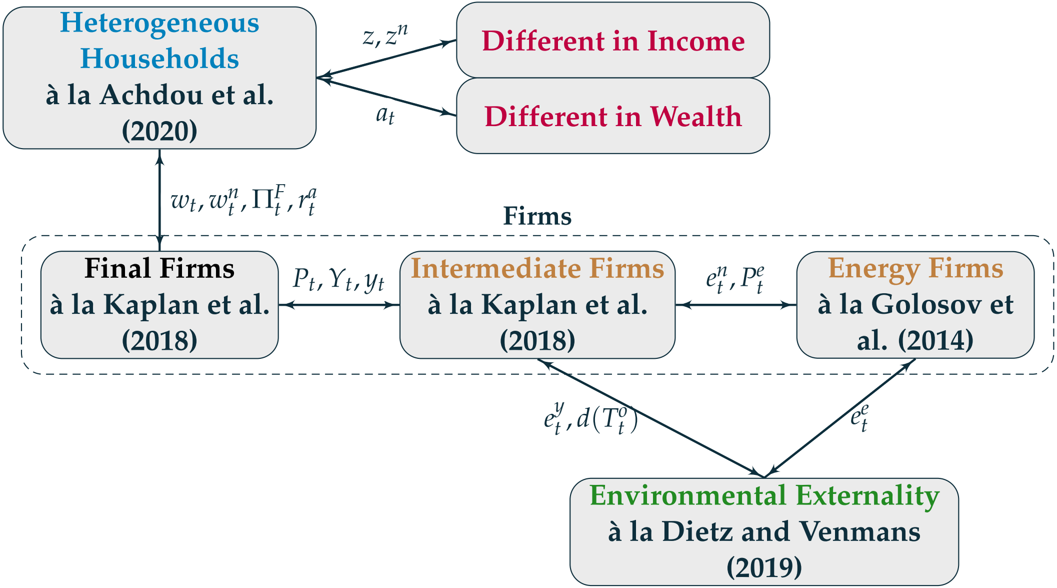
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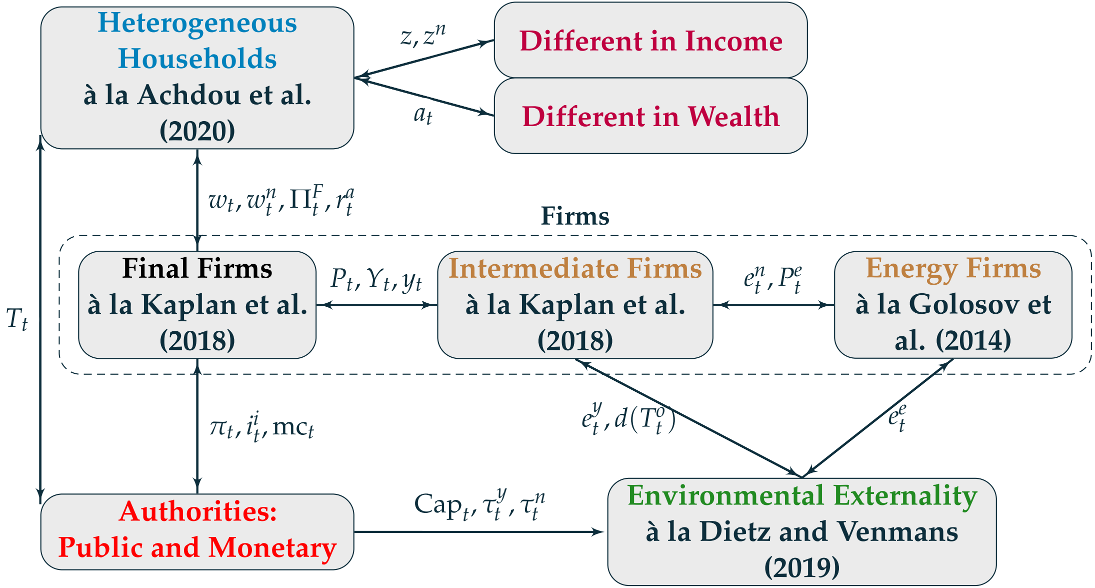
à la Dietz and Venmans (2019)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T_t
$\pi_t, i_t^i, \mathrm{mc}_t$
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e_t^e
Authorities:
Public and Monetary
$\mathrm{Cap}_t, \tau_t^y, \tau_t^n$
Environmental Externality
à la Dietz and Venmans (2019)

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:

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

$$e^y_{j,t} = (1-\mu^y_{j,t}) \underbrace{\varphi^y_t}_{\text{CO}_2 \text{ intensity} \downarrow \text{ trend}} y_{j,t} \tag{7}$$

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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

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

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

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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:

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

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

$$P_t^e = \left(mc_t - f(\mu_t^y) - \tau_t^y(e_t^y/y_t)\right)\alpha_2 y_t/e_t^n$$

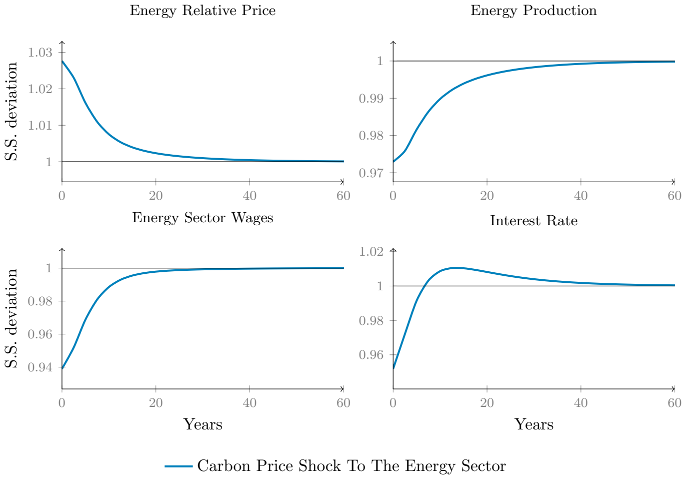
Note: The total marginal cost is constant in the case of flexible prices.

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

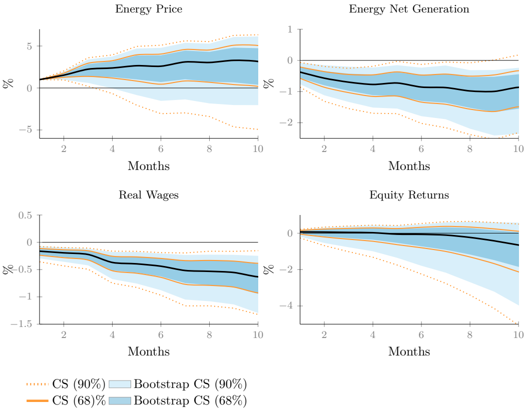
Results 1a: Carbon Price and Macroeconomic Dynamics

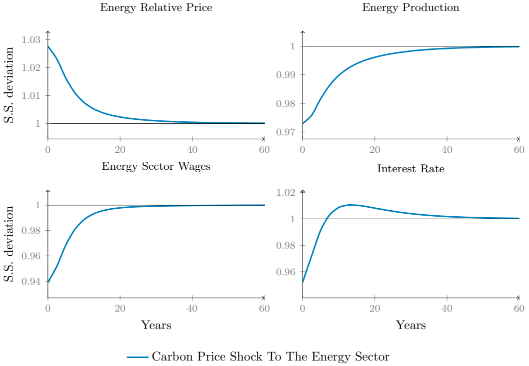


Note: The figure plots the responses to a carbon price shock leading to a 25% reduction in total emissions.

Results

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





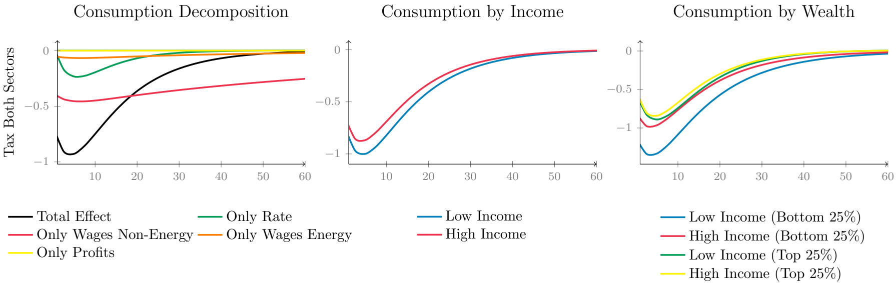
Empirical Strategy Details
Cholesky IRF

Results 1b: Carbon Price Transmission Mechanism

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

$$dC0 = \int_0^\infty \left(\underbrace{\frac{\partial C0}{\partial r_t^a} dr_t^a}_{\text{asset returns}} + \underbrace{\frac{\partial C0}{\partial w_t^n} dw_t^n}_{\text{energy wages}} + \underbrace{\frac{\partial C0}{\partial w_t^y} dw_t^y}_{\text{non-energy wages}} + \underbrace{\frac{\partial C0}{\partial \Pi_t^F} d\Pi_t^F}_{\text{profits}} + \underbrace{\frac{\partial C0}{\partial T_t} dT_t}_{\text{fiscal transfers}} \right) dt \tag{19}$$

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

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

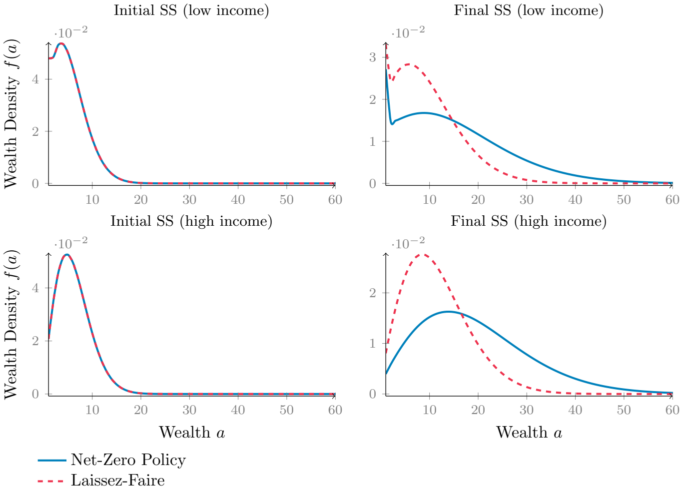
Table: Welfare: Net-zero versus Laissez-faire

		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

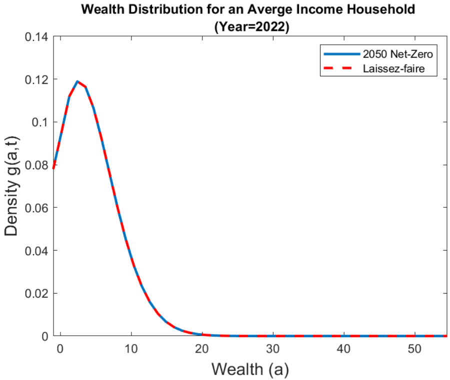
$$Welfare = \int v^{final}(a, z_j^y, z_j^n) g^{final}(a, z_j^y, z_j^n) d\mu \tag{20}$$

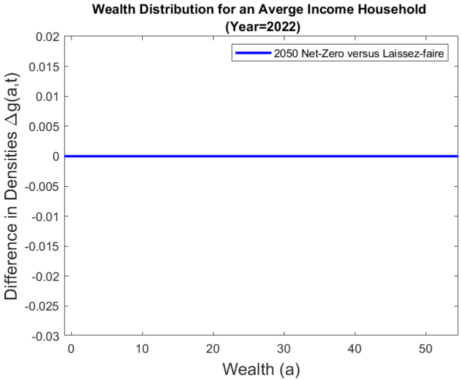
Results 2a: Net-zero long-run distributional impacts



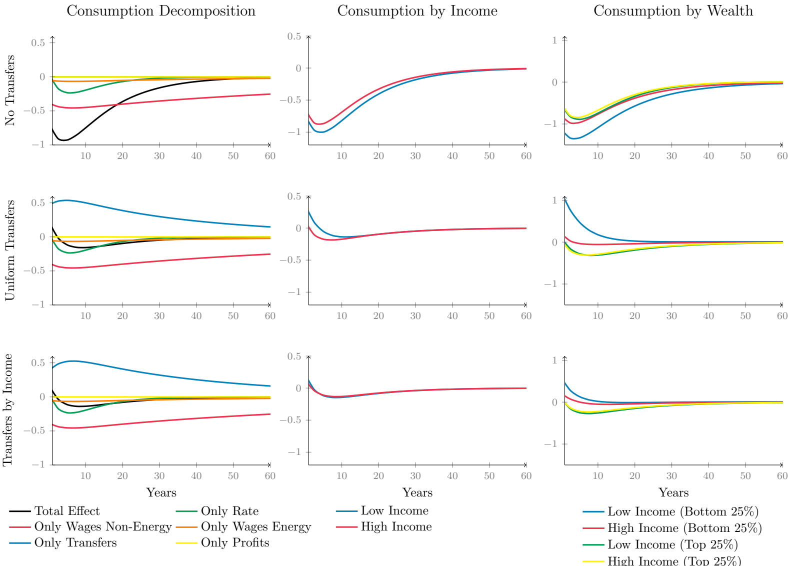
For net-zero long-run transitions please see here Income Gini over the transition here

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:

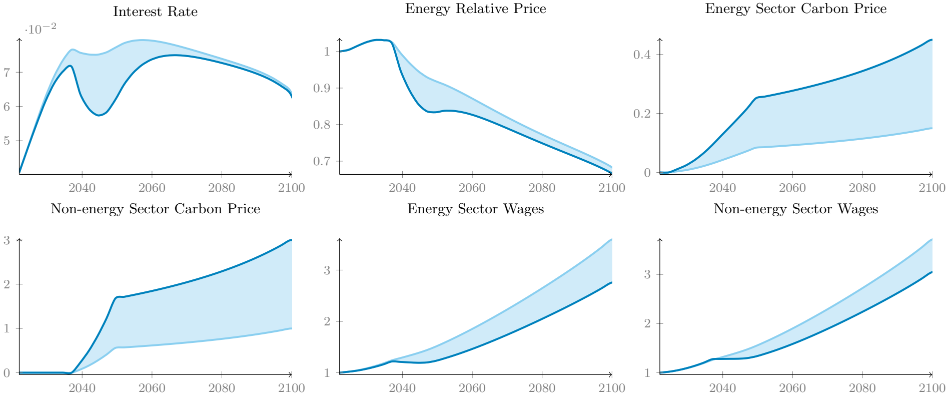
$$f(\mu_t^s) = \left(\int_0^{A_t^g} f(\mu_{j,t}^s)^{\frac{1}{\theta_3}} dj \right)^{\theta_3} \tag{21}$$

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. $A_t^g = \mu_t$):

$$f(\mu_t^s) = \theta_1 (\mu_t^s)^{\theta_2 - \theta_3} \tag{22}$$

Results 4b: Learning By Doing and Abatement Cost



2050 Net-Zero Emission Target

Abatement Sensitivity Confidence Range – $\theta_3 \in (0 ; 05)$

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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2. While **“precautionary savings”** lead to an increase in capital holdings at the beginning of the transition (as households expect lower future income given high environmental costs), the increasing carbon mitigation cost **increases inequality** over the transition

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

2. While **"precautionary savings"** lead to an increase in capital holdings at the beginning of the transition (as households expect lower future income given high environmental costs), the increasing carbon mitigation cost **increases inequality** over the transition

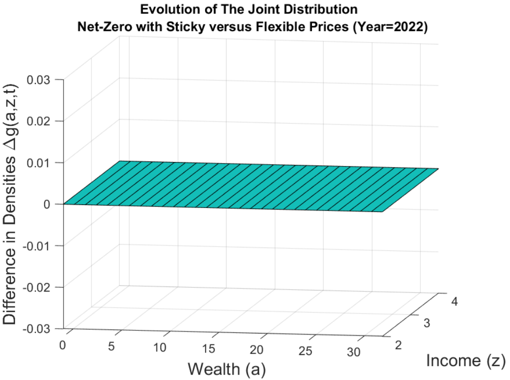
3. Carbon revenue redistribution—following an **income-based approach**—allows for an offset of most negative impacts on consumption

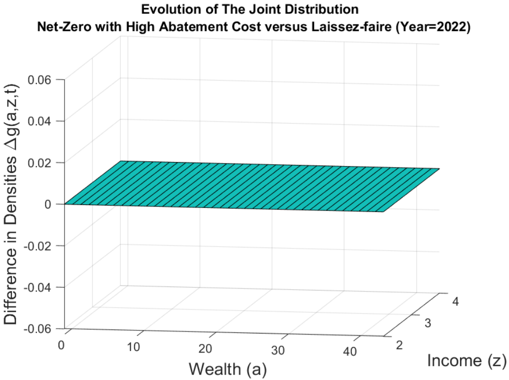
THANK YOU!

Annex

Impacts of Inflation and Abatement Cost on The Joint Distribution

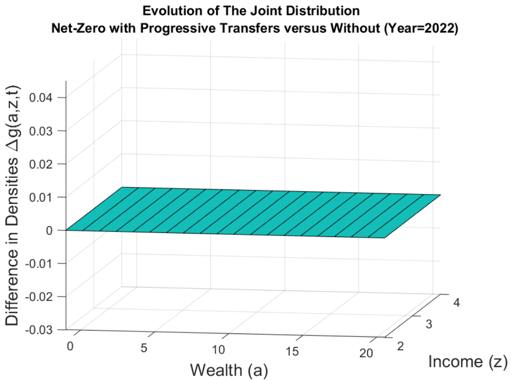
BACK

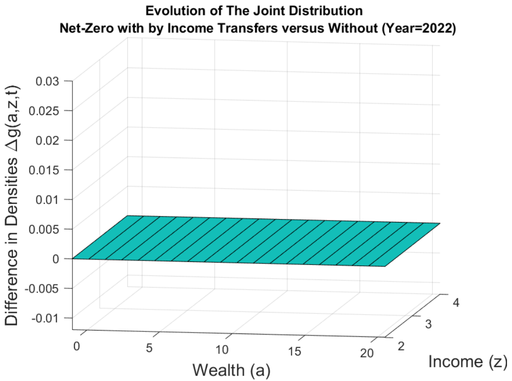




THE ROLE OF REDISTRIBUTION

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:

$$\tau_t^{\text{Shock}} = \begin{cases} \tau_t^C - \tau_{t-1}^C & \text{If } |\text{day}_t(\epsilon_t)| \geq \bar{\sigma}, \\ 0 & \text{otherwise.} \end{cases} \tag{23}$$

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):

$$Y_t = \sum_{j=1}^{p} A_j Y_{t-j} + \eta_t \tag{24}$$

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:

$$E(z_t \epsilon_{1,t}) \neq 0 \text{ (Relevance)} \tag{25}$$

$$E(z_t \epsilon_{j,t}) = 0 \text{with j} \neq 1 \text{ (Exogenity)} \tag{26}$$

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):

$$Y'_t = \sum_{j=1}^{p} A_j Y'_{t-j} + \eta_t \tag{27}$$

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):

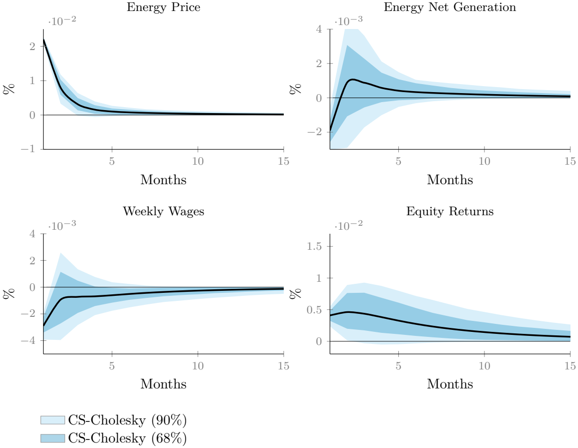
$$E(z_t \epsilon_{1,t}) \neq 0 \text{ (Relevance)} \tag{28}$$

$$E(z_t \epsilon_{j,t}) = 0 \text{with j} \neq 1 \text{ (Exogenity)} \tag{29}$$

$$E(z_t \epsilon_{t+j}) = 0 \text{for j} \neq 0 \text{ (Lead-lag exogenity)} \tag{30}$$

back

Cholesky IRF



back

Energy Firms Problem

- The energy producers maximize their profit subject to:

$$\dot{k}^n_{j,t} = i^n_{j,t} - \delta k^n_{j,t} \tag{31}$$

$$e^n_{j,t} = A^n_t {k^n_{j,t}}^{\alpha_n} {l^n_{j,t}}^{1-\alpha_n} \tag{32}$$

- The first order conditions read as:

$$p^e_t = \varrho^e_t + f(\mu^n_t) + \varphi^n_t \tau^n_t (1 - \mu^n_t) \tag{33}$$

$$r^e_t = \varrho^e_t \alpha_n e^n_t / k^n_t - \delta \tag{34}$$

$$\tau^n_t = f(\mu^n_{j,t})' / \varphi^n_t \tag{35}$$

$$w^n_t = \varrho^e_t (1 - \alpha_n) e^n_t / l^n_t \tag{36}$$

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:

$$\dot{k}^y_{j,t} = i^y_{j,t} - \delta k^y_{j,t} \tag{37}$$

$$y_{j,t} = A_t d(T^o_t) {k^y_{j,t}}^{\alpha_1} {e^n_{j,t}}^{\alpha_2} {l^y_{j,t}}^{1-\alpha_1-\alpha_2} \tag{38}$$

- The first order conditions read as:

$$p^e_t = \varrho^y_t \alpha_2 y_t / e^n_t \tag{39}$$

$$r^y_t = \varrho^y_t \alpha_1 y_t / k^y_t - \delta \tag{40}$$

$$w^y_t = \varrho^y_t (1 - \alpha_1 - \alpha_2) y_t / l^y_t \tag{41}$$

$$\tau^y_t = f(\mu^y_t)' / \varphi^y_t \tag{42}$$

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 $y_{j,t}$:

$$Y_t = \int_0^1 \left(y_{j,t}^{1-\frac{1}{\theta}} \right)^{\frac{1}{1-\frac{1}{\theta}}} \tag{43}$$

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:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t} \right)^{-\theta} Y_t \tag{44}$$

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

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

back

Firms Marginal Cost and Environmental Cost

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

$$\underbrace{mc_t}_{\text{Total Marginal Cost}} = \underbrace{\varrho_t^y}_{\text{Firms' Input Shadow Cost}} + \underbrace{\underbrace{f(\mu_t^y)}_{\text{Abatement Investment}} + \underbrace{\tau_t^y (e_t^y / y_t)}_{\text{Emission Intensity Carbon Price}}}_{\text{Total Environmental Costs}} \tag{46}$$

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:

$$\rho v(a, z_j^y, z_j^n, t) = \max_c u(c) + \partial_a v(a, z_j^y, z_j^n, t)\left(r(t)^a a + w(t)^n z_j^n + w(t)^y z_j^y + \frac{z_j^y}{\bar{\bar{z}}}\Pi_t^F + T_t - c\right) + \sum_{j'} \lambda_{jj'} v(a, z_{j'}^y, z_{j'}^n, t) + \partial_t v(a, z_j^y, z_j^n, t) \tag{47}$$

back

Households: Problem

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- ii) A Kolmogorov Forward equation:

$$\partial_t g(a, z_j^y, z_j^n, t) = -\partial_a[s(a, z_j^y, z_j^n, t) g(a, z_j^y, z_j^n, t)] + \sum_{j'} \lambda_{j'j} g(a, z_j^y, z_j^n, t) \tag{48}$$

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

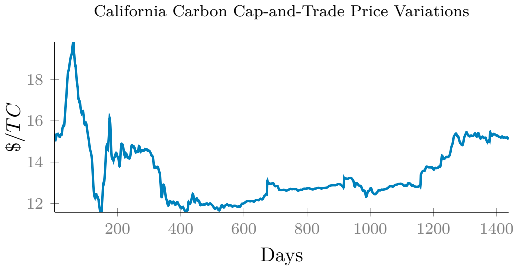
California Carbon Market At A Glance

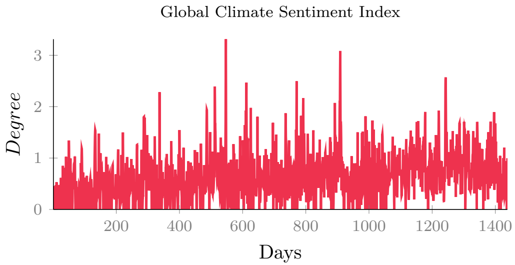
- One of the largest multi-sectoral **emissions trading systems** in the world along with the EU ETS
- Aims at reaching **carbon neutrality** by 2045
- The allowances are traded on secondary markets (spot and futures markets)
- Revenue from **carbon pricing** is used (5 billion USD of total revenue since 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:

$$\tau_t^{\text{Shock}} = \begin{cases} \tau_t^C - \tau_{t-1}^C & \text{If } \text{day}_t(\text{Carbon Index}) \geq \frac{1}{T}\sum_{i=1}^{T} \text{Carbon Index}_i, \\ 0 & \text{otherwise.} \end{cases} \tag{49}$$

For the AR(1) specification please see here

Distributional Impacts

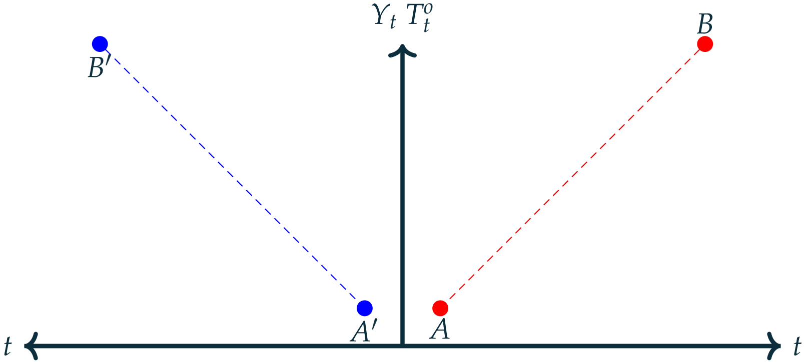
BACK

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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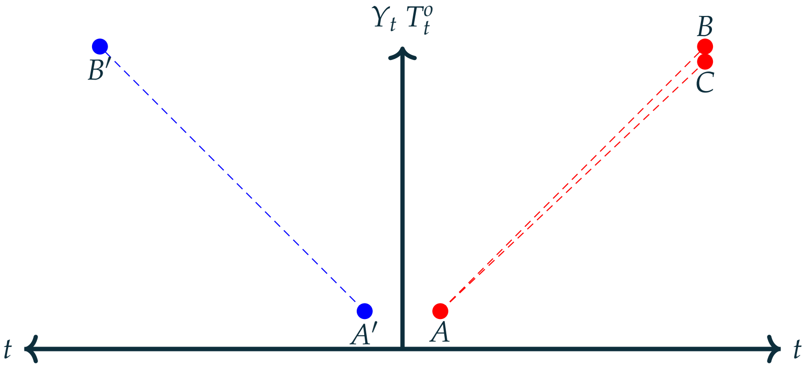

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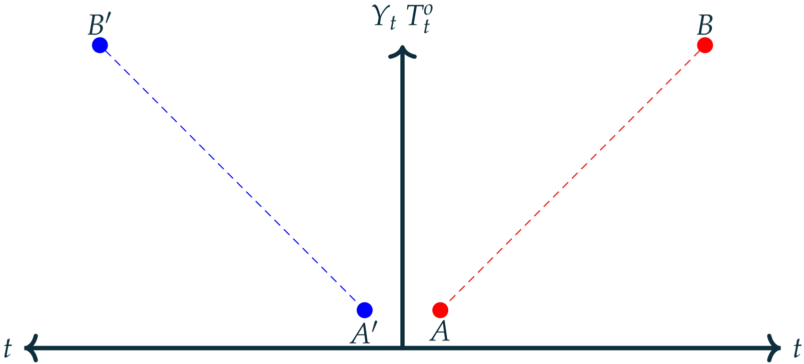
- Contrary to the non-climate feedback case, **climate dynamics** in our model imply adjustments to the standard method for finding the transition pathways



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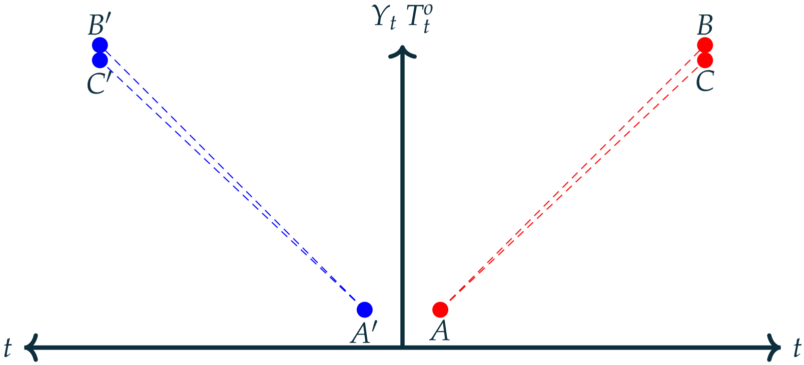
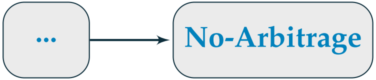


Solution Method: With Climate Feedback (Long-run)

- 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

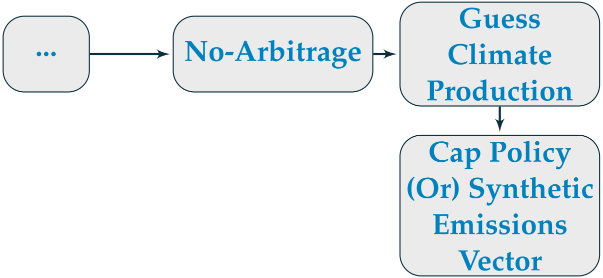
Solution Method: With Climate Feedback (Long-run) BACK



Solution Method: With Climate Feedback (Long-run)

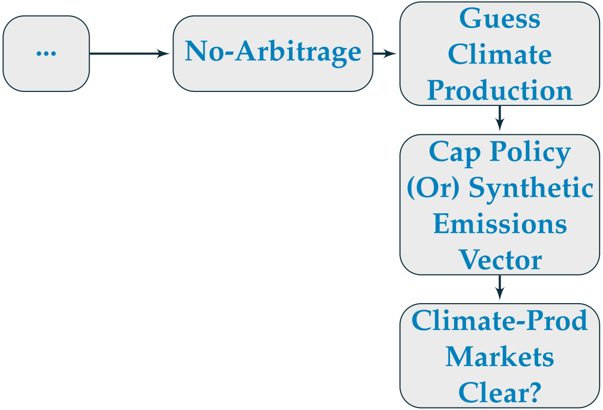
BACK

SOLUTION METHOD: WITH CLIMATE FEEDBACK (LONG-RUN) BACK



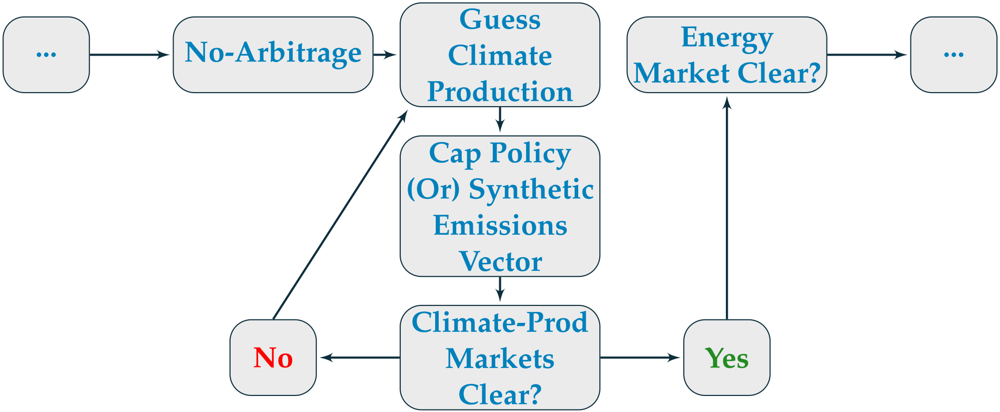
Solution Method: With Climate Feedback (Long-run)

▸▸ BACK

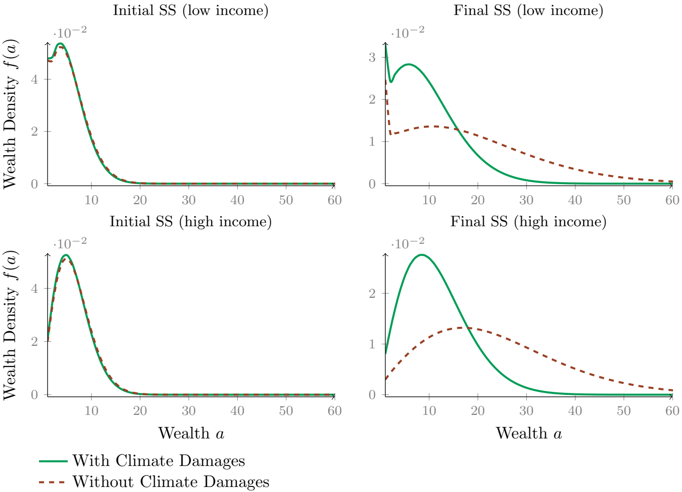


Solution Method: With Climate Feedback (Long-run)

BACK

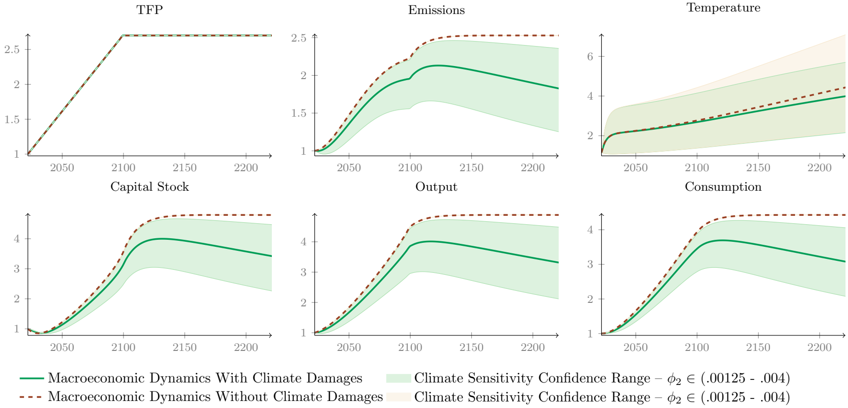


Results 2a: Climate implications for wealth distribution



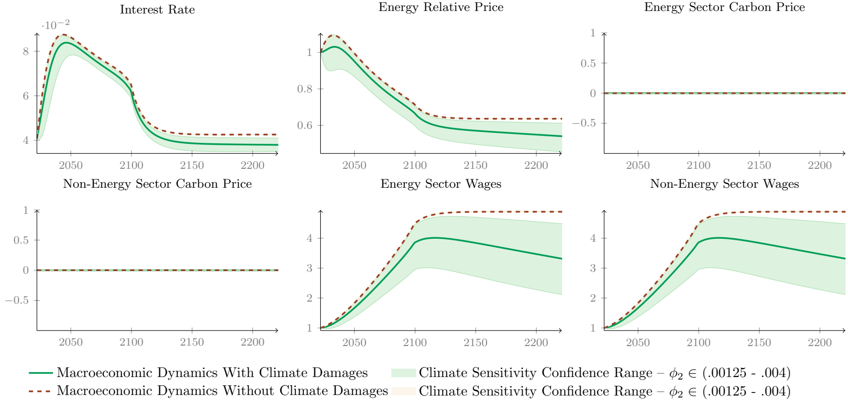
For long-run transitions please see here

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



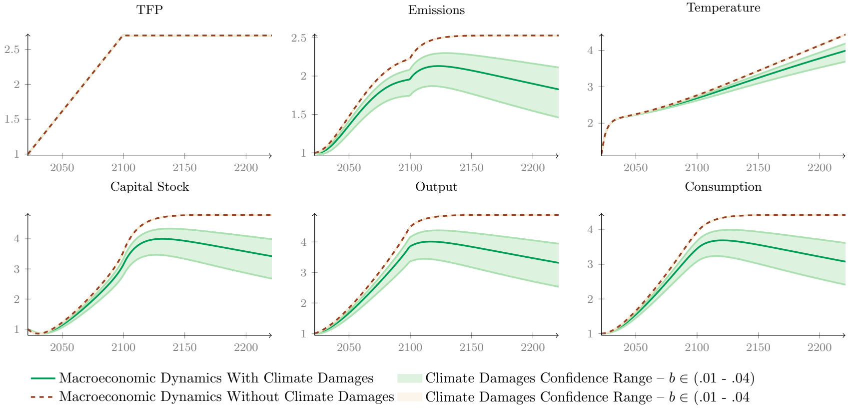
Note: Brown and green confidence ranges represent confidence range for values of ϕ_2 in line with IPCC scenarios. For damages uncertainty please see here back

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



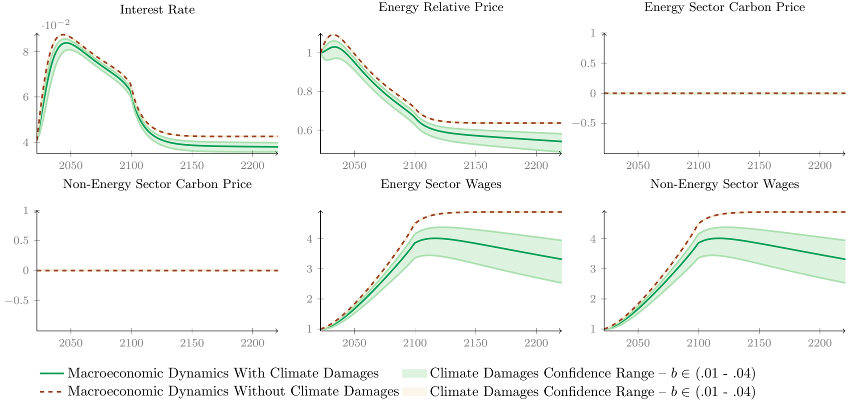
Note: Brown and green confidence ranges represent confidence range for values of ϕ_2 in line with IPCC scenarios. For damages uncertainty please see here back

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



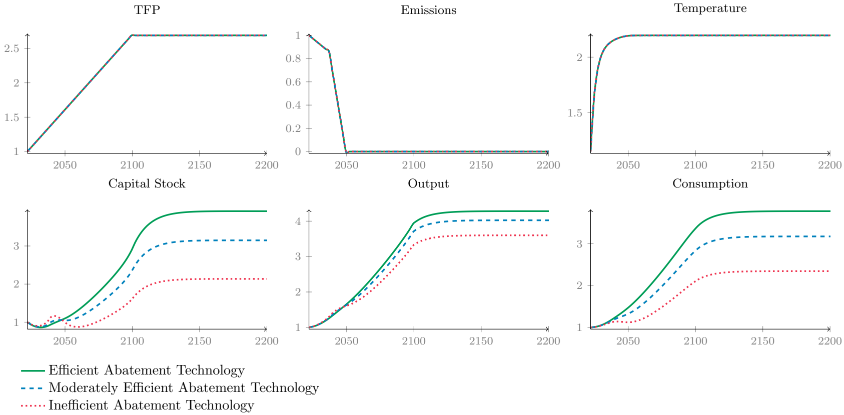
<u>Note:</u> Brown and green confidence ranges represent confidence ranges for values of the climate damages parameter. back

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



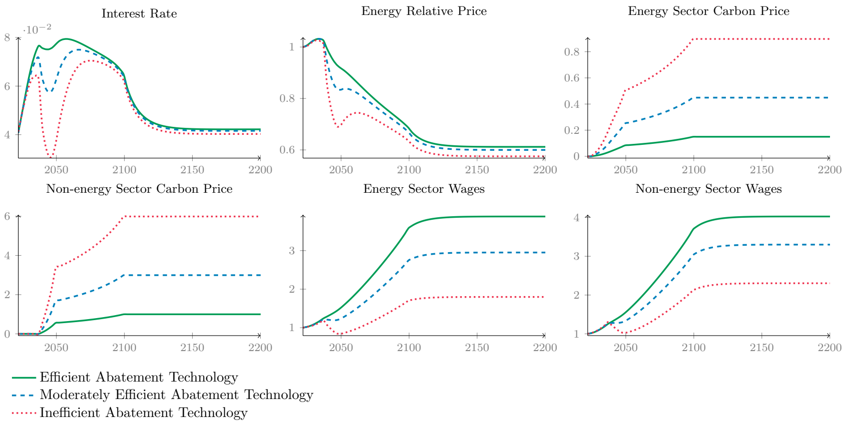
Note: Brown and green confidence ranges represent confidence ranges for values of the climate damages parameter. back

Results 2b: Meeting Net-Zero–Macro Aggregates



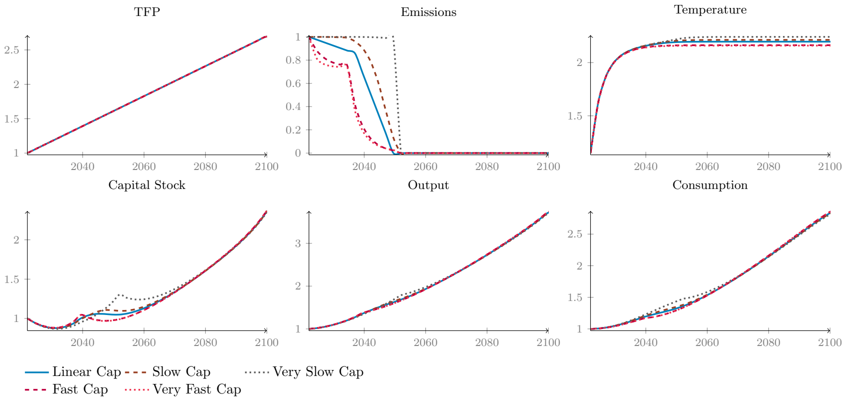
Note: This figure compares the net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 t0 2100. For trajectory uncertainty please see here back

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

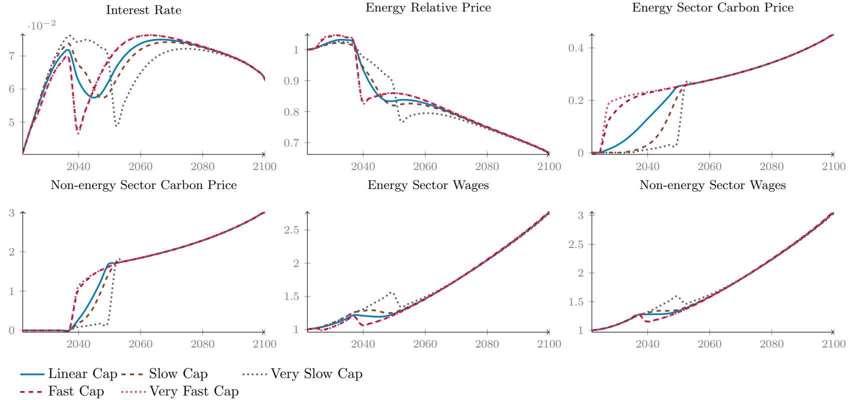
Results 2b(bis): Meeting Net-Zero Following Different Trajectories–Macro Aggregates



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.

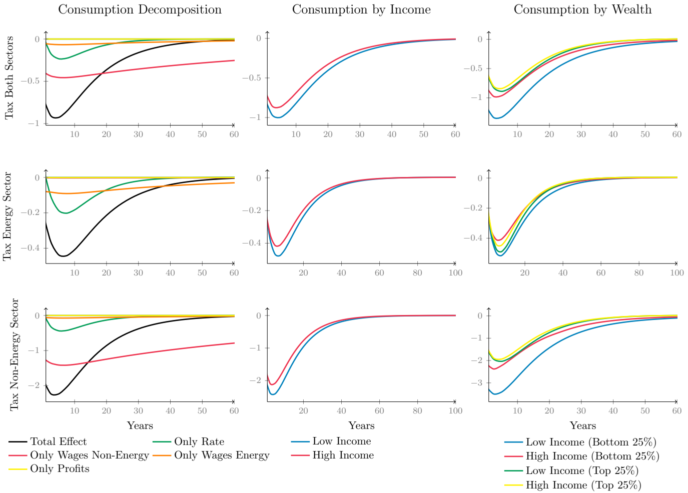
back

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

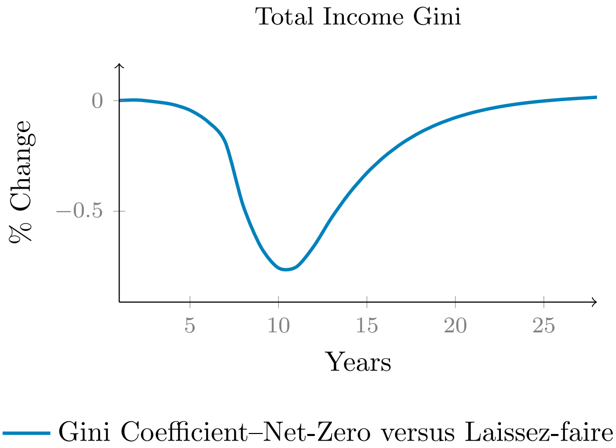
Results 1b: Carbon Price Transmission Mechanism



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

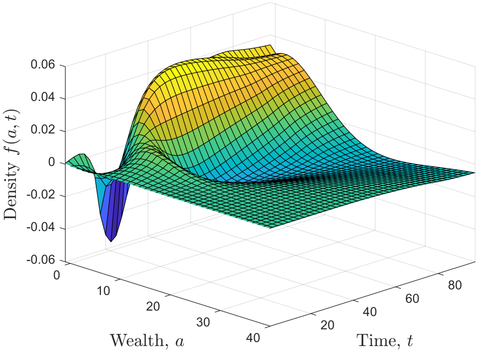
back

Results 2b(bis): Total Income Gini

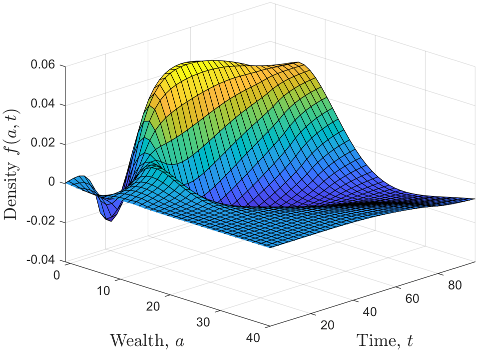


Note: This figure compares the 2050 net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 to 2100. back

RESULTS 2C: NET-ZERO VERSUS LAISSEZ-FAIRE MEDIUM-RUN DISTRIBUTIONAL IMPACTS



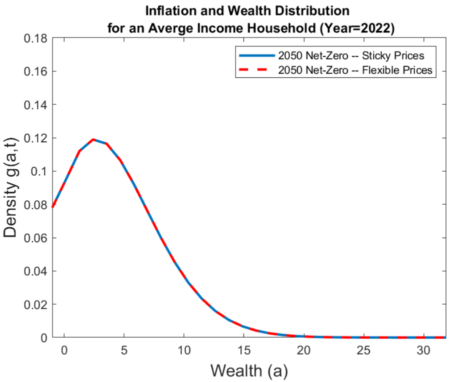
Low Income Households

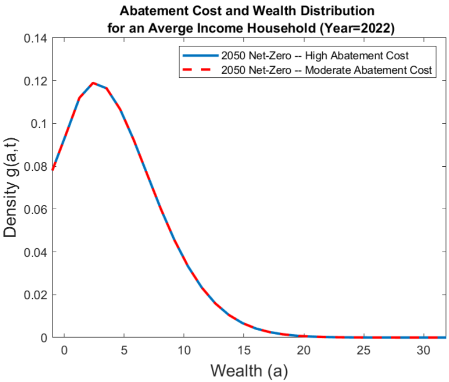


High Income Households

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

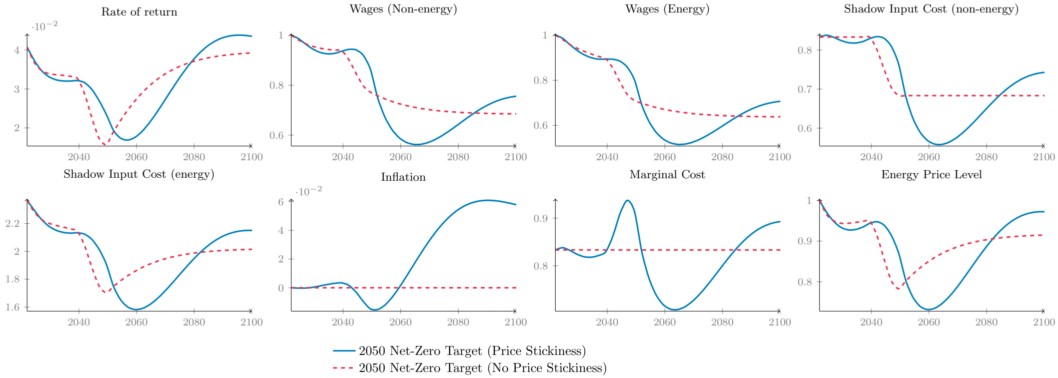
Results 4a: The Role of Inflation and Abatement Cost





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