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

G. Benmir and J. Roman

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QCGBF Conference

Ghassane Benmir

London School of Economics and Political Science  
PSL Research – Université Paris Dauphine

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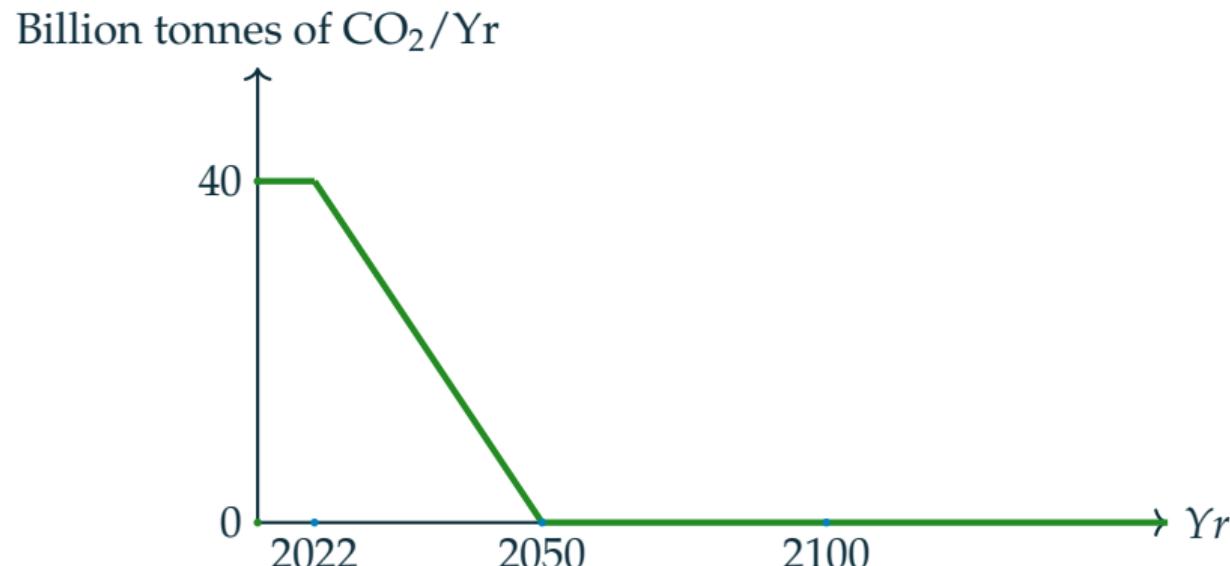
Main question:

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

# Motivation

## TEMPERATURE $< 1.5^{\circ}\text{C}$ AND NET-ZERO EMISSIONS

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



Adapted from the IPCC Special Report on Global Warming of  $1.5^{\circ}\text{C}$

# IMPLICIT CARBON PRICE: MAIN MITIGATION TOOL

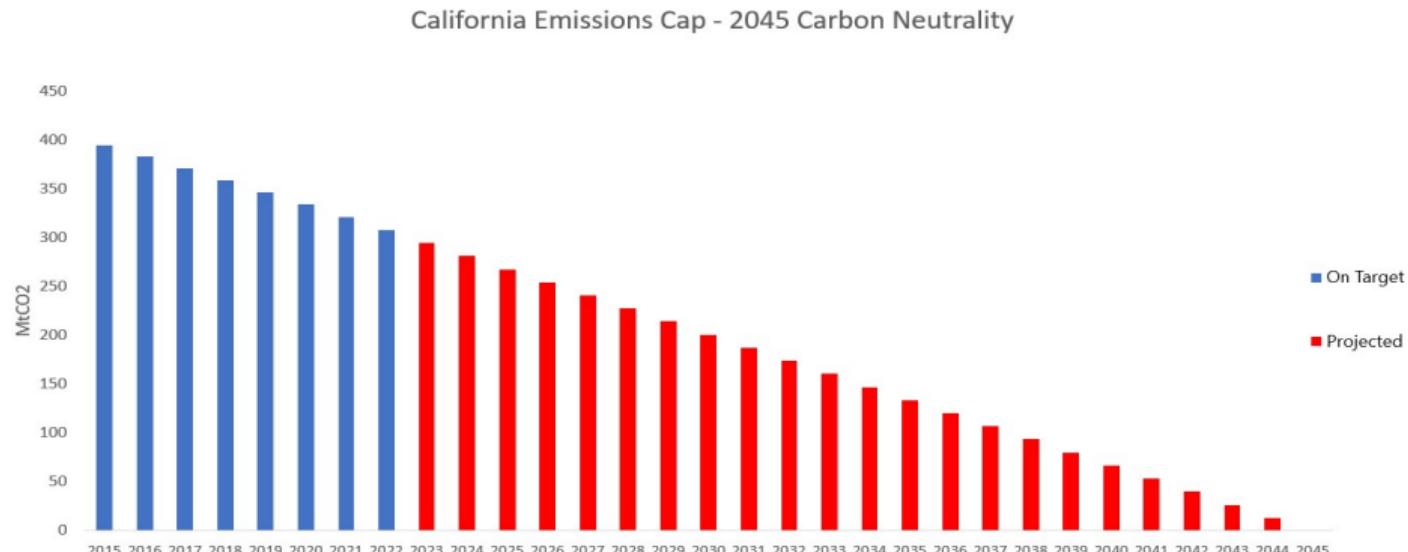
1. Carbon pricing is gaining momentum world wide



Source: International Carbon Action Partnership

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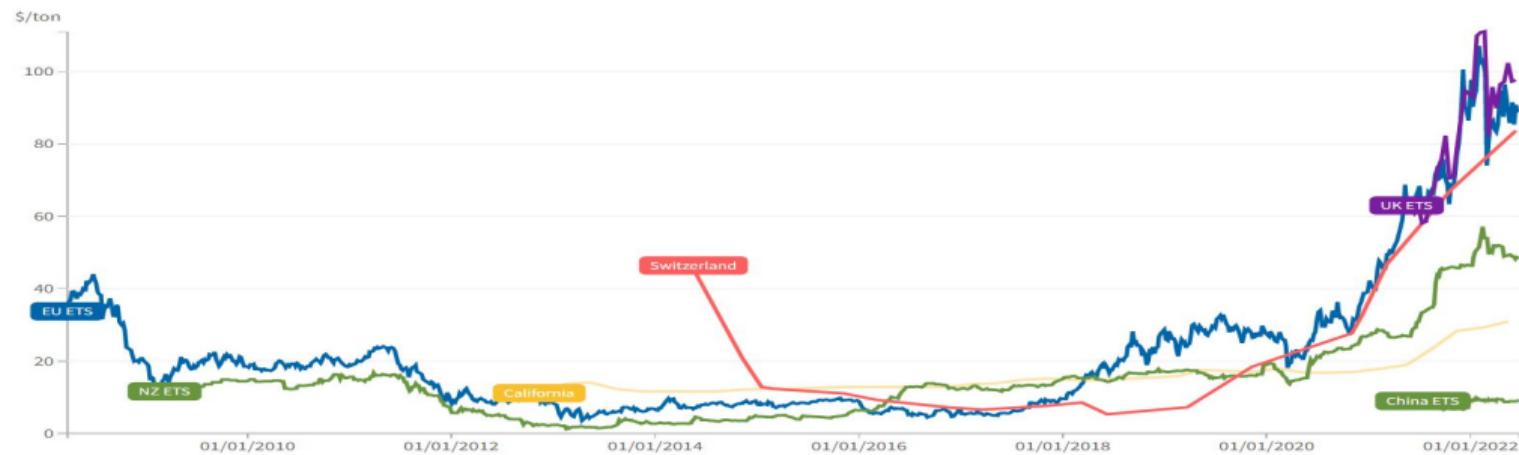
1. **Carbon pricing** is gaining momentum world wide
2. **Cap-and-Trade Market** is the major tool used in climate change mitigation



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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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)

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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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  - ⇒ **How we differ:** We use the climate news “**Sentometric**” instrument to identify shocks

## RELEVANT LITERATURE: THEORETICAL

- ▶ **Distributional Macro:** Den Haan [1997], Krusell and Smith [1998], Reiter [2009], Boppart et al. [2018], Ahn et al. [2018], Auclert [2019], Auclert et al. [2021], and Achdou et al. [2022]

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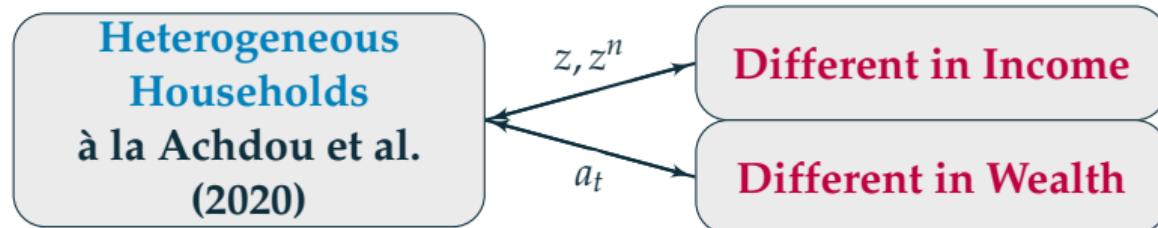
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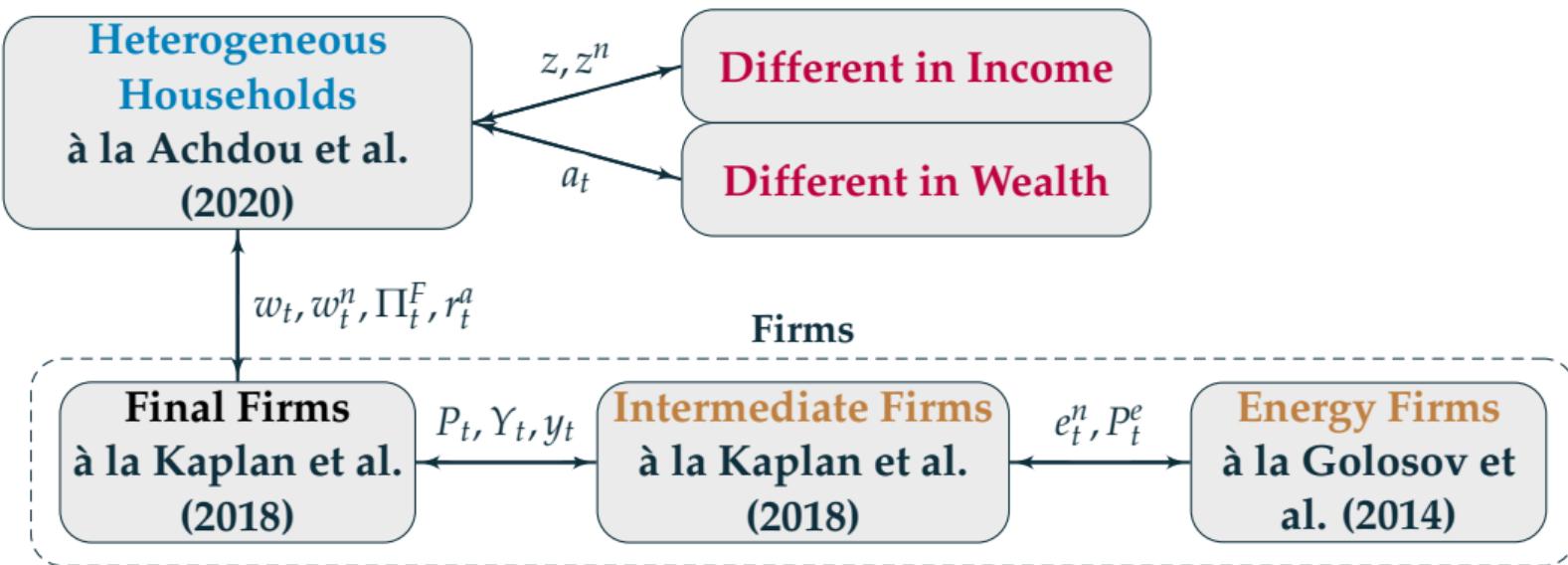
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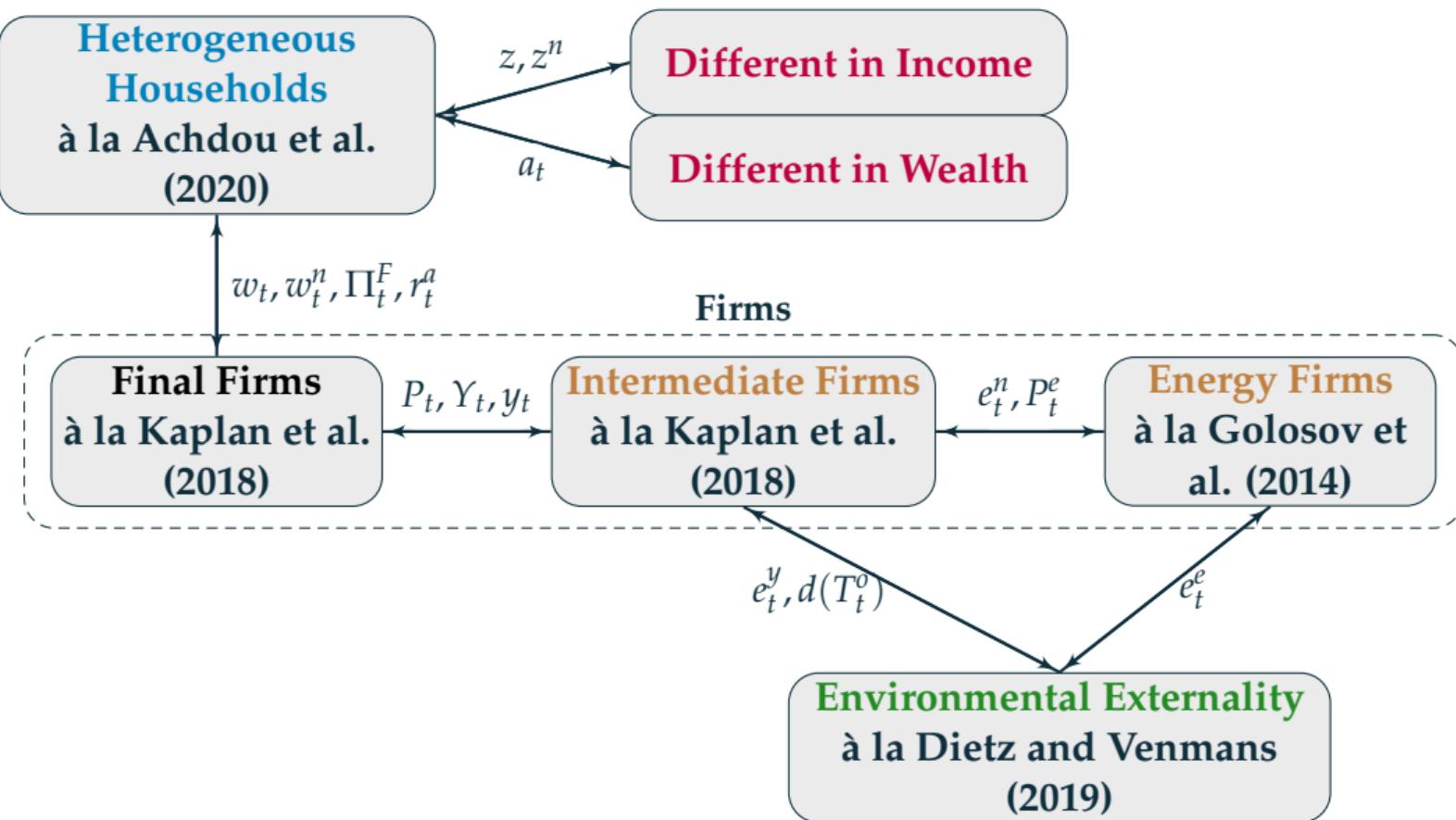
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  - ⇒ **How we differ:** We use a **full-fledged** macro-climate with heterogeneous agents and **inflation dynamics** and investigate **long-run transition**

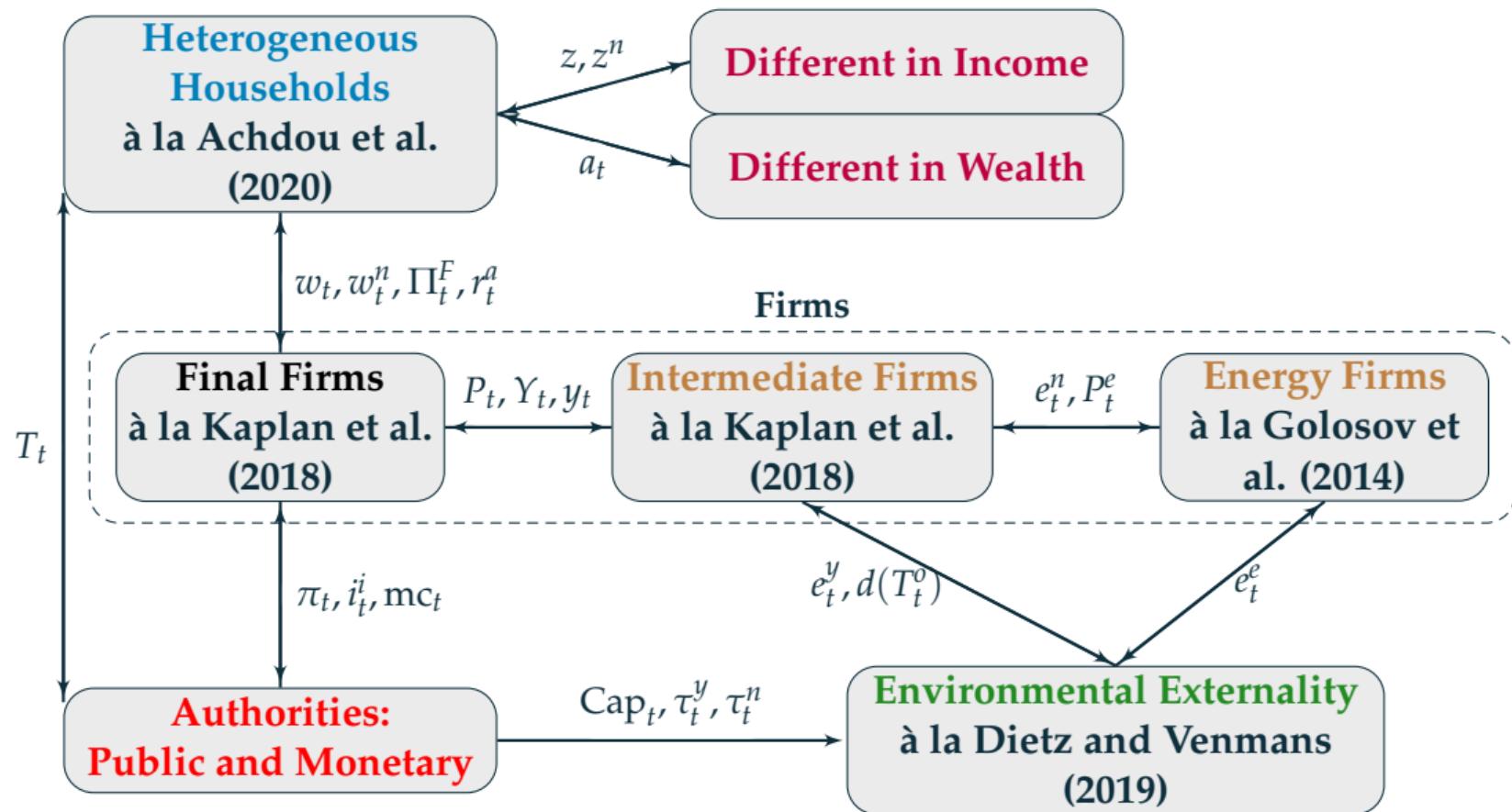
# Climate-HANK

**Heterogeneous  
Households  
à la Achdou et al.  
(2020)**









# 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<sub>2</sub> cumulative emissions  $X_t$  in the atmosphere is the sum of domestic  $E_t$  and international  $E_t^{Row}$  emission flows:

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In our framework, the total emissions flow reads as:

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

$e_{j,t}^y$  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:

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

## 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):

$$e_{j,t}^n = A_t^n k_{j,t}^{n \alpha_n} l_{j,t}^{n 1-\alpha_n} \quad (4)$$

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

$$y_{j,t} = A_t \underbrace{d(T_t^o)}_{\text{Convex Damages}} k_{j,t}^{y \alpha_1} e_{j,t}^{n \alpha_2} l_{j,t}^{y 1-\alpha_1-\alpha_2} \quad (5)$$

# ENERGY AND NON-ENERGY FIRMS: EMISSIONS AND ABATEMENT INVESTMENT

- Both energy and non-energy firms emit CO<sub>2</sub> emissions  $e_{j,t}^e$  and  $e_{j,t}^y$  when they produce goods:

$$e_{j,t}^e = \underbrace{(1 - \mu_{j,t}^n)}_{\text{Abatement efforts}} \varphi_t^n e_{j,t}^n \quad (6)$$

$$e_{j,t}^y = (1 - \mu_{j,t}^y) \underbrace{\varphi_t^y}_{\text{CO}_2 \text{ intensity } \downarrow \text{trend}} y_{j,t} \quad (7)$$

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

$$\underbrace{F(\mu_{j,t}^k)}_{\text{Convex cost function}} = \theta_1 \mu_{j,t}^{k \theta_2} \quad (8)$$

# ENERGY AND NON-ENERGY: PROFIT AND AGGREGATE FIRMS

- The energy producers' profit reads as follows: [» more](#)

$$\Pi_{j,t}^E = \underbrace{p_t^e e_{j,t}^n}_{\text{energy price and output}} - \underbrace{w_t^n l_{j,t}^n}_{\text{labour wages}} - \underbrace{i_{j,t}^n}_{\text{capital investment}} - \underbrace{f(\mu_{j,t}^n) e_{j,t}^n}_{\text{abatement cost}} - \underbrace{\tau_t^n e_{j,t}^n}_{\text{carbon price}} \quad (9)$$

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- The non-energy firms' profit reads as: [» more](#)

$$\Pi_{j,t}^F = \frac{p_{j,t}}{P_t} y_{j,t} - w_t^y l_{j,t}^y - i_{j,t}^y - \underbrace{p_t^e e_{j,t}^n}_{\text{energy cost}} - f(\mu_{j,t}^y) y_{j,t} - \tau_t^y e_{j,t}^y \quad (10)$$

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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:

$$mc_t = \frac{\theta - 1}{\theta} \quad (11)$$

(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:

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

► 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:

$$E_t = \text{Carbon Cap}_t \quad (15)$$

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

$$G_t + T_t = \sum_s \tau_t^s E_t^s \quad (16)$$

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  $i_t^i$ :

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

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:

$$i_t^i = r_t^a + \pi_t \quad (18)$$

# MODEL INTUITION SUMMARY

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

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

Total Marginal Cost      Abatement Investment      Emission Intensity Carbon Price  
 Total Environmental Costs

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

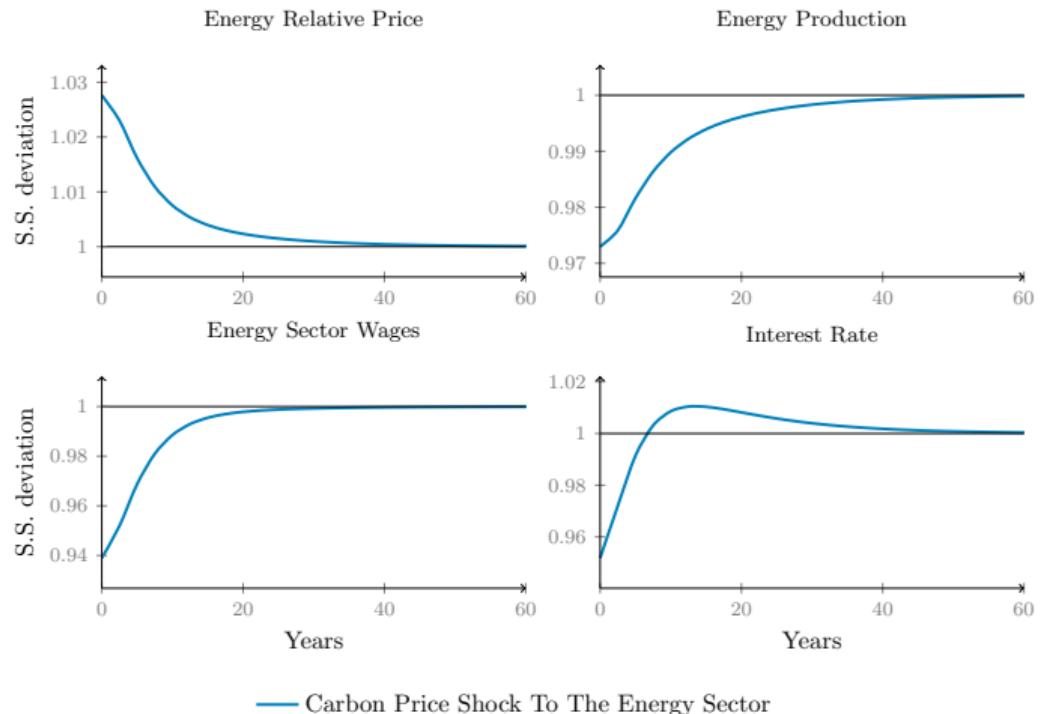
Note: The total marginal cost is constant in the case of flexible prices.

# 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
<b>Macro Aggregates:</b>			
Labor Share	0.567	0.597	FRED (2019)
Capital Share	0.260	0.311	BEA (2020)
<b>Environmental Aggregates:</b>			
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

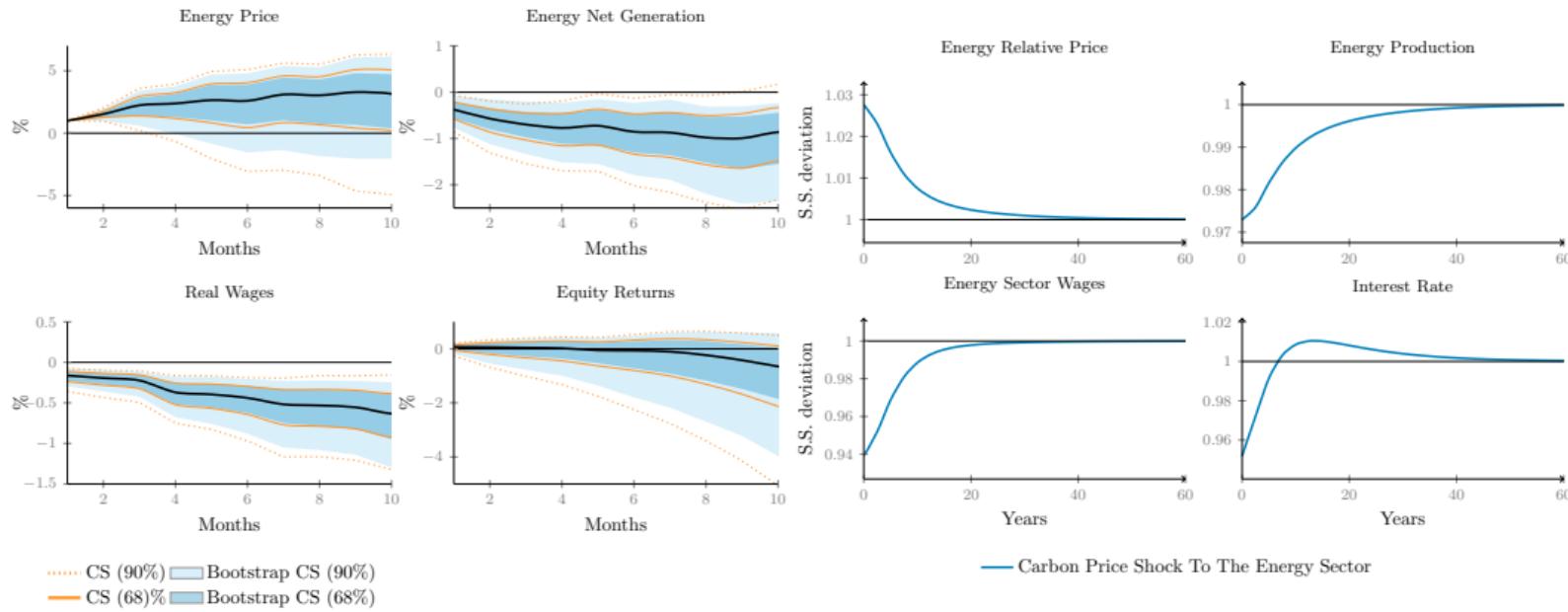
# RESULTS 1A: CARBON PRICE AND MACROECONOMIC DYNAMICS



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 heteroskedasticity-robust F-statistic:  $8.41 < 10$  but  $> 4$

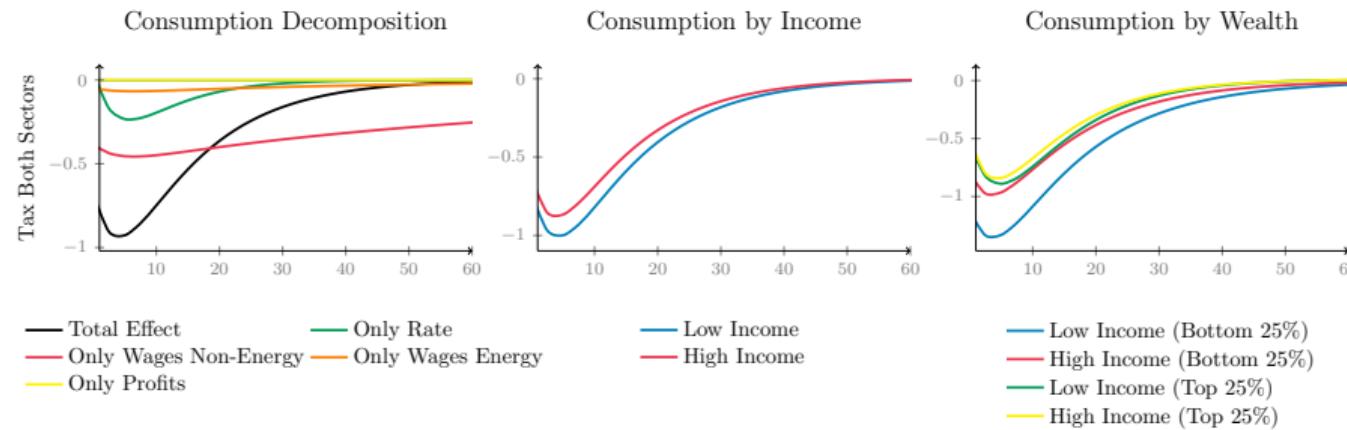


## RESULTS 1B: CARBON PRICE TRANSMISSION MECHANISM

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

$$dC_0 = \int_0^\infty \left( \underbrace{\frac{\partial C_0}{\partial r_t^a} dr_t^a}_{\text{asset returns}} + \underbrace{\frac{\partial C_0}{\partial w_t^n} dw_t^n}_{\text{energy wages}} + \underbrace{\frac{\partial C_0}{\partial w_t^y} dw_t^y}_{\text{non-energy wages}} + \underbrace{\frac{\partial C_0}{\partial \Pi_t^F} d\Pi_t^F}_{\text{profits}} + \underbrace{\frac{\partial C_0}{\partial T_t} dT_t}_{\text{fiscal transfers}} \right) dt \quad (19)$$

# 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

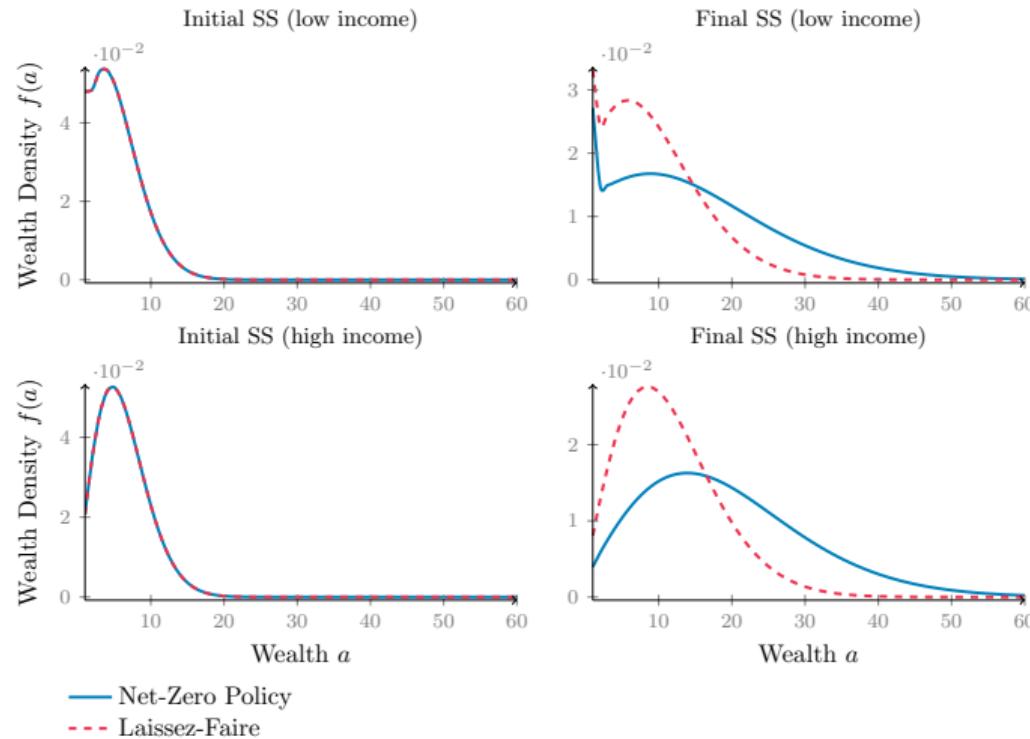
Table: Welfare: Net-zero versus Laissez-faire

		HA-Climate	RA-Climate
Welfare gains (in CE)	Low Abatement Cost	0.84%	1.05%
	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

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

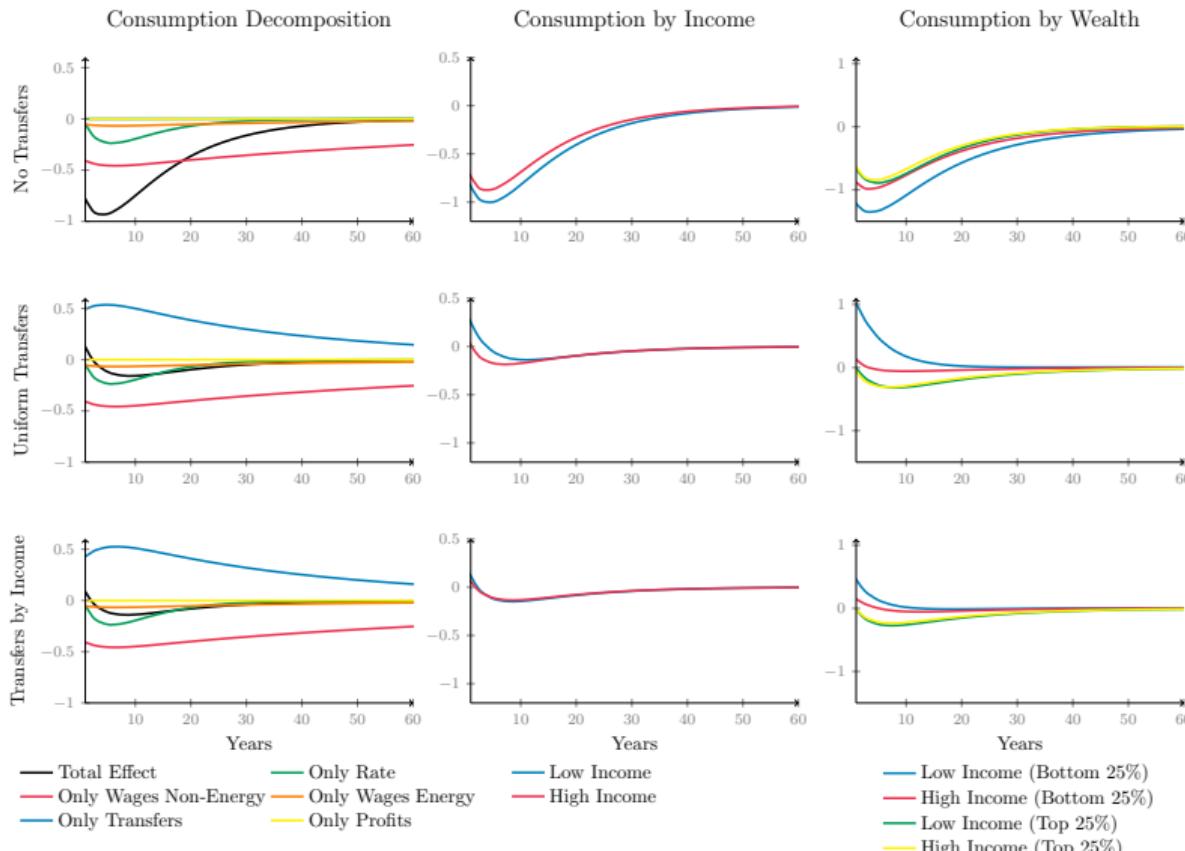
## RESULTS 2A: NET-ZERO LONG-RUN DISTRIBUTIONAL IMPACTS



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  $A_t^g$ :

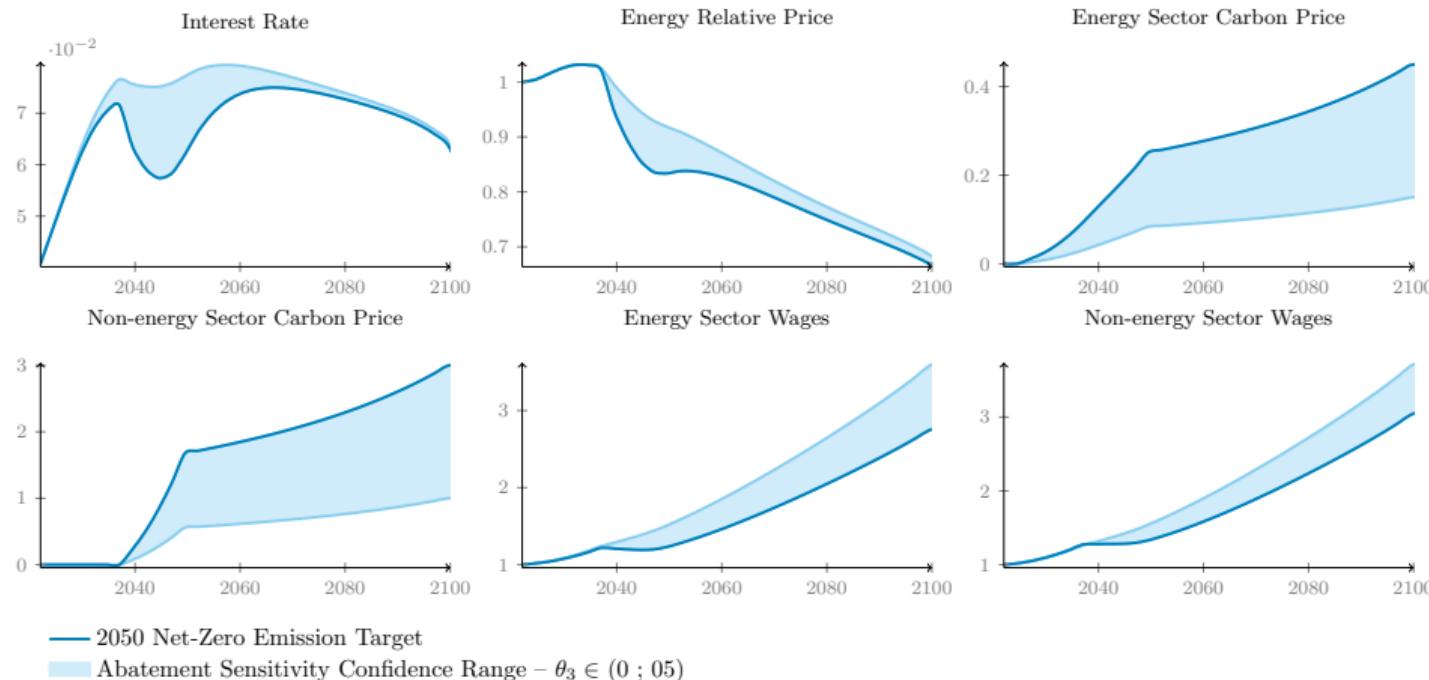
$$f(\mu_t^s) = \left( \int_0^{A_t^g} f(\mu_{j,t}^s)^{\frac{1}{\theta_3}} dj \right)^{\theta_3} \quad (21)$$

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

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

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

## RESULTS 4B: LEARNING BY DOING AND ABATEMENT COST



# 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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1. Carbon policy shock leads to a persistent increase in energy prices, triggering a **persistent decrease in net energy, wages, and returns**
2. Carbon policy shock leads to an **asymmetric consumption reaction** among the top and bottom 50 percent income distribution

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## 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  $\epsilon_t$ :

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

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  $4 \times 1$  vector of observables (energy prices, net energy generation, wages, equity index returns):

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

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:

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

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

## SVAR MODEL

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

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

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

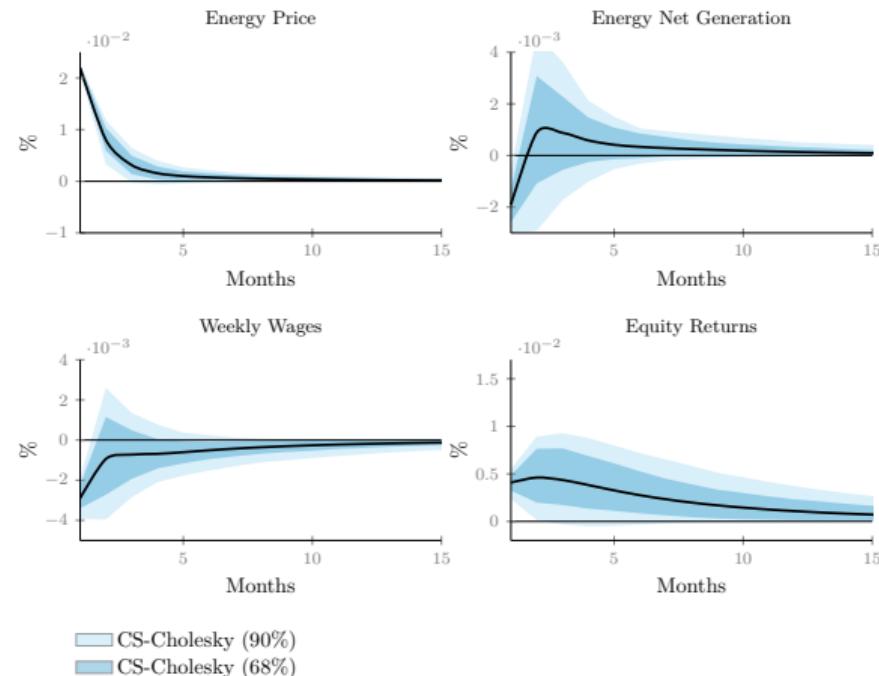
- ▶ The instrument has to be orthogonal to leads and lags of structural shocks (robust to non-invertibility):

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

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

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

# CHOLESKY IRF



## ENERGY FIRMS PROBLEM

- The energy producers maximize their profit subject to:

$$\dot{k}_{j,t}^n = i_{j,t}^n - \delta k_{j,t}^n \quad (31)$$

$$e_{j,t}^n = A_t^n k_{j,t}^{n\alpha_n} l_{j,t}^{n1-\alpha_n} \quad (32)$$

- The first order conditions read as:

$$p_t^e = \varrho_t^e + f(\mu_t^n) + \varphi_t^n \tau_t^n (1 - \mu_t^n) \quad (33)$$

$$r_t^e = \varrho_t^e \alpha_n e_t^n / k_t^n - \delta \quad (34)$$

$$\tau_t^n = f(\mu_{j,t}^n)' / \varphi_t^n \quad (35)$$

$$w_t^n = \varrho_t^e (1 - \alpha_n) e_t^n / l_t^n \quad (36)$$

where  $\varrho_{j,t}^e = \varrho_t^e$  is the input shadow cost.

## NON-ENERGY FIRMS PROBLEM

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

$$\dot{k}_{j,t}^y = i_{j,t}^y - \delta k_{j,t}^y \quad (37)$$

$$y_{j,t} = A_t d(T_t^o) k_{j,t}^{y \alpha_1} e_{j,t}^{n \alpha_2} l_{j,t}^{y 1-\alpha_1-\alpha_2} \quad (38)$$

- The first order conditions read as:

$$p_t^e = \varrho_t^y \alpha_2 y_t / e_t^n \quad (39)$$

$$r_t^y = \varrho_t^y \alpha_1 y_t / k_t^y - \delta \quad (40)$$

$$w_t^y = \varrho_t^y (1 - \alpha_1 - \alpha_2) y_t / l_t^y \quad (41)$$

$$\tau_t^y = f(\mu_t^y)' / \varphi_t^y \quad (42)$$

where  $\varrho_{j,t}^y = \varrho_t^y$  is the input shadow cost.

## FINAL FIRMS: AGGREGATION AND PRICES

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

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

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:

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

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

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

# FIRMS MARGINAL COST AND ENVIRONMENTAL COST

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

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

Total Environmental Costs

(46)

## 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:

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- ▶ i) A Hamilton-Jacobi-Bellman (HJB) equation:

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

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- ▶ ii) A Kolmogorov Forward equation:

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

# CALIBRATION: MACROECONOMIC BLOCK

	Calibrated parameters (annually)	Values
<u>Standard Macro Parameters</u>		
$\alpha^1$	Capital intensity for non-energy firms	0.19
$\alpha^2$	Elasticity of energy to non-energy production	0.15
$\alpha^n$	Capital intensity for energy firms	2/3
$\delta$	Depreciation rate of capital	0.05
$\sigma$	Risk aversion	2
$\rho$	Discount rate	5%
$\theta$	Price elasticity	6
$\bar{L}$	Labor supply	1/3
<u>NK Parameters</u>		
$\theta^P$	Rotemberg quadratic cost parameter	100
$\phi^\pi$	Inflation stance	1.25
$\phi_Y$	Output gap reaction parameter	0.1

# CALIBRATION: ENVIRONMENTAL BLOCK

	Calibrated parameters (annually)	Values
<u>Environmental Parameters</u>		
$\bar{e}^n / \bar{e}^e = \varphi^n$	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
$\theta_1$	Abatement cost parameter	0.1
$\theta_2$	Abatement cost parameter	2.7
$\theta_3$	Abatement learning elasticity	$\in (0,1)$
$\phi_1^o$	Temperature parameter	0.5
$\phi_2^o$	Temperature parameter	0.00125
$a$	Damage function parameter	1.004
$b$	Damage function parameter	0.02

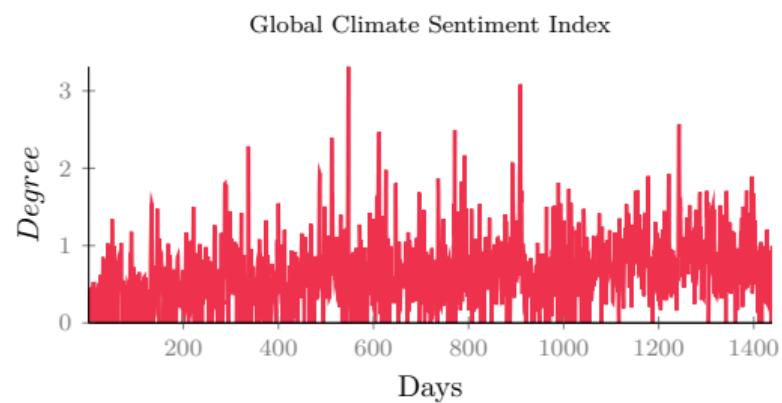
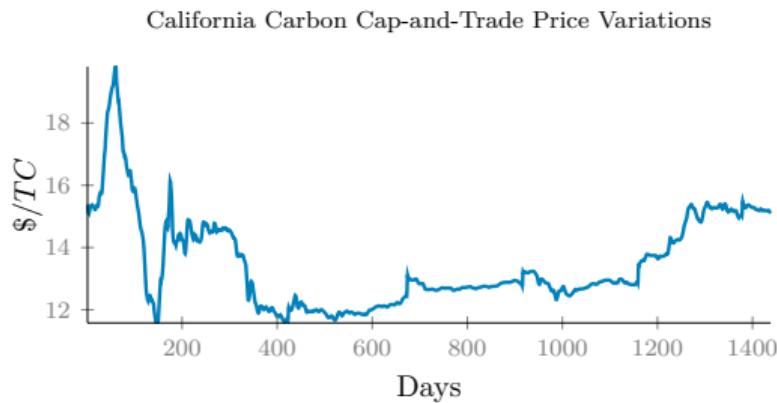
# CALIFORNIA CARBON MARKET AT A GLANCE

- ▶ 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  $\tau_t^C$  reads as changes in California futures market price in a tight window around climate news events:

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

For the AR(1) specification please see [here](#)

# DISTRIBUTIONAL IMPACTS

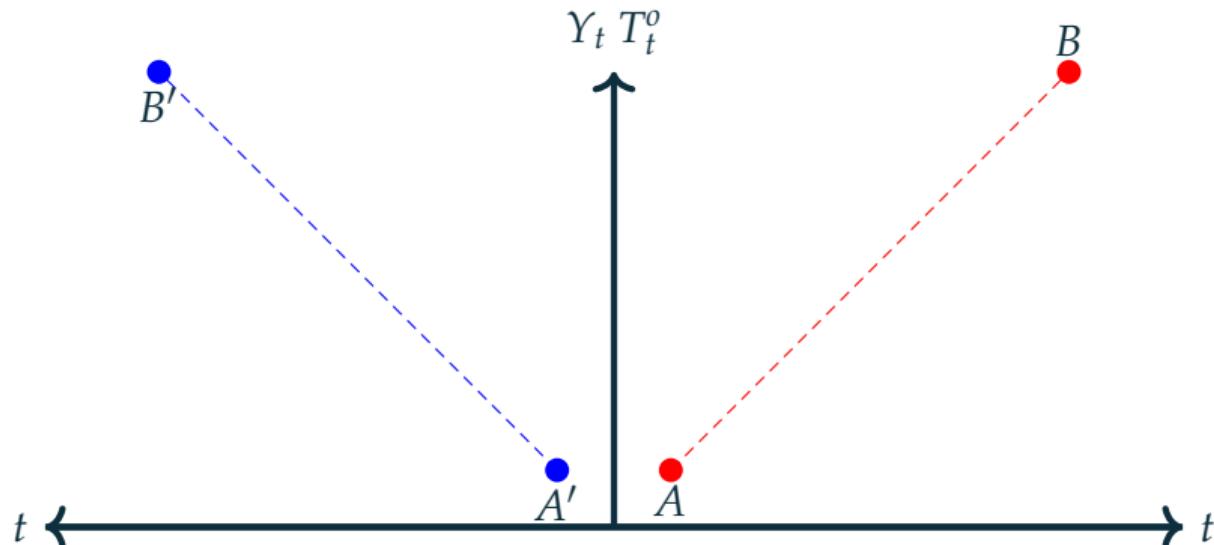
◀ BACK

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

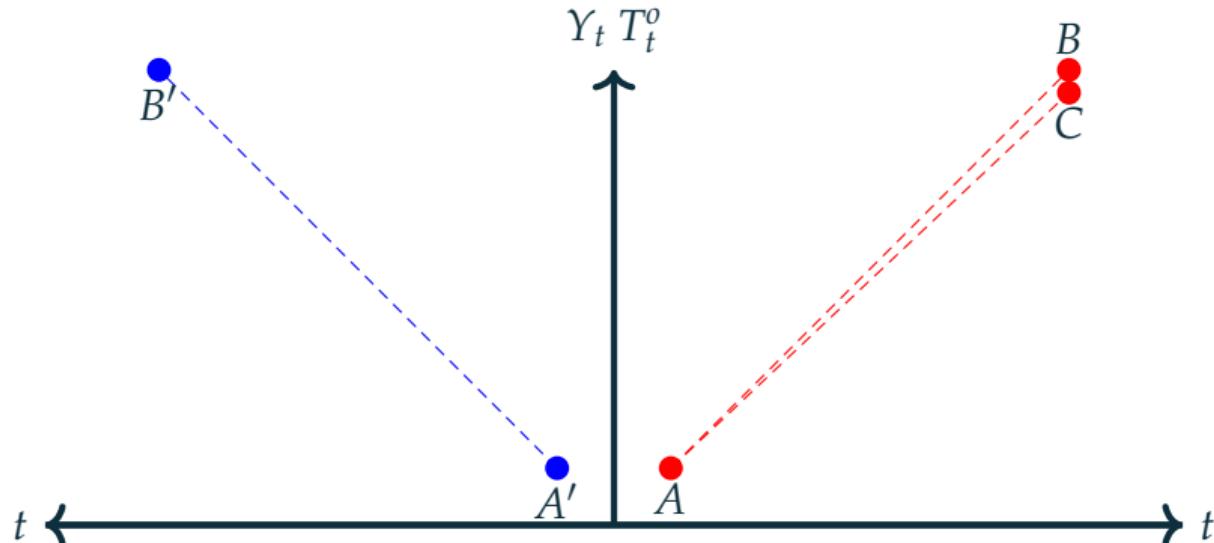
## SOLUTION METHOD: WITH CLIMATE FEEDBACK (LONG-RUN)

- 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



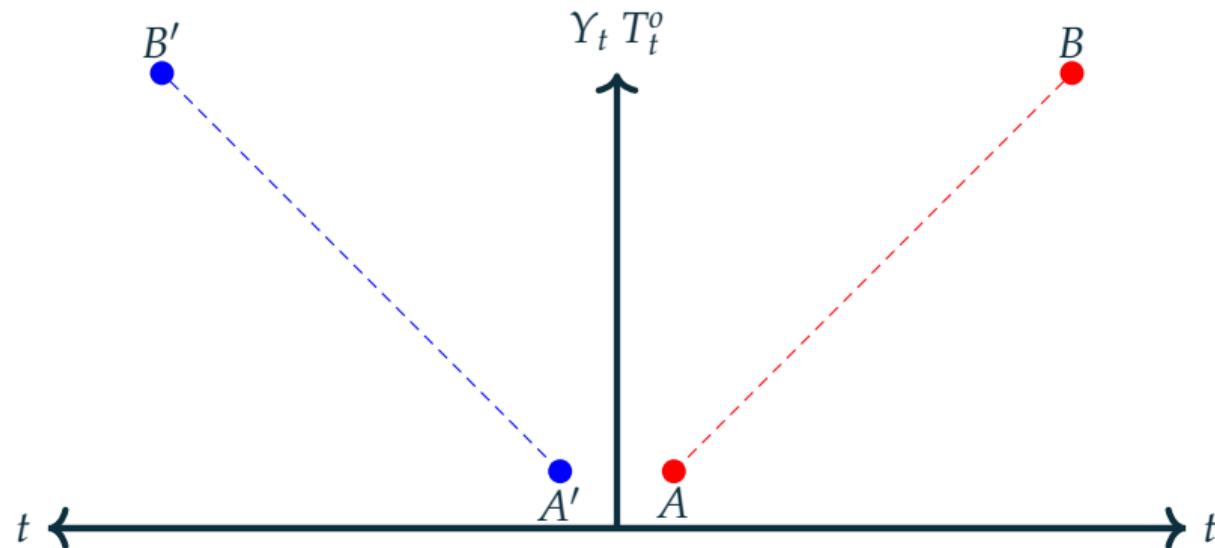
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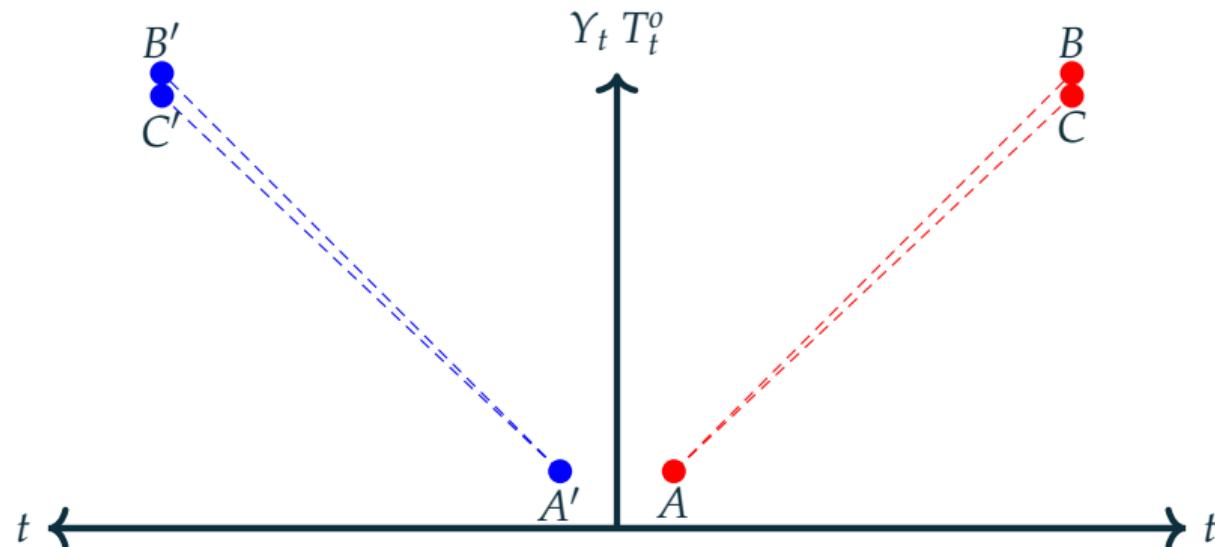
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- ▶ Contrary to the non-climate feedback case, **climate dynamics** in our model imply adjustments to the standard method for finding the transition pathways



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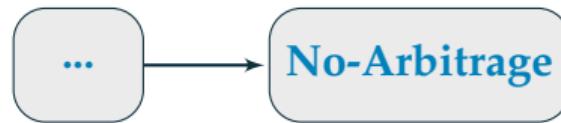


## SOLUTION METHOD: WITH CLIMATE FEEDBACK (LONG-RUN)

- ▶ **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



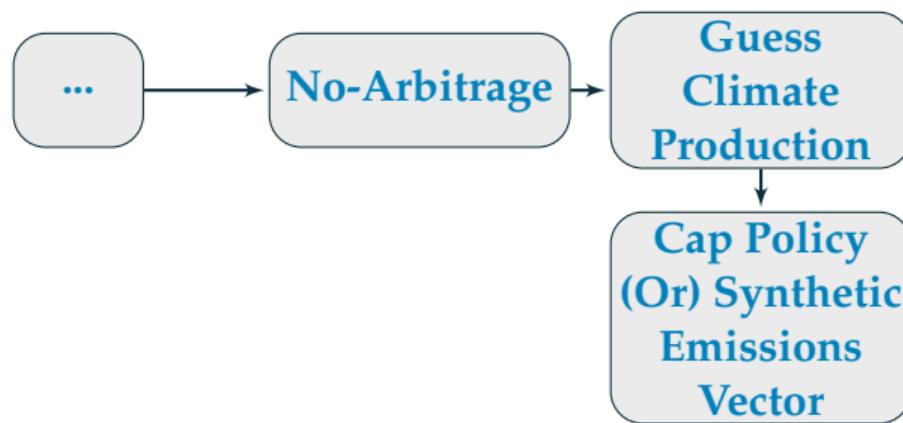
# SOLUTION METHOD: WITH CLIMATE FEEDBACK (LONG-RUN)

◀ BACK



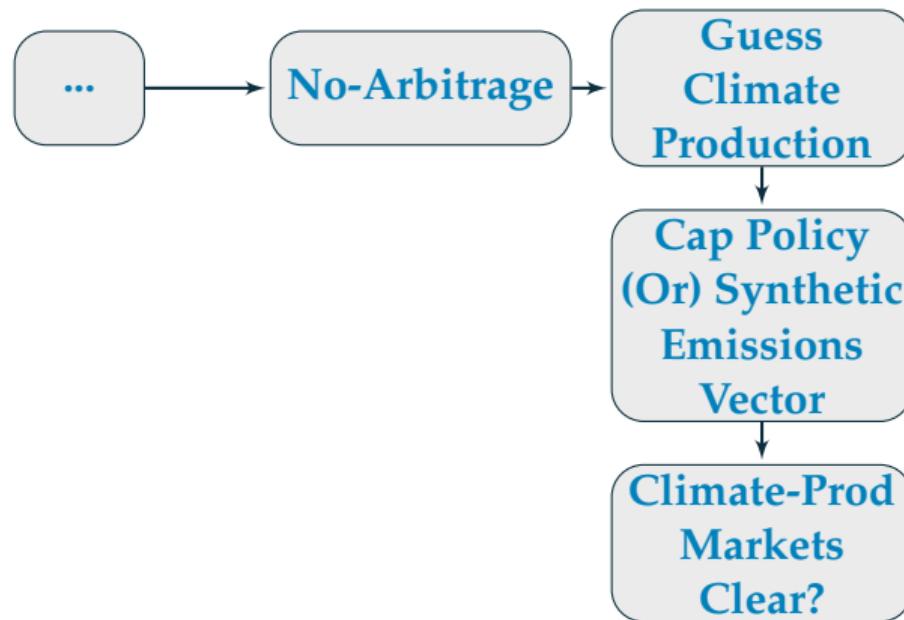
# SOLUTION METHOD: WITH CLIMATE FEEDBACK (LONG-RUN)

◀ BACK

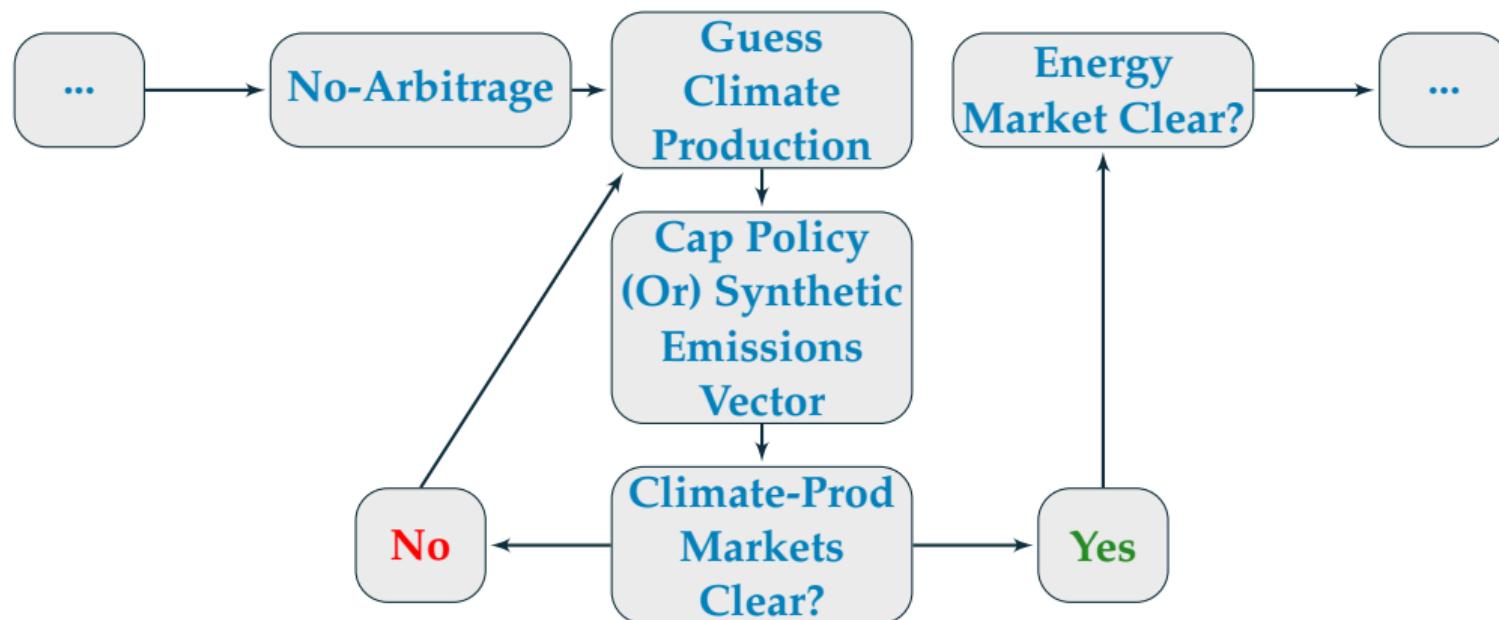


# SOLUTION METHOD: WITH CLIMATE FEEDBACK (LONG-RUN)

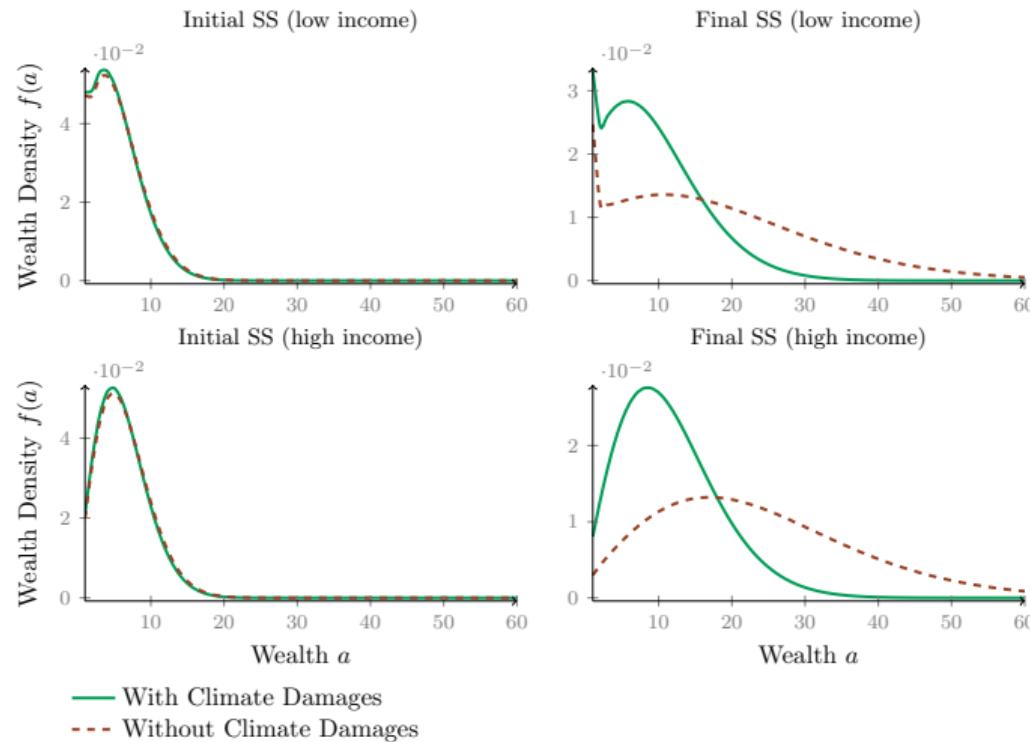
◀ BACK



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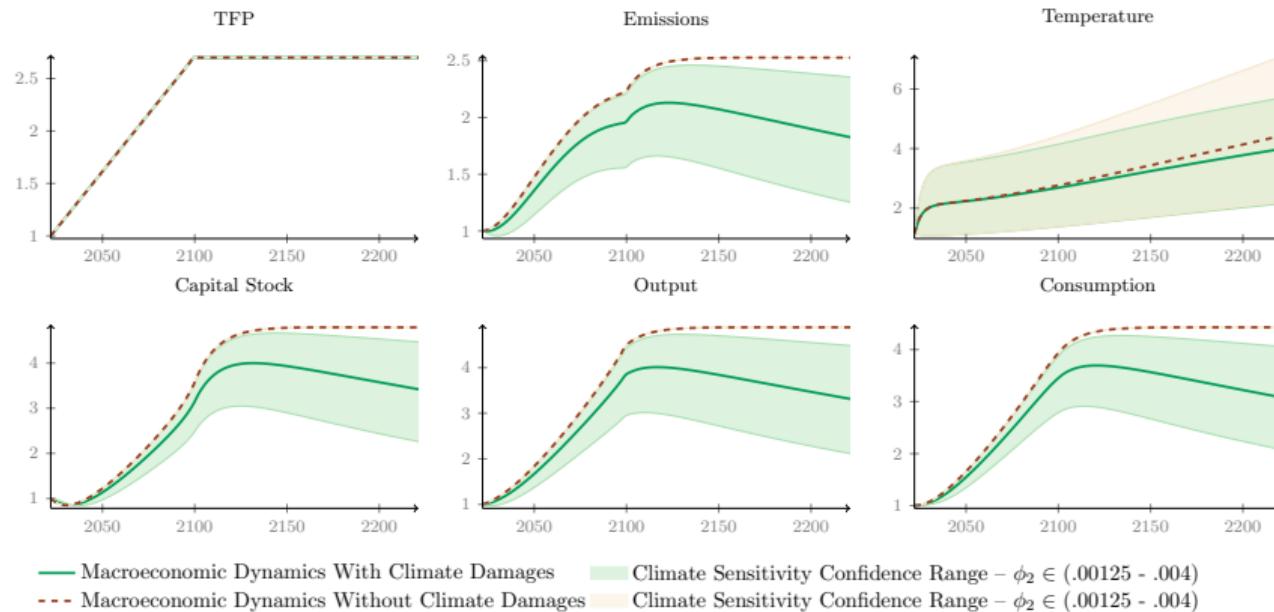
[▶ BACK](#)

## RESULTS 2A: CLIMATE IMPLICATIONS FOR WEALTH DISTRIBUTION



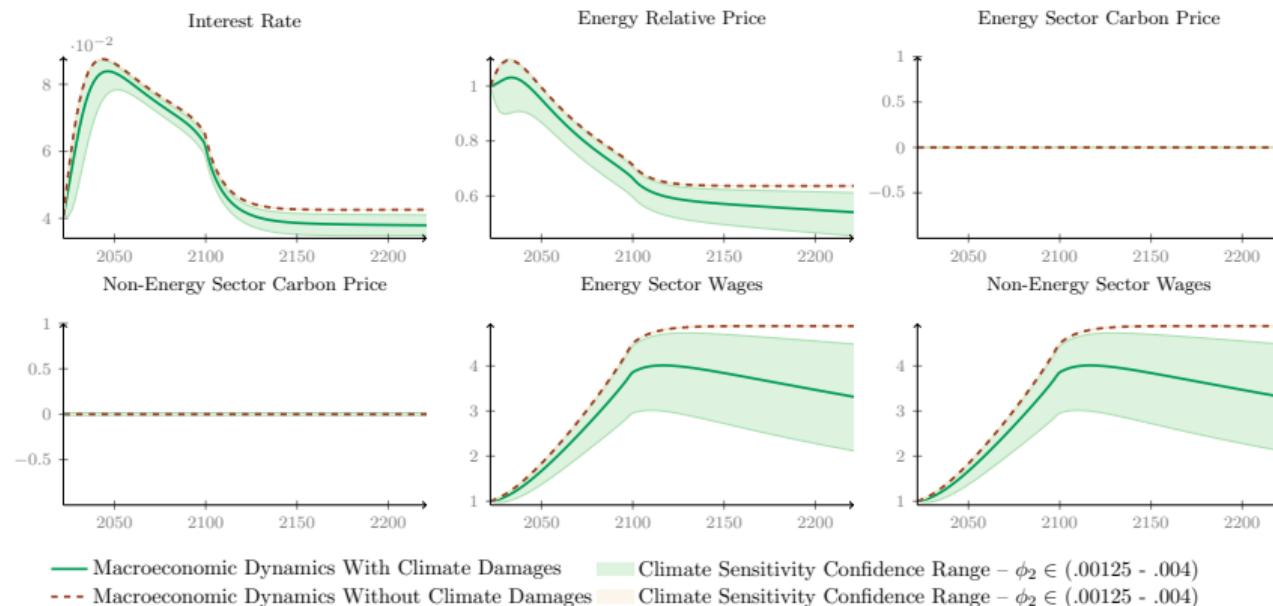
For long-run transitions please see [here](#)

# RESULTS 2A: CLIMATE DAMAGES, CLIMATE UNCERTAINTY, AND LAISSEZ-FAIRE TRANSITION PATHWAYS—MACRO AGGREGATES



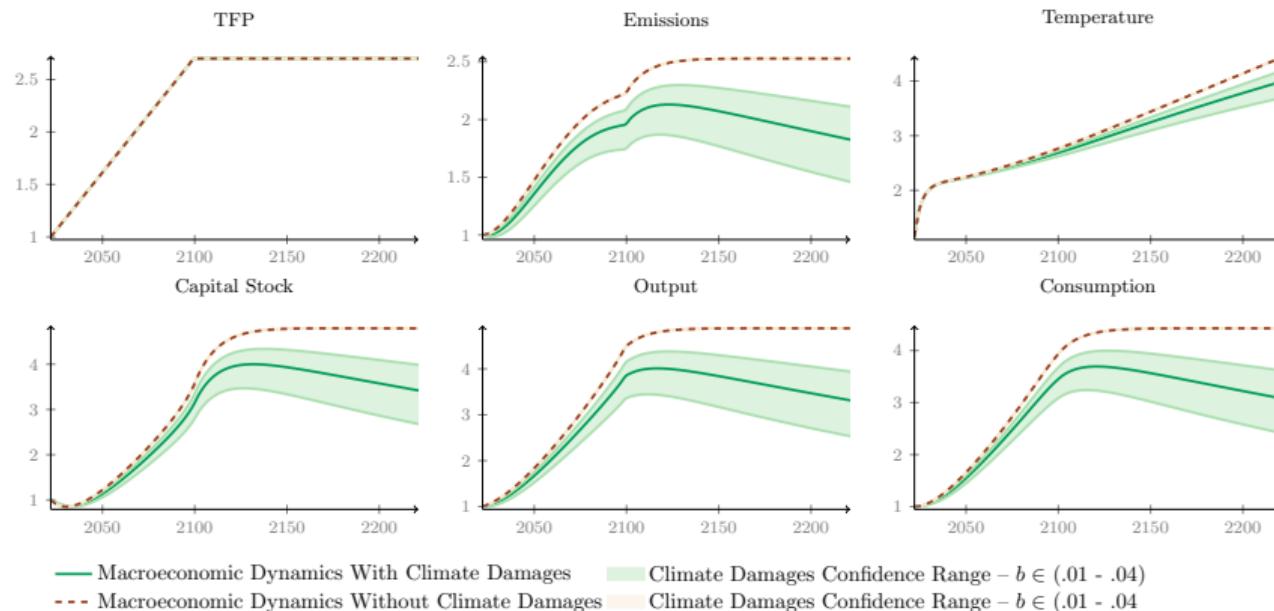
Note: Brown and green confidence ranges represent confidence range for values of  $\phi_2$  in line with IPCC scenarios. For damages uncertainty please see [here](#) [back](#)

# RESULTS 2A: CLIMATE DAMAGES, CLIMATE UNCERTAINTY, AND LAISSEZ-FAIRE TRANSITION PATHWAYS—PRICE AGGREGATES



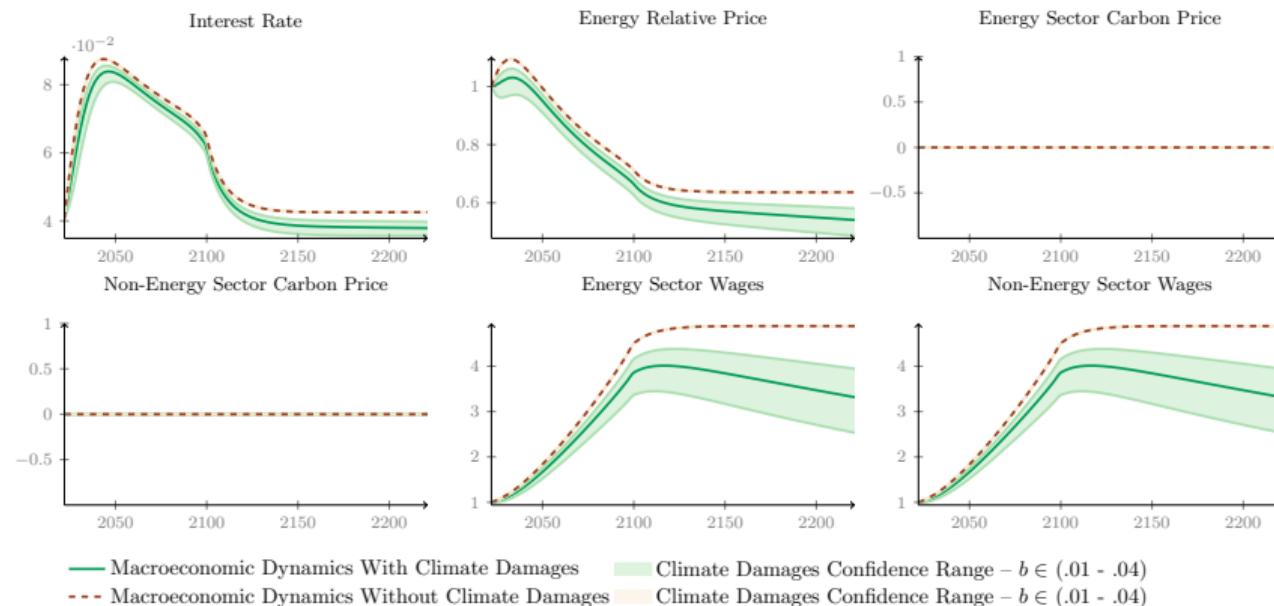
Note: Brown and green confidence ranges represent confidence range for values of  $\phi_2$  in line with IPCC scenarios. For damages uncertainty please see [here](#) [back](#)

# RESULTS 2A(BIS): CLIMATE DYNAMICS, DAMAGES UNCERTAINTY, AND LAISSEZ-FAIRE TRANSITION PATHWAYS—MACRO AGGREGATES



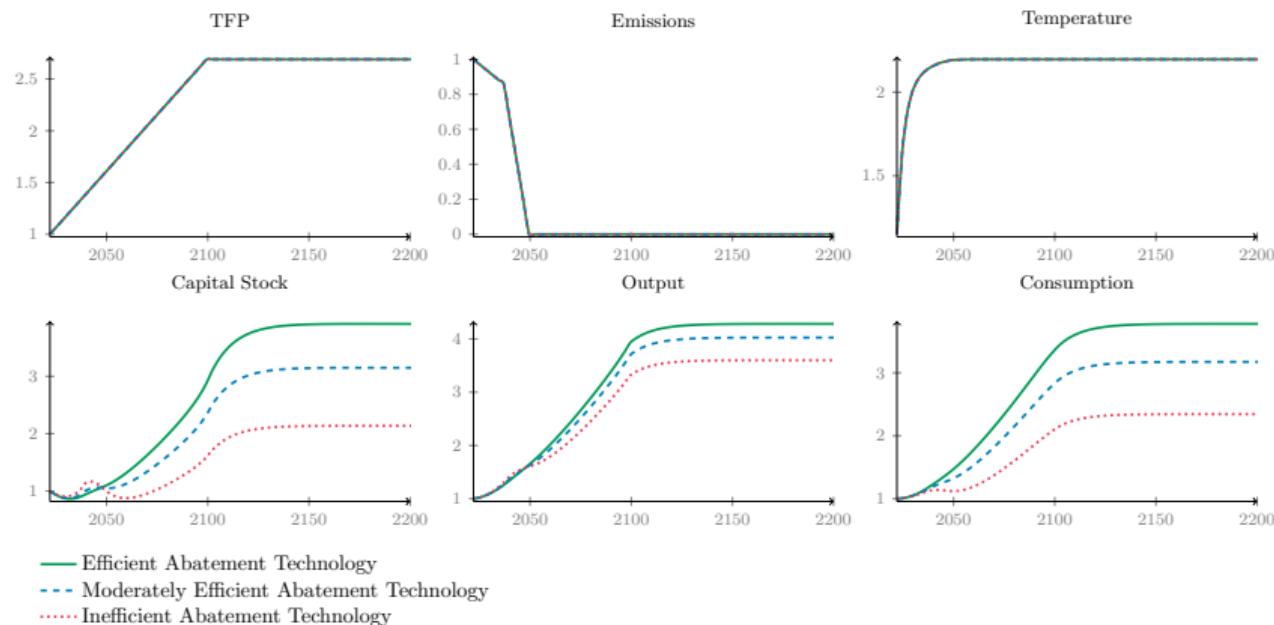
Note: Brown and green confidence ranges represent confidence ranges for values of the climate damages parameter. [» back](#)

# RESULTS 2A(BIS): CLIMATE DYNAMICS, DAMAGES UNCERTAINTY, AND LAISSEZ-FAIRE TRANSITION PATHWAYS—PRICE AGGREGATES



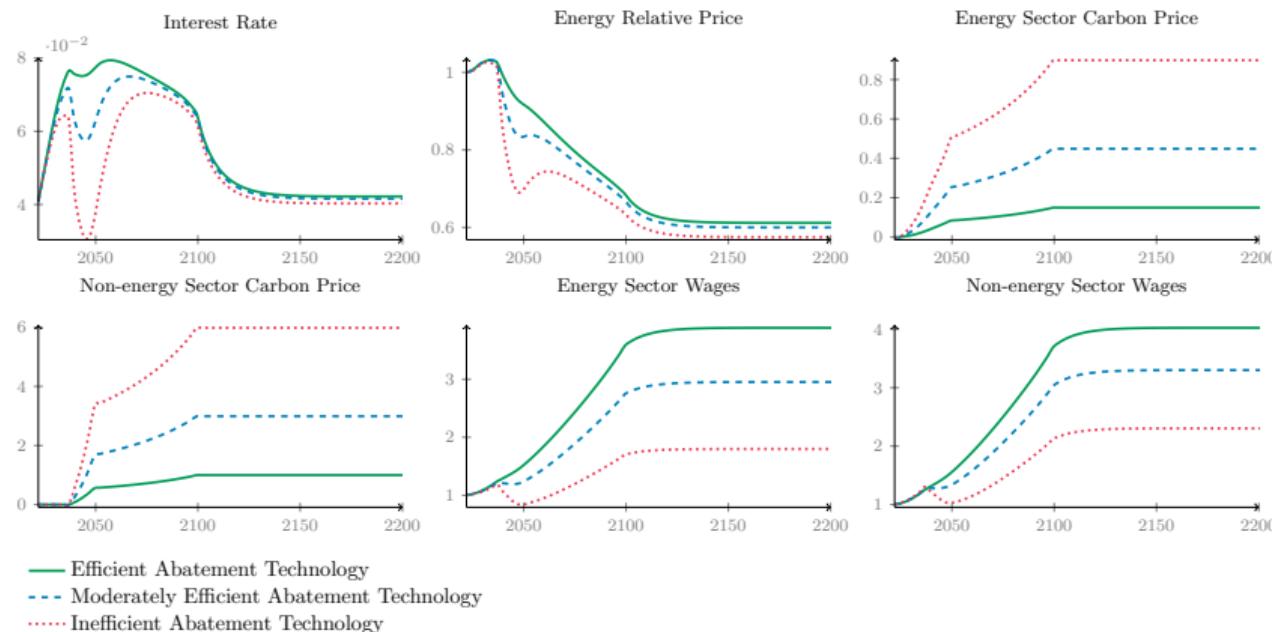
Note: Brown and green confidence ranges represent confidence ranges for values of the climate damages parameter. [» back](#)

## RESULTS 2B: MEETING NET-ZERO-MACRO AGGREGATES



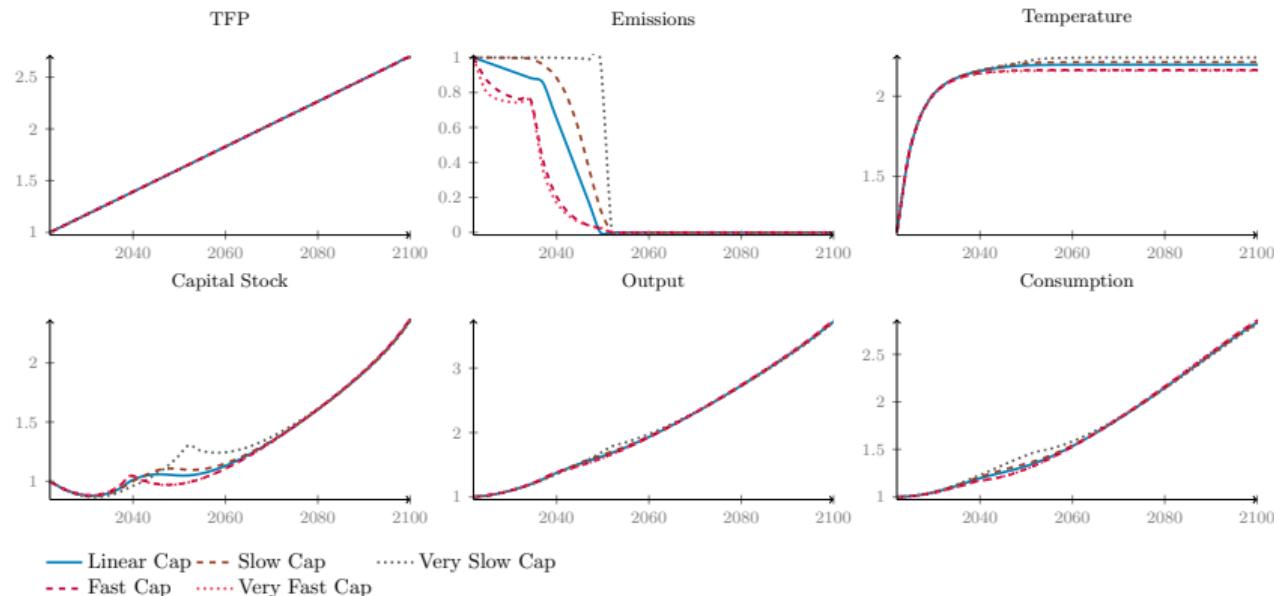
Note: This figure compares the net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 to 2100. For trajectory uncertainty please see [here](#) [back](#)

## RESULTS 2B: MEETING NET-ZERO-PRICES AGGREGATES



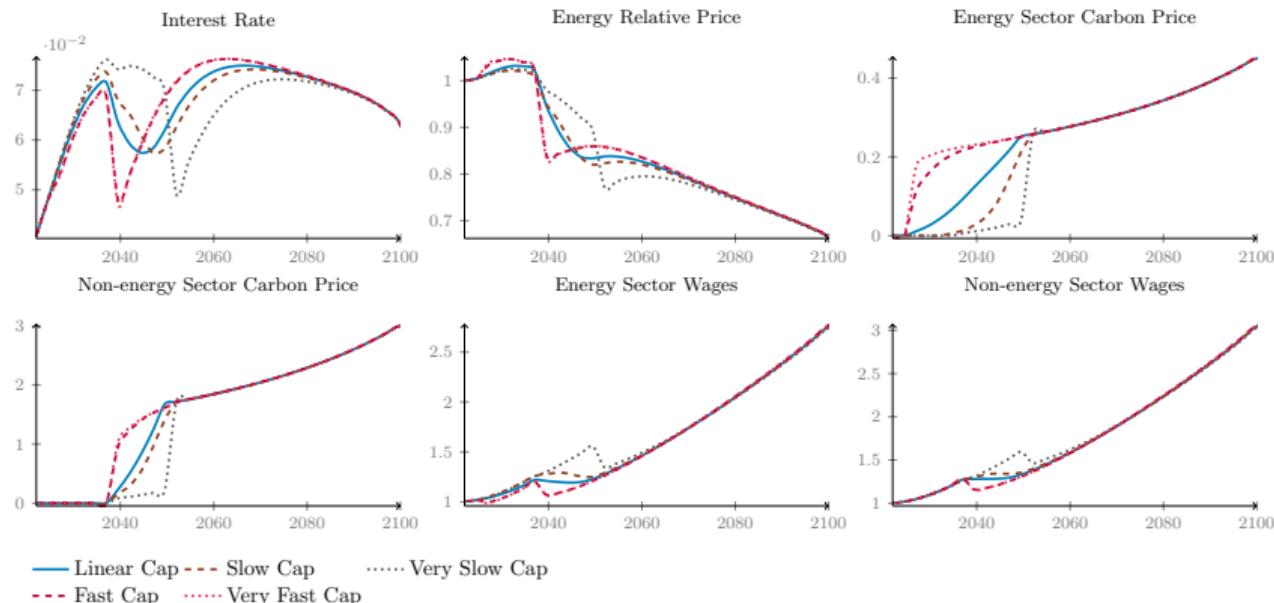
Note: This figure compares the net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 to 2100. For trajectory uncertainty please see [► here](#) [► back](#)

## RESULTS 2B(BIS): MEETING NET-ZERO FOLLOWING DIFFERENT TRAJECTORIES—MACRO AGGREGATES



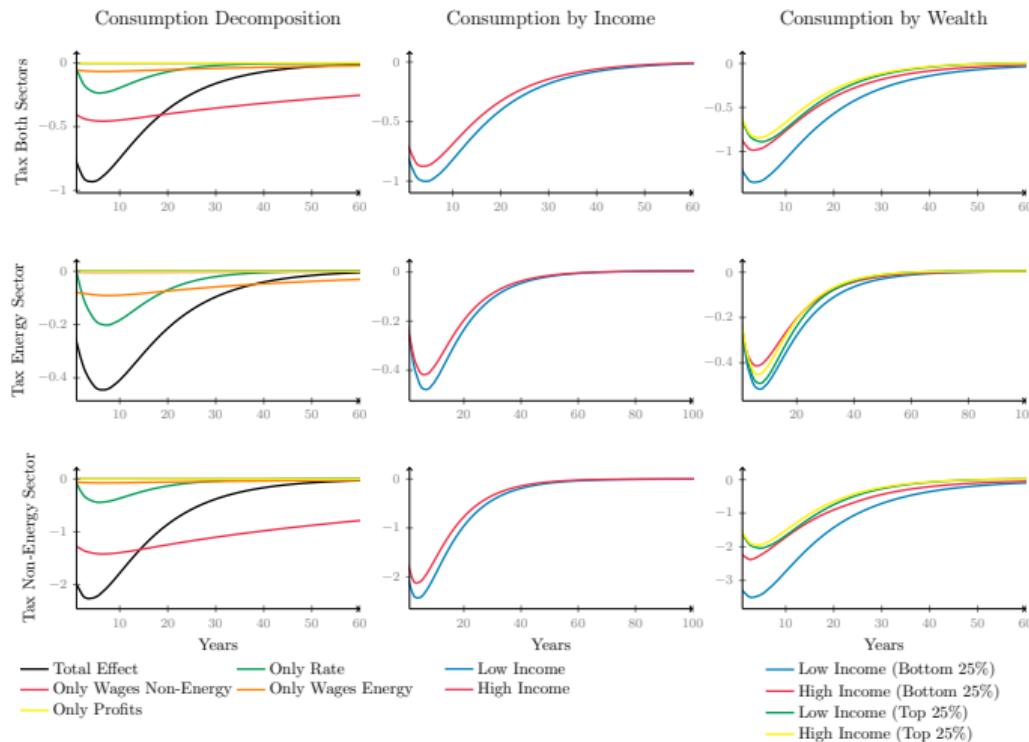
Note: This figure compares the net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 to 2100. [» back](#)

## 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](#)

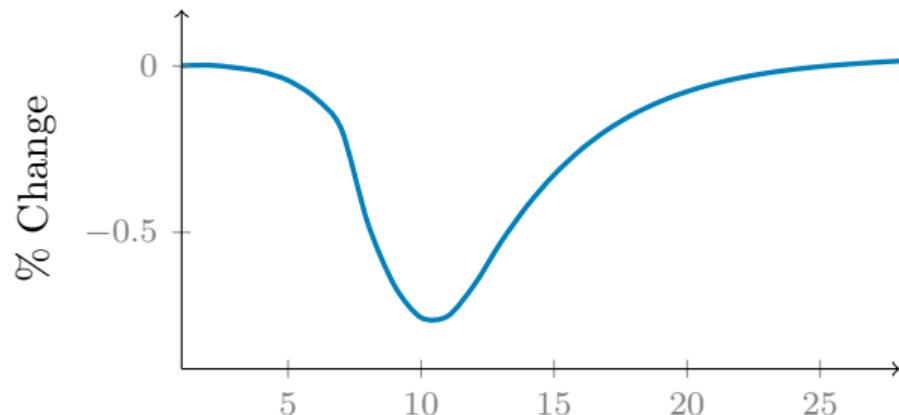
# RESULTS 1B: CARBON PRICE TRANSMISSION MECHANISM



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

## RESULTS 2B(BIS): TOTAL INCOME GINI

Total Income Gini

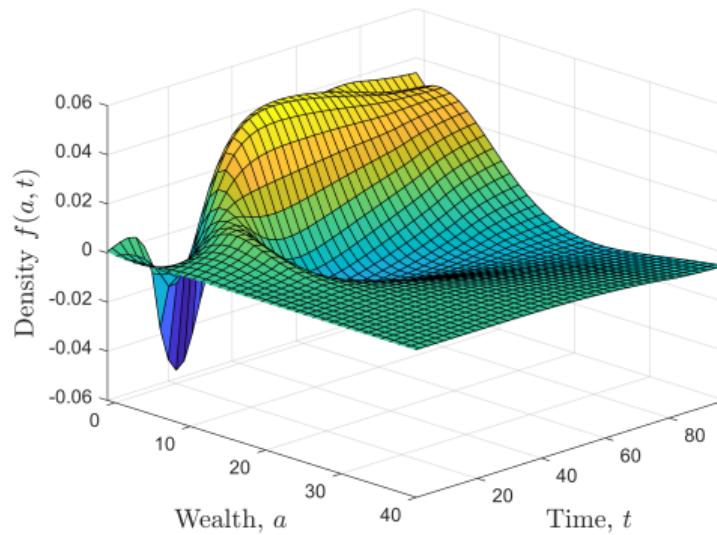


— Gini Coefficient—Net-Zero versus Laissez-faire

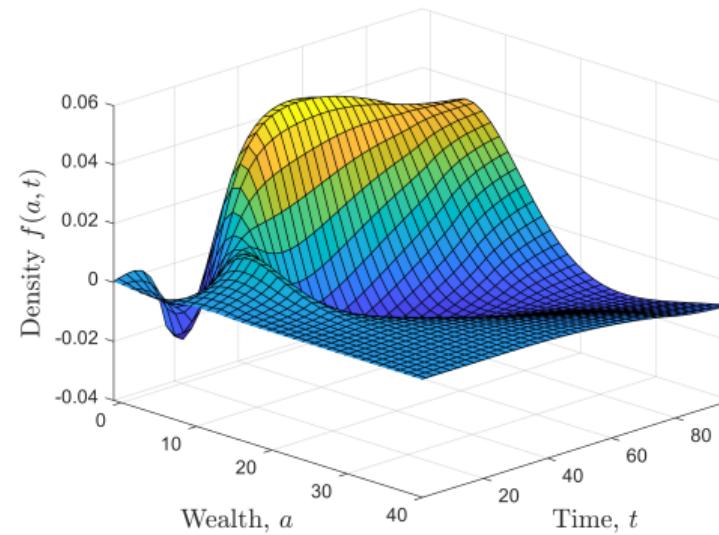
Note: This figure compares the 2050 net-zero scenario to a laissez-faire scenario under a 2 percent growth rate over the period 2022 to 2100.

► back

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

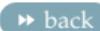


Low Income Households



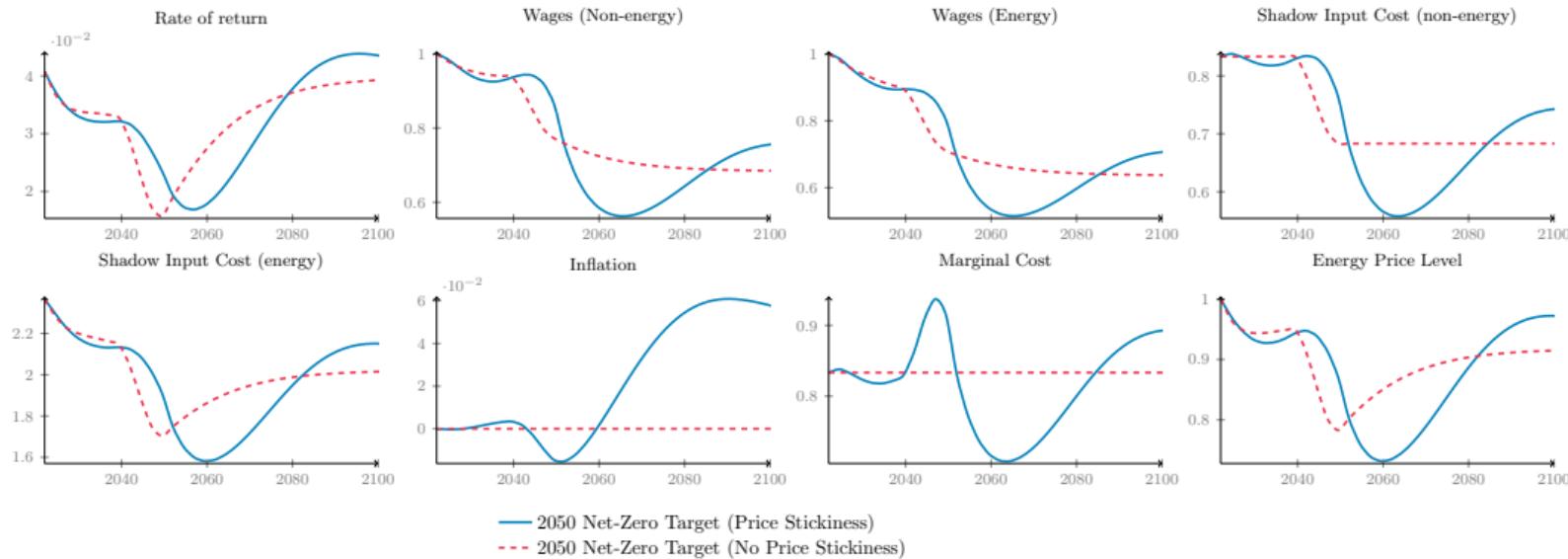
High Income Households

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



# RESULTS 4A: THE ROLE OF INFLATION AND ABATEMENT COST

## 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](#)