A Crash Course on Climate Economics:

from structural transitions to immediate stabilization

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Introduction

It's a crash and thus imperfect course on climate economics based on Nordhaus (1992) and Sahuc et al. (2025).

Schedule:

1. A Long Run View on Climate: The DICE Model (20 min)
2. A Short Term View: the New Keynesian Climate Model (20 min)
3. Simulating both short and long term dynamics of simple climate macroeconomic models (20min)

All materials and code are available at:
https://github.com/Vermandel/Climate-Economics-Dynare

Why macroeconomists should care

- Climate change reshapes macroeconomic dynamics: productivity, inflation, employment.
- Monetary and fiscal policies are impacted through:
  - *Climateflation:* Damages reduce productivity, raise prices.
  - *Greenflation:* Carbon taxes raise costs during the transition.
- Macroeconomic tools must adapt: from stable-steady-state thinking to structural transitions.
- Need for integrated models that capture both physical and nominal frictions.

What is an Integrated Assessment Model (IAM)?

- IAMs link **economic activity** and **climate dynamics** to assess the costs and benefits of climate policies.
- The **IPCC** relies on a large pool of IAMs to produce long-term climate scenarios.
- These models are **highly heterogeneous**: many do not include optimization, forward-looking behavior, microfoundations, or expectations.
- The traditional benchmark is **DICE** (Nordhaus, 1992):
  - Embeds climate science into a **Ramsey-type growth model**.
  - Delivers optimal carbon pricing paths based on welfare maximization.

Why Climate Economics Needs a Short-Term View

- Policy institutions - central banks, treasuries, regulators - increasingly face the need to assess:
  - **Climate shocks** (e.g. disasters, weather volatility),
  - **Transition dynamics** (e.g. carbon tax, green investment),
  - **Stability risks** (price, financial, macroeconomic).
- This calls for models that are not only long-term and normative, but also **short-term and dynamic**.
- Yet, our standard macro tools are not designed for this:
  - DSGE models often focus on stationary dynamics near a steady state,
  - IAMs neglect shocks, expectations, and nominal frictions.
- This creates a **methodological gap** when addressing climate change as both a long-term trend and a short-term source of instability.

Outline

1. Introduction
2. A Long Term View: The DICE Model
3. A short term view: the New Keynesian Climate Model

Plan

Introduction

- DICE (Dynamic Integrated Climate-Economy model) was developed by Nordhaus (1992) and went through several (minor) updates up to the lastest 2023 snapshot;
- Simple but powerful model to provide fast estimates of the social cost of carbon and transition pathways for the world economy;
- It has become an intuitive benchmark.
- Back in the 90s, Bill Nordhaus's work on climate has never been plublished in top 5 journals (always rejected) but got published in Sciences, PNAS, etc.

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- The framework is old-fashion:
  - Solow growth model with climate externality;
  - Centralized equilibrium based on Ramsey allocations;
  - Purely deterministic setup;
- Physical capital, temperatures and carbon boxes are the main state variables that the planner uses to optimally maximize welfare.
- These slides are based on 2016 snapshot.

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Carbon cycle

- Atmospheric loading of CO_2 is a system of differential equations:

$$M_t = \Phi_M M_{t-1} + \Xi_M E_t, \tag{1}$$

where $M_t = [M_t^{AT}, M_t^{UP}, M_t^{LO}]'$ comprises 3 layers of carbon: atmospheric, upper and lower ocean respectively.

- Matrices are determined by:

$$\Phi_M = \begin{bmatrix} 1-\phi_{12} & \phi_{21} & 0 \\ \phi_{12} & 1-\phi_{21}-\phi_{23} & \phi_{32} \\ 0 & \phi_{23} & 1-\phi_{32} \end{bmatrix} \text{ and } \Xi_M = \begin{bmatrix} \xi_M \\ 0 \\ 0 \end{bmatrix}$$

- Carbon emissions go into the atmosphere, before being captured by oceans through a long lasting process.

Temperatures

- Temperature anomalies $T_t = [T_t^{AT}, T_t^{OC}]$ of atmosphere and ocean respectively:
$$T_t = \Phi_T T_{t-1} + \Xi_T F_t, \tag{2}$$

- Matrices are given by:
$$\Phi_T = \begin{bmatrix} \varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22} \end{bmatrix} \text{ and } \Xi_T = \begin{bmatrix} \xi_T \\ 0 \end{bmatrix}$$

- Cooling effects of oceans through φ_{12}, ξ_T is the heating sensitivity to radiative forcing F_t.

Radiative forcing

- Greenhouse effect via radiative forcing (W/m^2):

$$F_t = \eta \ \log\left(M_t^{AT}/M_{1750}\right)/\log(2) + F_t^{EX} \tag{3}$$

- Here, η denote the forcing (Wm-2) of equilibrium CO2 doubling ($M_t^{AT} = 2M_{1750}$).

- F_t^{EX} is an exogenous process tracking the contribution of other sources of GHG (i.e. methane) on F_t

Input structure

- World population (billion):

$$L_t = L_{t-1} \left(L_T / L_{t-1} \right)^{\ell_g} , \tag{4}$$

$\ell_g \in [0,1]$ convergence rate, $L_T \in [0,+\infty)$ long term population.

- Law of motion of capital:

$$K_t = (1 - \delta_K) K_{t-1} + I_t, \tag{5}$$

$\delta_K \in [0,1]$ is the depreciation rate.

Production of goods and emissions

- Production is Cobb-Douglas:

$$Y_t = A_t K_{t-1}^{\gamma} L_t^{1-\gamma} \tag{6}$$

where $\gamma \in [0, 1]$ is capital intensity, exogenous TFP A_t, physical capital K_{t-1}.

- Emissions (GtCO2):

$$E_t = \sigma_t \left(1 - \mu_t\right) Y_t + E_t^{\text{land}} \tag{7}$$

where σ_t decoupling rate, μ_t is abatement share, E_t^{land} is exogenous process of carbon emission from change in land use (i.e. deforestation).

Equilibrium in goods and climate

- Resource constraint:

$$Y_t \left(1 - \theta_{1,t}\mu_t^{\theta_2}\right) \Omega\left(T_t\right) = C_t + I_t \tag{8}$$

LHS is output loss from abatement and damage, RHS is demand side.

- Damages are given by:

$$\Omega\left(T_t\right) = 1/(1 + aT_t^2) \tag{9}$$

This expression is subject to deep uncertainty, and should be taken as a normative measure of the social loss for the society of rising temperatures. Tipping points could be introduced [Weitzman, 2012].

Exogenous trends

Total factor productivity:

$$\Delta \log A_t = g_A - \delta_a \log \left(A_t / A_0 \right)$$

Decoupling rate of carbon emission to GDP:

$$\Delta \log \sigma_t = g_\sigma - \delta_\sigma \log \left(\sigma_t / \sigma_0 \right)$$

Cost of abating carbon emissions:

$$\theta_{1,t} = \left(1 - \delta_\theta \right) \theta_{1,t-1} \sigma_t / \sigma_{t-1}$$

Non-CO2 forcing law of motion:

$$F_t^{EX} = \min \left(F_{t-1}^{EX} + \Delta_F, F_{CAP} \right)$$

Land-use law of motion:

$$E_t^{\text{land}} = \left(1 - \delta_e \right) E_{t-1}^{\text{land}}$$

World population dynamic:

$$L_t = L_{t-1} \left(L_T / L_{t-1} \right)^{\ell_g}$$

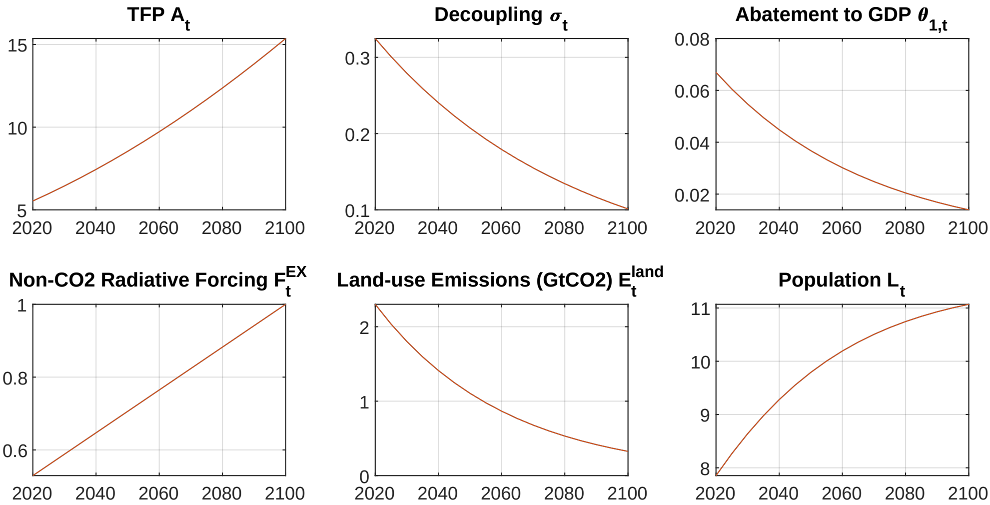

Figure. Exogenous variables

Introducing a saving rate

- How should we determine optimally C and I?

- Could use decentralized decision problem, or use old-fashion centralized equation following Ramsey allocation;

- Introduce optimal saving rate S, consumption and investment becomes:

$$C_t = (1 - S_t) \times Y_t \left(1 - \theta_{1,t}\mu_t^{\theta_2}\right) \Omega\left(T_t\right) \tag{10}$$

$$I_t = S_t \times Y_t \left(1 - \theta_{1,t}\mu_t^{\theta_2}\right) \Omega\left(T_t\right) \tag{11}$$

$\rightarrow$implicitely assuming that income spent between C_t and I_t.

- Economists typically assume that economic decisions are taken 'optimally' by solving an optimal control problem: e.g. maximizing welfare under budget constraint. Here optimal determination of S.

Introducing a saving rate

- The planner maximizes the social welfare:

$$\max_{\{S_t,\mu_t\}} \sum_{t=0}^{\infty} \beta^t L_t \left(c_t^{1-\alpha} - 1\right)(1-\alpha)^{-1} \tag{12}$$

where $c_t = C_t / L_t$ is the per capita consumption, utility function concave.

- How to solve the problem?

1. **Numerical solver:** use solver to find sequences $\{S_t, \mu_t\}_{t=0}^{T}$ that maximizes objective (12).
2. **Ramsey solution:** maximize social welfare 12 based on N equations and $N + I$ control variables (I corresponding to the number of instruments).
3. **Dynamic programming:** use Bellman equation and value function iterations or projections.

The Ramsey (1927) problem:

$$
\begin{aligned}
& \max_{\{c_t, Y_t, K_t, T_t, M_t, \mu_t, S_t\}} \textstyle\sum_{t=0}^{\infty} \beta^t L_t \left(c_t^{1-\alpha} - 1\right) (1-\alpha)^{-1} \\
& + \beta^t \lambda_{1,t} \left[(1 - S_t)\, Y_t \left(1 - \theta_{1,t} \mu_t^{\theta_2}\right) \Omega\left(T_t\right) - L_t c_t \right] \\
& + \beta^t \lambda_{2,t} \left[K_t - (1 - \delta_K)\, K_{t-1} - S_t Y_t \left(1 - \theta_{1,t} \mu_t^{\theta_2}\right) \Omega\left(T_t\right) \right] \\
& + \beta^t \lambda_{3,t} \left[Y_t - A_t K_{t-1}^{\gamma} L_t^{1-\gamma} \right] \\
& + \beta^t \lambda_{4,t} \left[T_t - \Phi_T T_{t-1} - \Xi_T \left(\eta \ \log\left(M_t^{AT} / M_{1750} \right) / \log(2) + F_t^{EX} \right) \right] \\
& + \beta^t \lambda_{5,t} \left[M_t - \Phi_M M_{t-1} - \Xi_M \left(\sigma_t \left(1 - \mu_t\right) Y_t + E_t^{\text{land}} \right) \right]
\end{aligned}
$$

Summary: optimal control problem with 7 control variables, 5 constraints $\rightarrow$ 12 variables/equations.
(note that climate variables include more equations + Lagrangian multipliers)

Model summary:

- 6 exogenous variables $\{A_t, \sigma_t, \theta_{1,t}, F_t^{EX}, E_t^{\text{land}}, L_t\}$ and 6 exogenous processes;

- 5 core equations (from initial model) and 7 first order conditions (from Ramsey problem);

- There are 7 core endogenous variables $\{c_t, Y_t, K_t, T_t, M_t, \mu_t, S_t\}$ and 5 Lagrangian multipliers (from Ramsey) $\{\lambda_{1,t}, ..., \lambda_{5,t}\}$;

- **In sum:** 18 equations and variables.
- **Next step:** get numerical simulations from the model.

Numeric solution

- The presence of state variables in constraints (1-5) implies that current decisions depend on future outcome; example with capital
- Stacking our equations into f:

$$\begin{bmatrix} (1-S_t)\, Y_t \left(1-\theta_{1,t}\mu_t^{\theta_2}\right) \Omega\left(T_t\right) - L_t c_t = 0 \\ K_t - (1-\delta_K)\, K_{t-1} - S_t Y_t \left(1-\theta_{1,t}\mu_t^{\theta_2}\right) \Omega\left(T_t\right) = 0 \\ Y_t - A_t K_{t-1}^{\gamma} L_t^{1-\gamma} = 0 \\ .... \end{bmatrix}$$

$$\rightarrow f\left(y_{t+1}, y_t, y_{t-1}\right) = 0$$

where $f\left(y_{t+1}, y_t, y_{t-1}\right)$ is the state-space representation of our model featuring forward and backward looking variables.

- Here, $y_t = [K_t, S_t, \mu_t, ...]$ is the vector of endogenous variables.

Numeric solution

A sketch of the numeric problem:

- Finite horizon problem for $t = 0, 2, ...T + 1$;
- Terminal y_{T+1} and initial y_0 conditions are given $\rightarrow$ need to numerically get $y_1, y_2, ...y_T$;
- In absence of stochastic variables $\rightarrow$ deterministic problem $\rightarrow$ perfect foresight setup where any variable in y_{t+1} corresponds to the realized variable in $t + 1$;
- Forward-looking models admit infinity of stable solutions $\rightarrow$ imposing a terminal condition is an instrument to obtain one unique solution (Boucekkine (1995));

Numeric solution

- Over the time horizon $t = 1, 2, ...T$, stacking f() over time:

$$F(Y) = \begin{bmatrix} f(y_2, y_1, y_0) \\ f(y_3, y_2, y_1) \\ \cdots \\ f(y_T, y_{T-1}, y_{T-2}) \end{bmatrix}$$

with $Y = [y'_t, y'_{t+1}, ..., y'_T]'$ and $F : \mathbb{R}^{NT} \to \mathbb{R}^{NT}$

- Y and $F(Y)$ are two vectors of size $NT \times 1$.

Numeric solution

- The goal is to numerically solve:

$$Y^* = \arg\min_{\{Y\}} |F(Y)|$$

- How? Newton–Raphson method very efficient as shown by Laffargue (1990), Boucekkine (1995) and Juillard et al. (1996). Basic idea:
  - Set an initial value $Y^{(0)}$.
  - n^{th} Newton iterations:

$$Y^{(n)} = Y^{(n-1)} - J_F\left(Y^{(n-1)}\right)^{-1} F(Y^{(n-1)})$$

    where $J_F\left(Y^{(n-1)}\right)$ is Jacobian matrix of F of dimensions $NT \times NT$.
  - Stop the iterations if $|F(Y^{(n-1)})| < \varepsilon$.

- To simulate the model, we need to calibrate initial state variables (subset of y_0) to match values observed in 2015.
- Terminal conditions computed asymptotically $t \to +\infty$ by determining y_{T+1} that satisfies:

$$f\left(y_{T+1}, y_{T+1}, y_{T+1}\right) = 0$$

- In finite horizon problem, T must be large enough to verify condition:

$$\left| f\left(y_{T+1}, y_{T}, y_{T-1}\right) - f\left(y_{T+1}, y_{T+1}, y_{T+1}\right) \right| < \varepsilon$$

- $\Delta t = 5$ years, $t = \{t_0, t_1, ..., T\}$, with $t_0 = 2015$ and $T = 2600$;
- Consider two policies:

1. The mitigation policy:

$$\max_{\{c_t, Y_t, K_t, T_t, M_t, \mu_t, S_t\}} \sum_{t=0}^{\infty} \beta^t L_t \left(c_t^{1-\alpha} - 1 \right) (1-\alpha)^{-1}$$
$$s.t.\ (1) - (5)$$

2. The *laisser-faire* / Business As Usual (BAU) policy:

$$\max_{\{c_t, Y_t, K_t, T_t, M_t, S_t\}} \sum_{t=0}^{\infty} \beta^t L_t \left(c_t^{1-\alpha} - 1 \right) (1-\alpha)^{-1}$$
$$s.t.\ (1) - (5)$$
$$s.t.\ \mu_t = 0.03$$

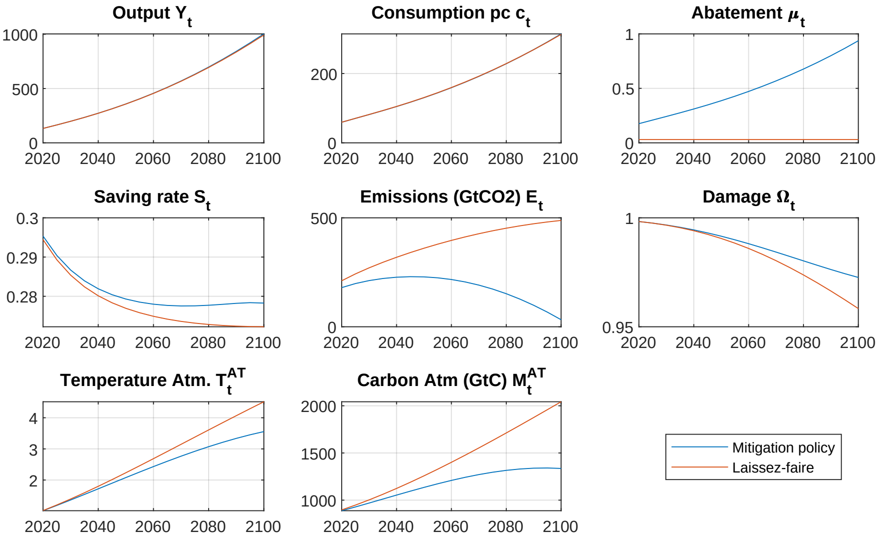

Figure. Simulations under two policy scenarios

Some striking but controversial results from DICE:

- "Optimal" to warm the planet up to $3.5°C$;
- Mitigation policy saves about 2% of climate damage;
- Net zero emission optimal by 2100, 50 years later than in Paris-Agreement;
- Main critic from DICE's policy output: those results have scientifically grounded climate inaction in policy circles...

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Social cost of carbon

- Why is it optimal to warm so much the planet according to DICE?
- An optimal carbon tax = how much the society is willing to pay to reduce emissions ($ per ton of carbon).
- This is usually referred to as the Social Cost of Carbon (SCC) in literature.
- SCC reflects the society's gains and losses from implementing the carbon tax.
- What is the model implied SCC?

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- Get back to FOCs of the Ramsey-planner:

$$M_t^{AT}: \lambda_{5,t}^{AT} = \beta \Phi_M \lambda_{5,t+1}^{AT} + \lambda_{4,t}^{AT} F'(M_t)$$
$$T_t^{AT}: \lambda_{4,t}^{AT} = \beta \Phi_T \lambda_{4,t+1} + \lambda_{2,t}^{AT} S_t Y_t \left(1 - \theta_{1,t} \mu_t^{\theta_2}\right) \Omega'(T_t)$$

$\lambda_{5,t}^{AT}$ ($\lambda_{4,t}^{AT}$) is the marginal loss from carbon (temperature) increase.

- SCC expresses the social loss into numeraire equivalents (here consumption):

$$SSC_t = -1000 \times \lambda_{5,t}^{AT} / \lambda_{1,t} \simeq -1000 \times (\partial W_t / \partial M_t) / (\partial W_t / \partial C_t)$$

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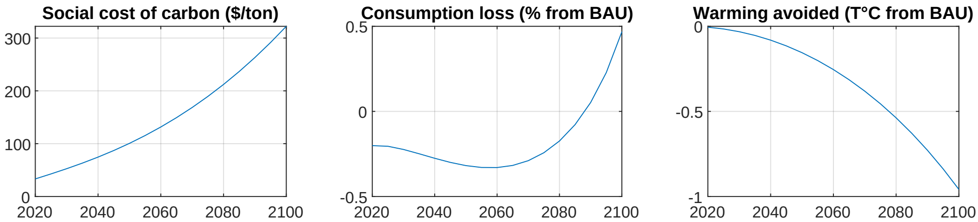
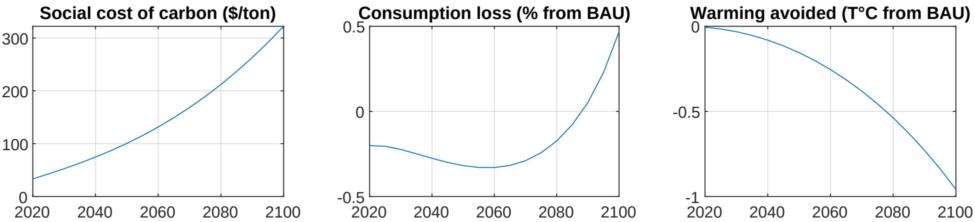


Figure. Social cost of carbon

- SCC reflect the planner's relative gains in terms of welfare from controlling M_t against its consumption losses C_t from such action;
- Optimal to cut consumption now by 0.5% in order to avoid 1°C of warming in 2100;
- As well off between scenarios by 2090 on current consumption grounds (but not in welfare terms).



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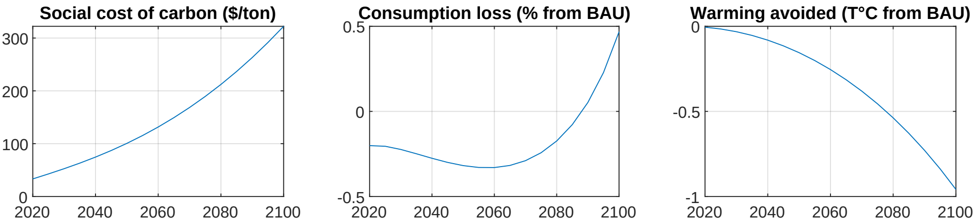

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  - On the one hand, a warming planet causes damages that will make resources scarcer & prices higher $\rightarrow$ climateflation.
  - On the other hand, the fight against climate change through increasing carbon taxes will increase production costs $\rightarrow$ greenflation.
- How should the central bank conduct monetary policy in this new landscape?
- Answering this question requires a new class of IAM with New Keynesian ingredients to capture inflation dynamics.
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- Climate change will shake the macroeconomic landscape in the next decades and the central bank will have to face 2 phenomena [Schnabel 2022]:
  - On the one hand, a warming planet causes damages that will make resources scarcer & prices higher → climateflation.
  - On the other hand, the fight against climate change through increasing carbon taxes will increase production costs → greenflation.
- How should the central bank conduct monetary policy in this new landscape?
- Answering this question requires a new class of IAM with New Keynesian ingredients to capture inflation dynamics.
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This paper

- The canonical New Keynesian model (e.g. Woodford, 2003) not designed for climate analysis.
- This paper develops The New Keynesian Climate (NKC) model by:
  - extending with a **carbon accumulation** constraint and a **mitigation policy** from the Integrated Assessment Model (IAM) [Barrage and Nordhaus 2023];
  - estimating NKC for the world economy with techniques that take into account nonlinearities resulting from climate change;
  - providing projections up to horizon 2100 under mitigation versus *laissez-faire* policy by changing an exogenous carbon tax rate.
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Methodological breakthrough

- Standard view: stable propagation mechanism with fluctuations naturally decaying over time back to a steady state [Smets and Wouters 2007].
- Climate problem: Cumulative emissions permanently alter the propagation mechanism $\rightarrow$ no steady state.

- Why? Cumulative carbon induces permanent shifts in productivity, structurally similar to an endogenous (de-)growth model.
- Climate damages $\Omega(M)$ in production ($Y = \Phi(M) \cdot L$) does not scale proportionally with economic growth, violating the homogeneity assumption required for Solow's detrending techniques.
- **Our methodological breakthrough:** update the macroeconomist's toolkit with nonlinear methods that do not rely on local steady-state.

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Literature

Our paper is connected to three literatures:

- **Long-term climate analysis:** IAMs analyze the long-term effect of carbon accumulation [Nordhaus 1992; Dietz and Venmans 2019; Barrage and Nordhaus 2023; Folini et al. 2024] & IPCC models, but ignore fluctuations and/or price rigidity.
- **Short-term climate models:** E-DSGE with nominal rigidities [Annicchiarico and Di Dio 2015; Ferrari and Nispi Landi 2022; Benmir and Roman 2022; Coenen et al. 2023; Del Negro et al. 2023; Airaudo et al. 2023; Nakov and Thomas 2023; Olovsson and Vestin 2023], but no explicit demographic and climate trends → inacurate un medium/long term for climate projections.
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The New Keynesian Climate Model

Carbon accumulation and its damages:

$$
\begin{aligned}
\textbf{IS:} \quad \left(\frac{\tilde{y}_t x_t-\omega d}{1-\omega}\right)^{-\sigma_c} &= \beta \mathbb{E}_t \, \frac{\varepsilon_{b,t+1}}{\varepsilon_{b,t}} \frac{r_t}{\pi_{t+1}} \left((1-\omega)\left(\frac{x_{t+1}\tilde{y}_{t+1}-\omega d}{1-\omega}\right)^{-\sigma_c} + \omega d^{-\sigma_c}\right) \\
x_t &= 1-(1-\vartheta)0.5\kappa\left(\pi_t-\pi_t^*\right)^2 - \vartheta(1-\varepsilon_{p,t} mc_t) \\
\textbf{PC:} \quad \left(\pi_t-\pi_t^*\right)\pi_t &= (1-\vartheta)\beta \mathbb{E}_t \, g_{z,t}\tilde{y}_{t+1}/\tilde{y}_t\left(\pi_{t+1}-\pi_{t+1}^*\right)\pi_{t+1} + \zeta\kappa^{-1}\varepsilon_{p,t} mc_t + \kappa^{-1}(1-\zeta) \\
mc_t &= \psi\left(x_t\tilde{y}_t-\omega d\right)^{\sigma_c} \tilde{y}_t^{(1+\sigma_n)/\alpha-1} \, \Phi\left(\tilde{m}_t\right)^{-(1+\sigma_n)/\alpha} \\
\textbf{MP:} \quad r_t &= r_{t-1}^{\rho}\left[r_r \pi_t^*\left(\pi_t/\pi_t^*\right)^{\phi_\pi}\left(\tilde{y}_t/\tilde{y}_t^n\right)^{\phi_y}\right]^{1-\rho} \varepsilon_{r,t} \\
\textbf{CC:} \quad \tilde{m}_t &= \tilde{m}_{t-1} + \xi_m \, \sigma_t \, z_t \, l_t \, \tilde{y}_t \, \varepsilon_{e,t}
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$$\left(\frac{\tilde{y}_t x_t - \omega d}{1-\omega}\right)^{-\sigma_c} = \beta \mathbb{E}_t \frac{\varepsilon_{b,t+1}}{\varepsilon_{b,t}} \frac{r_t}{\pi_{t+1}} \left((1-\omega) \left(\frac{x_{t+1}\tilde{y}_{t+1} - \omega d}{1-\omega}\right)^{-\sigma_c} + \omega d^{-\sigma_c} \right)$$
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MP:
$$r_t = r_{t-1}^{\rho} \left[r_r \pi_t^* \left(\pi_t / \pi_t^*\right)^{\phi_\pi} \left(\tilde{y}_t / \tilde{y}_t^n\right)^{\phi_y} \right]^{1-\rho} \varepsilon_{r,t}$$

CC:
$$\tilde{m}_t = \tilde{m}_{t-1} + \xi_m \, \sigma_t \, z_t \, l_t \, \tilde{y}_t \, \varepsilon_{e,t}$$

Anthropogenic carbon stock

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Deterministic Decoupling trend

Anthropogenic carbon stock

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Deterministic Decoupling trend

MP: $$r_t = \ldots \left[\ldots \right)^{\phi_\pi} \left(\tilde{y}_t/\tilde{y}_t^n\right)^{\phi_y} \Big]^{1-\rho} \varepsilon_{r,t}$$

CC: $$\tilde{m}_t = \tilde{m}_{t-1} + \xi_m\, \sigma_t\, z_t\, l_t\, \tilde{y}_t\, \varepsilon_{e,t}$$

Anthropogenic carbon stock

Deterministic TFP trend

The New Keynesian Climate Model

Carbon accumulation and its damages:

$$
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\end{aligned}
$$

$$
\textbf{MP:}\quad r_t = \cdots
$$

Deterministic Decoupling trend

Deterministic population trend

$$
\textbf{CC:}\quad \tilde{m}_t = \tilde{m}_{t-1} + \xi_m\, \sigma_t\, z_t\, l_t\, \tilde{y}_t\, \varepsilon_{e,t}
$$

Anthropogenic carbon stock

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MP:
$$r_t \quad \phi_\pi$$

Deterministic Decoupling trend

Deterministic population trend

Emission AR(1) shock

CC:
$$\tilde{m}_t = \tilde{m}_{t-1} + \xi_m \, \sigma_t \, z_t \, l_t \, \tilde{y}_t \, \varepsilon_{e,t}$$

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Carbon accumulation and its damages:

$$\textbf{IS:} \quad \left(\frac{\tilde{y}_t x_t - \omega d}{1-\omega}\right)^{-\sigma_c} = \beta \mathbb{E}_t \frac{\varepsilon_{b,t+1}}{\varepsilon_{b,t}} \frac{r_t}{\pi_{t+1}} \left((1-\omega)\left(\frac{x_{t+1}\tilde{y}_{t+1} - \omega d}{1-\omega}\right)^{-\sigma_c} + \omega d^{-\sigma_c}\right)$$

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$$\textbf{MP:} \quad r_t = r_{t-1}^{\rho} \left[r_r \left(\pi_t^*/\pi\right)\left(\pi_t/\pi_t^*\right)^{\phi_\pi} \left(\tilde{y}_t/\tilde{y}_t^n\right)^{\phi_y}\right]^{1-\rho} \varepsilon_{r,t}$$

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Mitigation policies as function of exogenous carbon tax $\tilde{\tau}_t$:

Mitigation expenditures

$$\textbf{IS:}\quad \left(\frac{\tilde{y}_t x_t - \omega d}{1-\omega}\right)^{-\sigma_c} = \beta \mathbb{E}_t \frac{\varepsilon_{b,t+1}}{\varepsilon_{b,t}} \frac{r_t}{\pi_{t+1}} \left((1-\omega)\left(\frac{x_{t+1}\tilde{y}_{t+1} - \omega d}{1-\omega}\right)^{-\sigma_c} + \omega d^{-\sigma_c}\right)$$

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The New Keynesian Climate Model

Mitigation policies as function of exogenous carbon tax $\tilde{\tau}_t$:

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x_t &= 1 - (1-\vartheta) 0.5 \kappa \left(\pi_t - \pi_t^*\right)^2 - \vartheta (1 - \varepsilon_{p,t} mc_t) - \theta_{1,t} \tilde{\tau}_t^{\theta_2/(\theta_2-1)}
\end{aligned}
$$

Carbon tax costs

$$
\begin{aligned}
\textbf{PC:} \quad \left(\pi_t - \pi_t^*\right) \pi_t &= (1-\vartheta) \beta \mathbb{E}_t \; g_{z,t} \tilde{y}_{t+1} / \tilde{y}_t \left(\pi_{t+1} - \pi_{t+1}^*\right) \pi_{t+1} + \zeta \kappa^{-1} \varepsilon_{p,t} mc_t + \kappa^{-1} (1-\zeta) \\
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$$

$$
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$$

$$
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$$

Mitigation policies as function of exogenous carbon tax $\tilde{\tau}_t$:

Mitigation expenditures

$$\textbf{IS:} \quad \left(\frac{\tilde{y}_t x_t - \omega d}{1-\omega}\right)^{-\sigma_c} = \beta \mathbb{E}_t \frac{\varepsilon_{b,t+1}}{\varepsilon_{b,t}} \frac{r_t}{\pi_{t+1}} \left((1-\omega)\left(\frac{x_{t+1}\tilde{y}_{t+1} - \omega d}{1-\omega}\right)^{-\sigma_c} + \omega d^{-\sigma_c} \right)$$

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Carbon tax costs

$$\textbf{PC:} \quad \left(\pi_t - \pi_t^*\right)\pi_t = (1-\vartheta)\beta\mathbb{E}_t \; g_{z,t}\tilde{y}_{t+1}/\tilde{y}_t \left(\pi_{t+1} - \pi_{t+1}^*\right)\pi_{t+1} + \zeta\kappa^{-1}\varepsilon_{p,t} mc_t + \kappa^{-1}(1-\zeta)$$

$$mc_t = \psi\left(x_t\tilde{y}_t - \omega d\right)^{\sigma_c} \tilde{y}_t^{(1+\sigma_n)/\alpha - 1} \; \Phi\left(\tilde{m}_t\right)^{-(1+\sigma_n)/\alpha} + \theta_{1,t}\tilde{\tau}_t\left(\theta_2 + (1-\theta_2)\tilde{\tau}_t^{1/(\theta_2-1)}\right)$$

Abatement share

$$\textbf{MP:} \quad r_t = r_{t-1}^{\rho}\left[r_r\left(\pi_t^*/\pi\right)\left(\pi_t/\pi_t^*\right)^{\phi_\pi}\left(\tilde{y}_t/\tilde{y}_t^n\right)^{\phi_y}\right]^{1-}$$

$$\textbf{CC:} \quad \tilde{m}_t = \tilde{m}_{t-1} + \xi_m \, \sigma_t \, z_t \, l_t \, \tilde{y}_t \, \varepsilon_{e,t}\left(1 - \tilde{\tau}_t^{1/(\theta_2-1)}\right)$$

Estimation

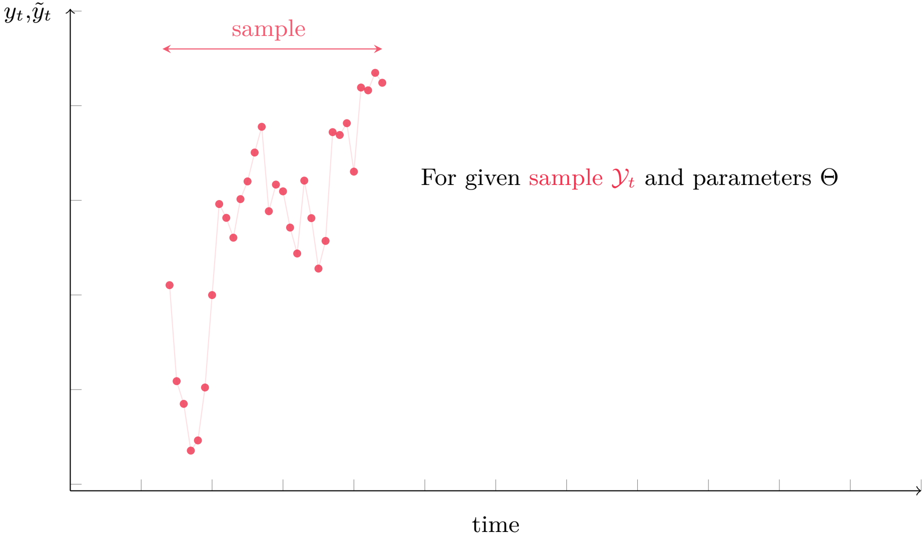
- Estimation on world data from 1985Q1 to 2023Q3 (sources: World Bank, OECD and OurWorldInData).

- There are four observable variables:

$$\begin{bmatrix} \text{Real output growth rate} \\ \text{Inflation rate} \\ \text{Short-term interest rate} \\ CO_2 \text{ emissions growth rate} \end{bmatrix} = 100 \times \begin{bmatrix} \Delta \log(y_t) \\ \pi_t - 1 \\ r_t - 1 \\ \Delta \log(e_t) \end{bmatrix}$$

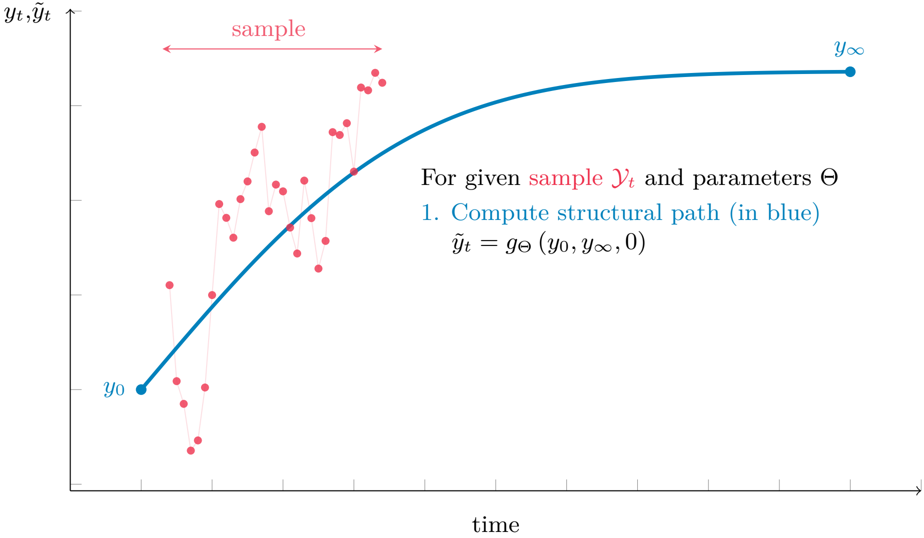
- Solution & filtering methods from Fair and Taylor (1983): fully nonlinear, MIT shocks and no aggregate uncertainty.

Estimation



For given sample $\mathcal{Y}_t$ and parameters Θ

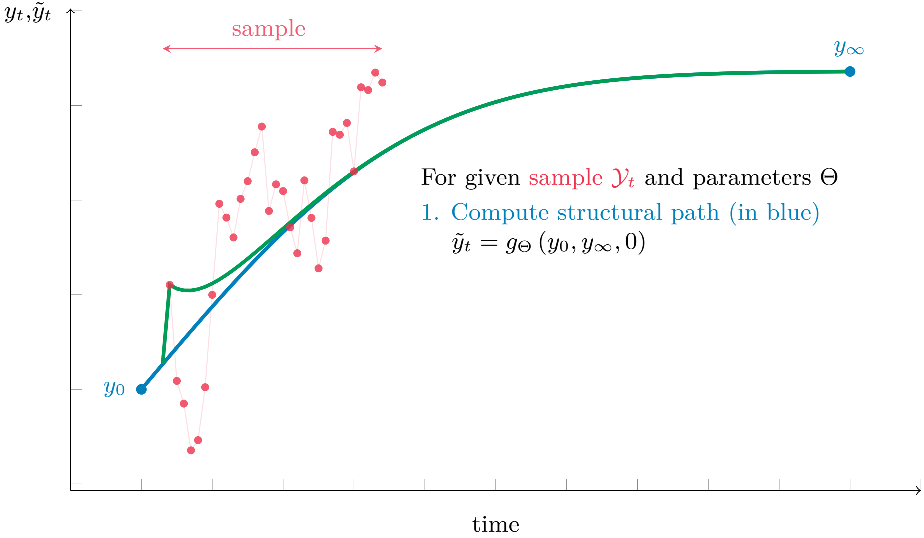
Estimation



For given sample $\mathcal{Y}_t$ and parameters Θ

1. Compute structural path (in blue)
   $\tilde{y}_t = g_\Theta\left(y_0, y_\infty, 0\right)$

Estimation



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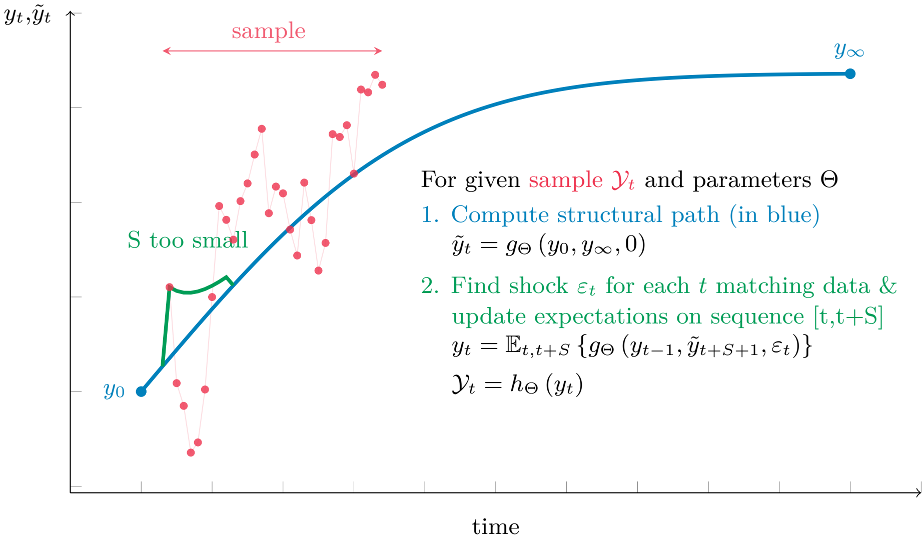

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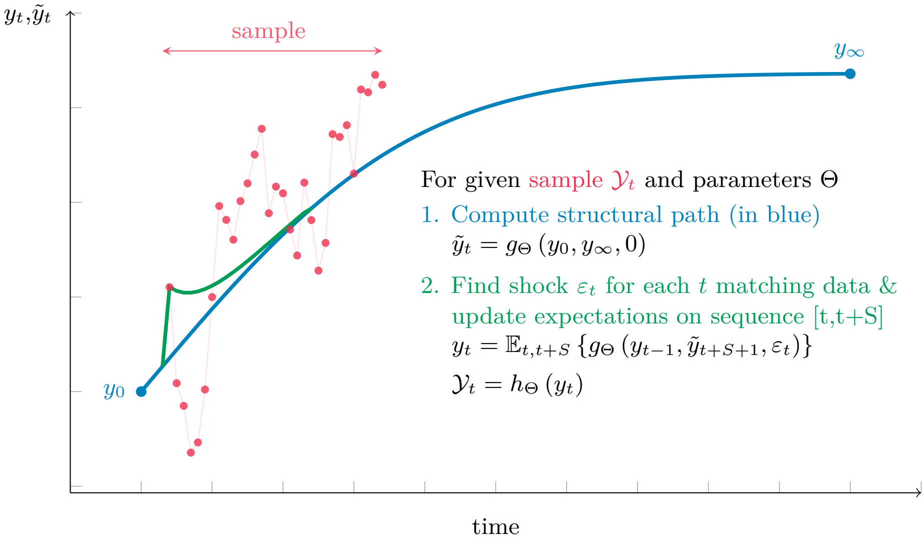
2. Find shock ε_t for each t matching data & update expectations on sequence [t,t+S]
   $y_t = \mathbb{E}_{t,t+S} \{ g_\Theta (y_{t-1}, \tilde{y}_{t+S+1}, \varepsilon_t) \}$
   $\mathcal{Y}_t = h_\Theta (y_t)$

Estimation



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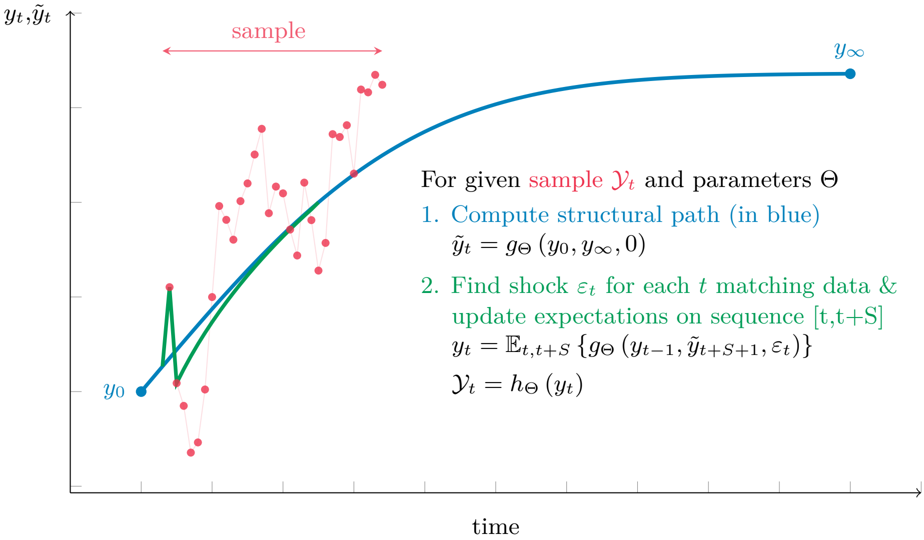

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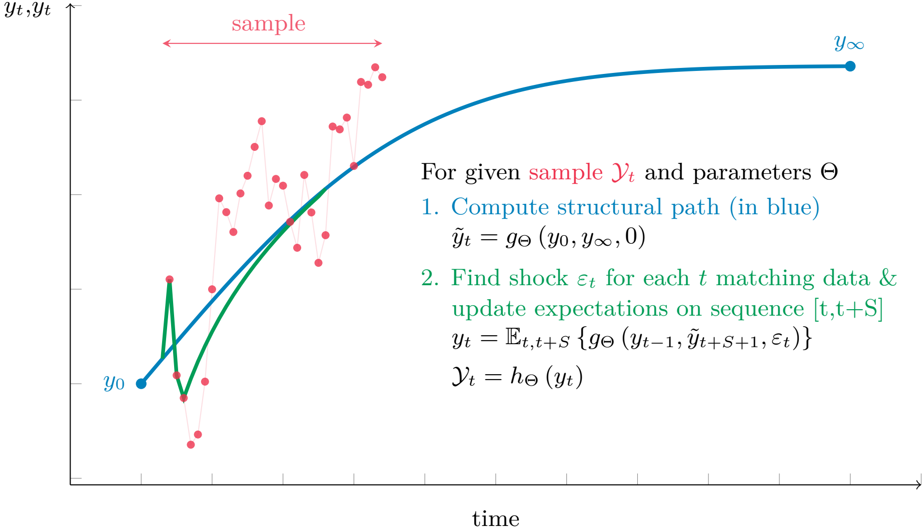

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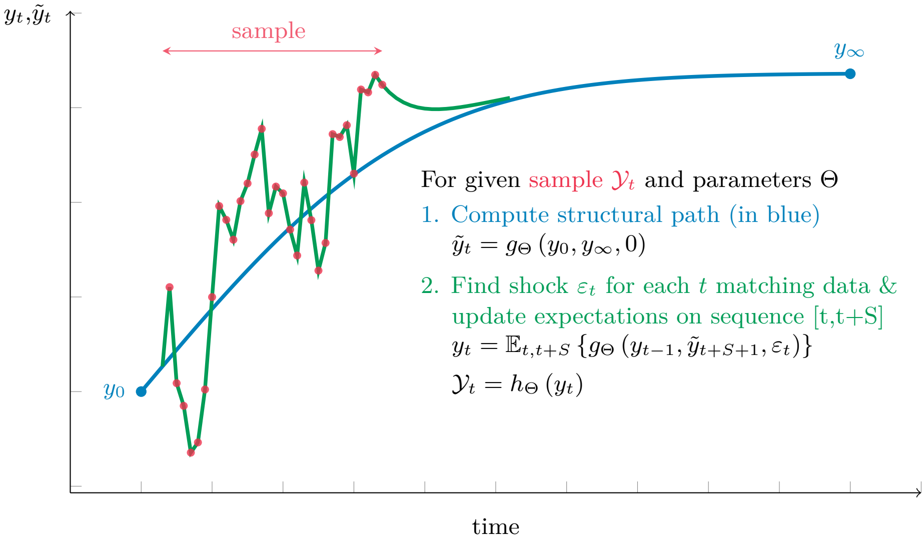

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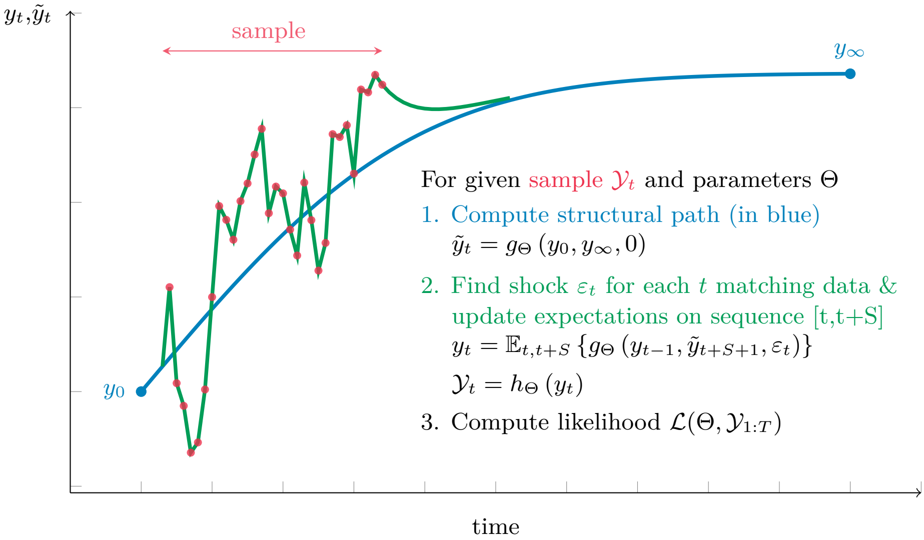

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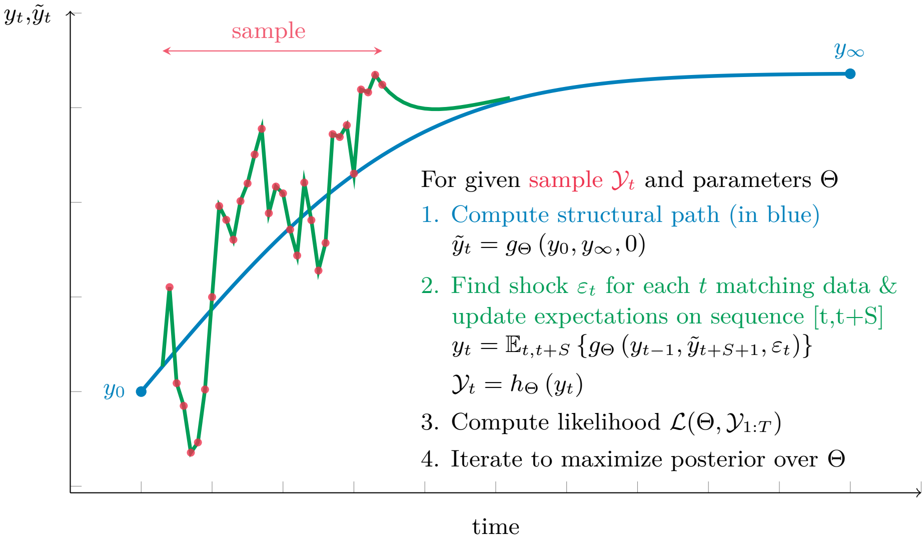
3. Compute likelihood $\mathcal{L}(\Theta, \mathcal{Y}_{1:T})$

Estimation



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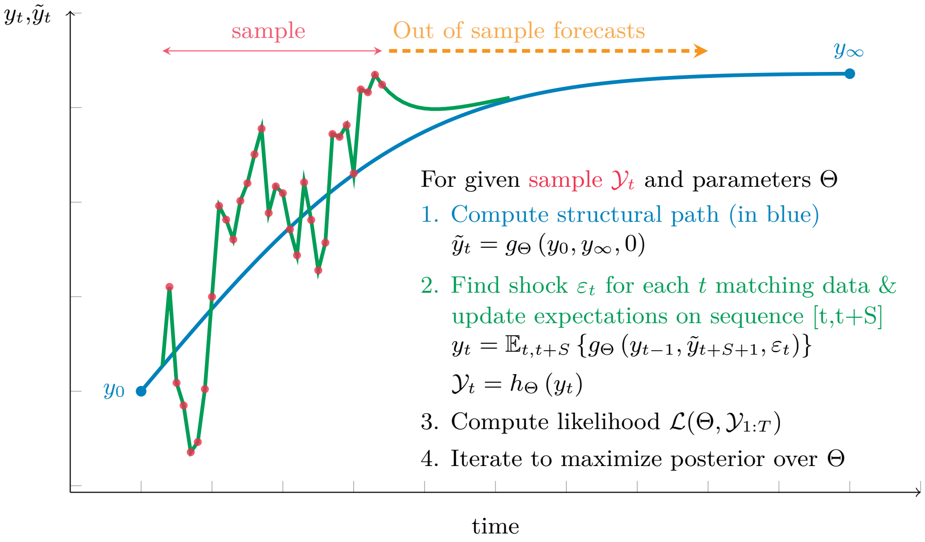
3. Compute likelihood $\mathcal{L}(\Theta, \mathcal{Y}_{1:T})$
4. Iterate to maximize posterior over Θ

Estimation



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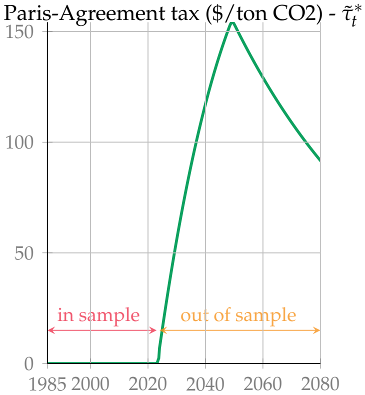
Estimation

- Large uncertainty about future carbon tax: implications for estimation in particular at the end of the sample
- Let $\tilde{\tau}_t^*$ denote the Paris-Agreement tax, with linear decrease in carbon emissions up to 2050
- We let the data inform about the market-based expectations on future carbon mitigation policies:

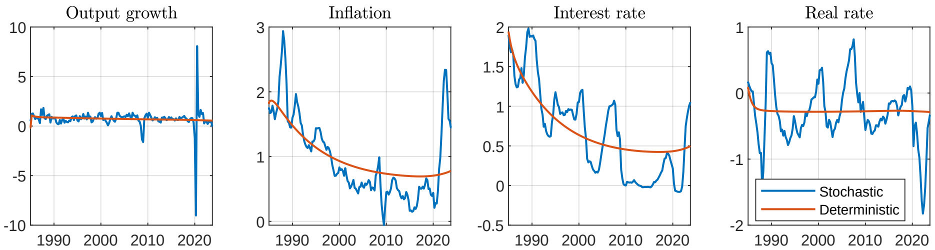
$$\mathbb{E}_t\{\tilde{\tau}_t\} = \varphi\tilde{\tau}_t^*$$

where $\varphi \in [0,1]$ is the fraction of believers (or expected intensity) of Paris-Agreement policy.



Stochastic and deterministic paths

Figure 1: Implied deterministic and stochastic paths

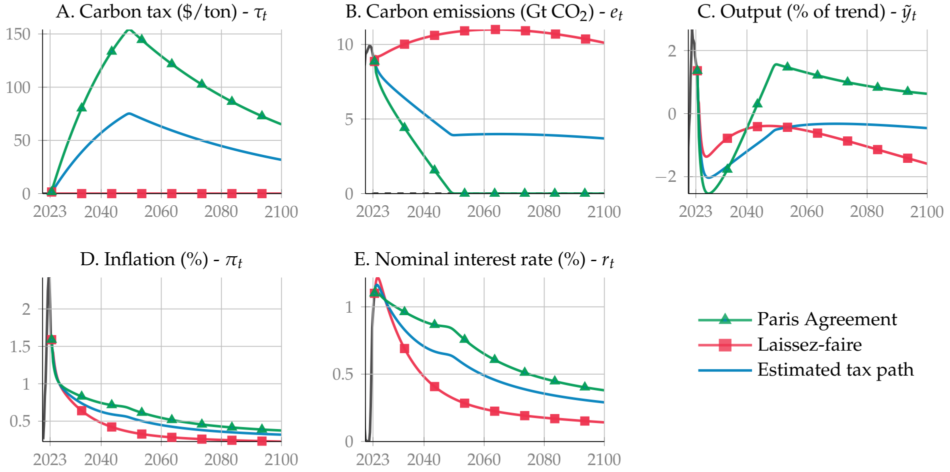


The Anatomy of Green/Climateflation

- What is the future macroeconomic landscape by the end of the century?
- We consider three alternative scenarios based on the realization of the carbon tax $\varphi\tilde{\tau}_t^*$:
  - Paris-Agreement with $\varphi = 1$
  - Estimated carbon path with $\varphi = 0.53$
  - Laissez-faire with $\varphi = 0$

Three Transitions

Figure 2: Model-implied projections based on alternative control rates of emissions



Dissecting the PC curve

- Stabilization objective of a central bank: important to understand how climate affects inflation.
- One can split the marginal cost into three term:

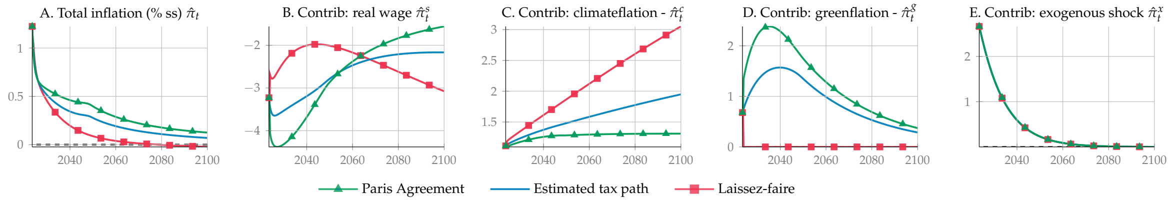
$$mc_t = \underbrace{\tilde{w}_t}_{\text{real wage}} / \underbrace{\Phi\left(m_t\right)}_{\text{climateflation}} + \underbrace{\theta_{1,t}\mu_t^{\theta_2} + \tau_{e,t}\sigma_t\left(1-\mu_t\right)\varepsilon_{e,t}}_{\text{greenflation}}, \tag{13}$$

which allows to break down inflation into 4 different forces:

$$\hat{\pi}_t \simeq \underbrace{\hat{\pi}_t^s}_{\text{wage term}} + \underbrace{\hat{\pi}_t^c}_{\text{climateflation}} + \underbrace{\hat{\pi}_t^g}_{\text{greenflation}} + \underbrace{\hat{\pi}_t^x}_{\text{exogenous shocks}} \tag{14}$$

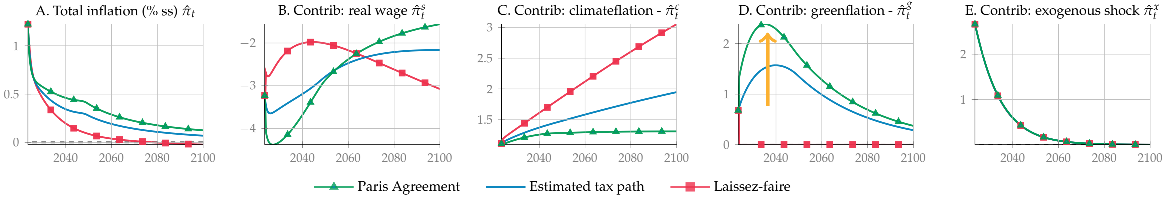
with $\hat{\pi}_t = \pi_t - \pi_t^\star$

Dissecting the PC curve



- Under Paris Agreement:
  - The immediate increase in carbon tax fuels inflation
  - General equilibrium effect: increasing abatement expenditures reduces both consumption and in turn the wealth effect on the labor supply
  - Net zero stabilizes damages, and hence climateflation

Dissecting the PC curve



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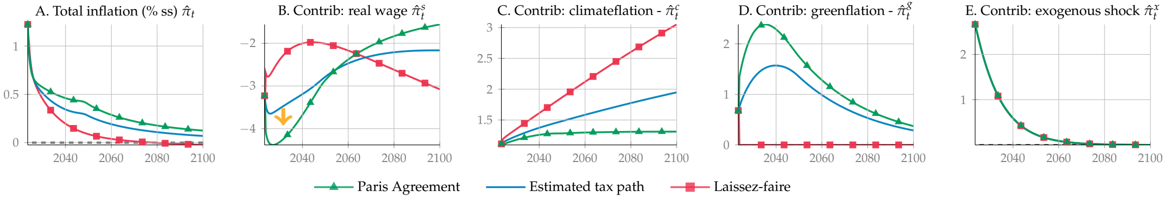

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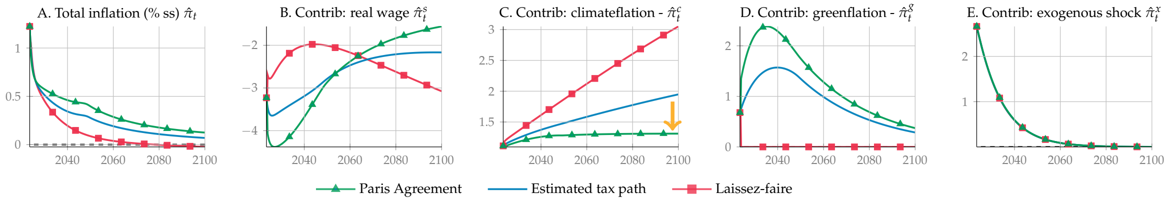

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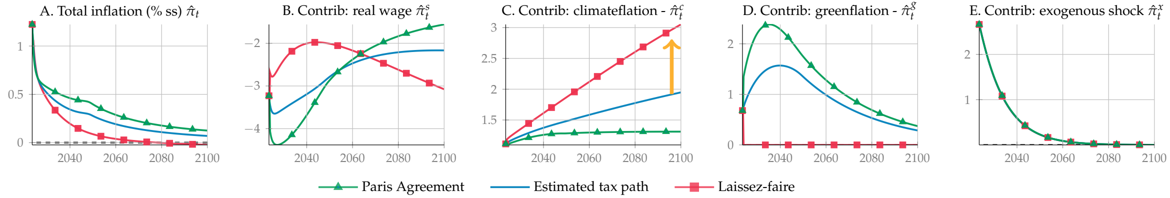

- Under Laissez-faire:
  - The rising damage makes resources scarcer: ever growing inflation as long as planet warms
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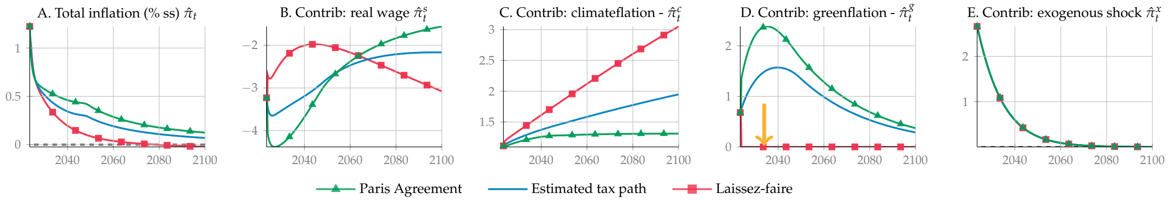
Dissecting the PC curve



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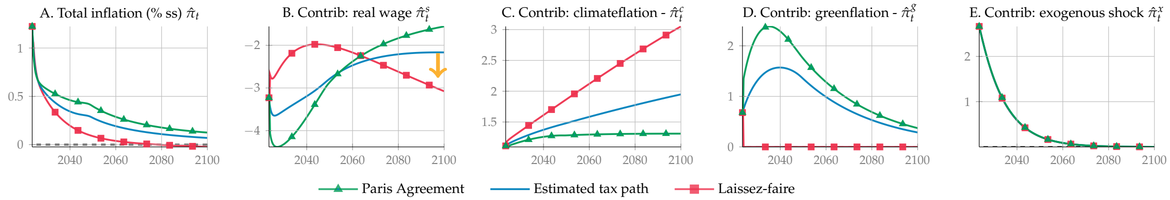

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Thank you for your attention

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