THE NEW KEYNESIAN CLIMATE MODEL

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INTRODUCTION

- Climate change will change 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 make fossil fuels & raw materials more expensive → **greenflation**.
- How should the central bank conduct monetary policy in this new landscape?
- Answering this question requires to understand the effects of climate change on the economy.

THIS PAPER

- The canonical New Keynesian model is silent on climate developments.
- This paper develops The New Keynesian Climate (NKC) model by:
  - extending the canonical model with a carbon accumulation constraint and a mitigation policy from the Integrated Assessment Model (IAM) literature;
  - estimating this model 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.
- This allows us to analyze the impact of climate change on inflation and monetary policy.

METHODOLOGICAL BREAKTHROUGH

- Standard view: stable propagation mechanism with fluctuations naturally decaying over time back to a steady state.
- Climate problem: the way carbon emissions cumulate over time permanently changes the propagation patterns → no steady state.
- We solve our nonlinear model taking into account both long and short term effects using the Fair and Taylor (1983)'s extended path solution method.
- We estimate the model using Bayesian nonlinear techniques based on the inversion filter from Fair and Taylor (1983).

OUTLINE

PLAN

The New Keynesian Climate Model

Carbon accumulation and its damages:

IS:

$$\begin{aligned} \left(\frac{\tilde{y}_t x_t-\omega d}{1-\omega}\right)^{-\sigma_c} &= \beta\mathbb{E}_t \, \frac{\varepsilon_{b,t+1}}{\varepsilon_{b,t}} \frac{r_t}{\pi_{t+1}} \left((1-\omega)\left(\frac{x_{t+1}\tilde{y}_{t+1}-\omega d}{1-\omega}\right)^{-\sigma_c} + \omega d^{-\sigma_c}\right) \\ x_t &= 1-0.5\kappa\left(\pi_t-\pi_t^*\right)^2(1-\vartheta)-\vartheta(1-\varepsilon_{p,t} mc_t) \end{aligned}$$

PC:

$$\begin{aligned} \left(\pi_t-\pi_t^*\right)\pi_t &= (1-\vartheta)\beta\mathbb{E}_t \; g_{z,t}\tilde{y}_{t+1}/\tilde{y}_t \left(\pi_{t+1}-\pi_{t+1}^*\right)\pi_{t+1} + \zeta\kappa^{-1}\varepsilon_{p,t} mc_t + \kappa^{-1}(1-\zeta) \\ mc_t &= \psi\left(x_t\tilde{y}_t-\omega d\right)^{\sigma_c} \tilde{y}_t^{\sigma_n} \; \Phi\left(\tilde{m}_t\right)^{-(1+\sigma_n)} \end{aligned}$$

MP:

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

CC:

$$\tilde{m}_t = (1-\delta_m)\tilde{m}_{t-1} + \xi_m \; \sigma_t \; z_t \; l_t \; \tilde{y}_t \; \varepsilon_{e,t}$$

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Anthropogenic carbon stock

THE NEW KEYNESIAN CLIMATE MODEL

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Deterministic Decoupling trend

MP:

$$r_t = r_{t-1}^{\rho} \Big[\text{[illegible]} \tilde{y}_t/\tilde{y}_t^n)^{\phi_y} \Big]^{1-\rho} \varepsilon_{r,t}$$

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$$mc_t = \psi \left(x_t \tilde{y}_t - \omega d\right)^{\sigma_c} \tilde{y}_t^{\sigma_n} \; \Phi\left(\tilde{m}_t\right)^{-(1+\sigma_n)}$$

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Anthropogenic carbon stock

Deterministic TFP trend

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$$mc_t = \psi \left(x_t \tilde{y}_t - \omega d\right)^{\sigma_c} \tilde{y}_t^{\sigma_n} \; \Phi\left(\tilde{m}_t\right)^{-(1+\sigma_n)}$$

MP:

$$r_t = r_{t-1}^{\rho} \left[\qquad \tilde{y}_t \qquad \right]$$

Deterministic Decoupling trend

Deterministic population trend

CC:

$$\tilde{m}_t = (1-\delta_m)\tilde{m}_{t-1} + \xi_m \; \sigma_t \; z_t \; l_t \; \tilde{y}_t \; \varepsilon_{e,t}$$

Anthropogenic carbon stock

Deterministic TFP trend

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Deterministic Decoupling trend

Deterministic population trend

Emission AR(1) shock

Anthropogenic carbon stock

Deterministic TFP trend

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\end{aligned}$$

PC:

$$\begin{aligned}
\left(\pi_t - \pi_t^*\right) \pi_t &= (1-\vartheta) \beta \mathbb{E}_t \; g_{z,t} \tilde{y}_{t+1} / \tilde{y}_t \left(\pi_{t+1} - \pi_{t+1}^*\right) \pi_{t+1} + \zeta \kappa^{-1} \varepsilon_{p,t} mc_t + \kappa^{-1} (1-\zeta) \\
mc_t &= \psi \left(x_t \tilde{y}_t - \omega d\right)^{\sigma_c} \tilde{y}_t^{\sigma_n} \; \Phi\left(\tilde{m}_t\right)^{-(1+\sigma_n)} \longleftarrow \boxed{\textbf{Climate damages}}
\end{aligned}$$

MP:

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

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$$\tilde{m}_t = (1-\delta_m) \tilde{m}_{t-1} + \xi_m \; \sigma_t \; z_t \; l_t \; \tilde{y}_t \; \varepsilon_{e,t}$$

THE NEW KEYNESIAN CLIMATE MODEL

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

Mitigation expenditures

IS:

$$\begin{aligned}\left(\frac{\tilde{y}_t x_t - \omega d}{1-\omega}\right)^{-\sigma_c} &= \beta \mathbb{E}_t \, \frac{\varepsilon_{b,t+1}}{\varepsilon_{b,t}} \frac{r_t}{\pi_{t+1}} \left((1-\omega) \left(\frac{x_{t+1}\tilde{y}_{t+1} - \omega d}{1-\omega}\right)^{-\sigma_c} + \omega d^{-\sigma_c} \right) \\ x_t &= 1 - (1-\vartheta) 0.5 \kappa \left(\pi_t - \pi_t^*\right)^2 - \vartheta (1 - \varepsilon_{p,t} mc_t) - \theta_{1,t} \tilde{\tau}_t^{\theta_2/(\theta_2 - 1)}\end{aligned}$$

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MP:

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

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\end{aligned}$$

Carbon tax costs

$$\begin{aligned}
\textbf{PC:}\quad \left(\pi_t - \pi_t^*\right) \pi_t &= (1-\vartheta) \beta \mathbb{E}_t \, g_{z,t} \tilde{y}_{t+1} / \tilde{y}_t \left(\pi_{t+1} - \pi_{t+1}^*\right) \pi_{t+1} + \zeta \kappa^{-1} \varepsilon_{p,t} mc_t + \kappa^{-1} (1-\zeta) \\
mc_t &= \psi \left(x_t \tilde{y}_t - \omega d\right)^{\sigma_c} \tilde{y}_t^{\sigma_n} \, \Phi \left(\tilde{m}_t\right)^{-(1+\sigma_n)} + \theta_{1,t} \tilde{\tau}_t \left(\theta_2 + (1-\theta_2) \tilde{\tau}_t^{1/(\theta_2-1)} \right)
\end{aligned}$$

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

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

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\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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Abatement share

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

PLAN

ESTIMATION

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

$$\begin{bmatrix} \text{Real output growth rate} \\ \text{Inflation rate} \\ \text{Short-term interest rate} \\ \text{CO}_2 \text{ emissions growth rate} \end{bmatrix} = 100 \times \begin{bmatrix} \Delta \log\left(y_t\right) \\ \pi_t - 1 \\ r_t - 1 \\ \Delta \log\left(e_t\right) \end{bmatrix}$$

ESTIMATION

- Our statistical model is an extension of Fair and Taylor (1983) to deal with trends:

$$\tilde{y}_t = g_\Theta\left(y_0, y, \{0\}_{1:T}\right) \tag{1}$$

$$y_t = \mathbb{E}_{t,t+S}\left\{g_\Theta\left(y_{t-1}, \tilde{y}_{t+S+1}, \varepsilon_t\right)\right\} \tag{2}$$

$$\mathcal{Y}_t = h_\Theta\left(y_t\right) \tag{3}$$

$$\varepsilon_t \sim \mathcal{N}\left(0, \Sigma_\varepsilon\right) \tag{4}$$

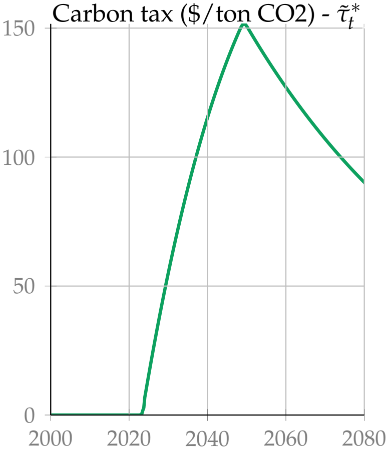
- Compute the deterministic path $\tilde{y}_t$, add stochastic innovations through extended path $\mathbb{E}_{t,t+S}\{\cdot\}$ with expectation horizon S.
- Maximize sample likelihood $\mathcal{L}(\theta, \mathcal{Y}_{1:T^*})$ & run Metropolis-Hastings to compute uncertainty bands.

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 rising carbon tax up to 2050, we let the data inform about the market-based expectations on future carbon mitigation policies:

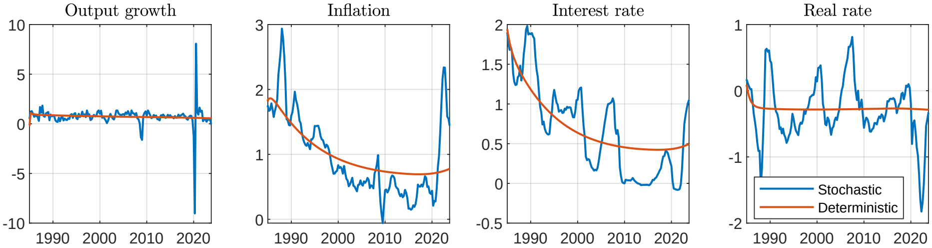
$$\mathbb{E}_{t,t+S}\{\tilde{\tau}_t\} = \varphi \tilde{\tau}_t^*$$

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



STOCHASTIC AND DETERMINISTIC PATHS

Figure 1: Implied deterministic and stochastic paths



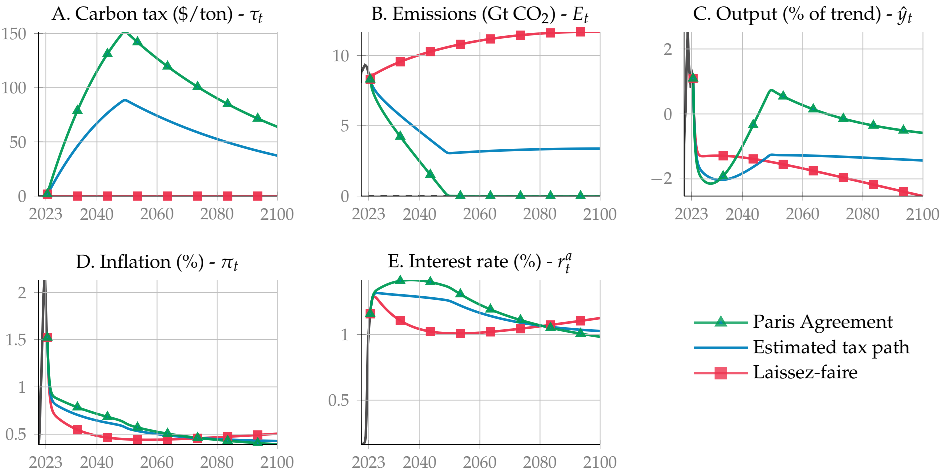
PLAN

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

One can split the marginal cost into three term:

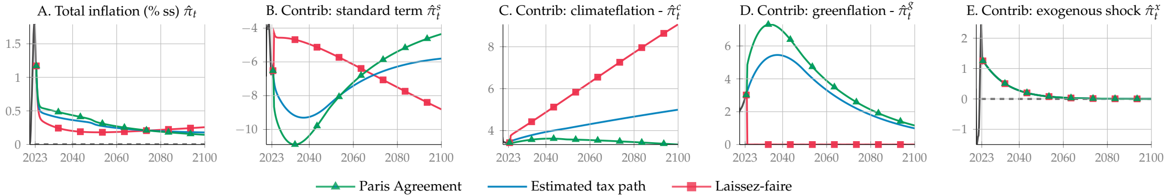
$$mc_t = \underbrace{\tilde{w}_t}_{\text{standard}} \; / \; \underbrace{\Phi\left(m_t\right)}_{\text{climateflation}} + \underbrace{\theta_{1,t}\mu_t^{\theta_2} + \tau_{e,t}\sigma_t\left(1-\mu_t\right)\varepsilon_{e,t},}_{\text{greenflation}} \tag{5}$$

which allows to break down inflation into 4 different forces:

$$\hat{\pi}_t \simeq \underbrace{\hat{\pi}_t^s}_{\text{standard term}} + \underbrace{\hat{\pi}_t^c}_{\text{climateflation}} + \underbrace{\hat{\pi}_t^g}_{\text{greenflation}} + \underbrace{\hat{\pi}_t^x}_{\text{exogenous shocks}} \tag{6}$$

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

DISSECTING THE PC CURVE



A. Total inflation (% ss) $\hat{\pi}_t$

B. Contrib: standard term $\hat{\pi}^s_t$

C. Contrib: climateflation - $\hat{\pi}^c_t$

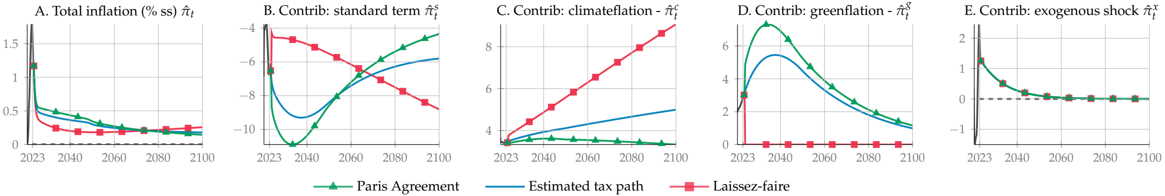
D. Contrib: greenflation - $\hat{\pi}^g_t$

E. Contrib: exogenous shock $\hat{\pi}^x_t$

- Very different inflation dynamics between the 2 regimes.

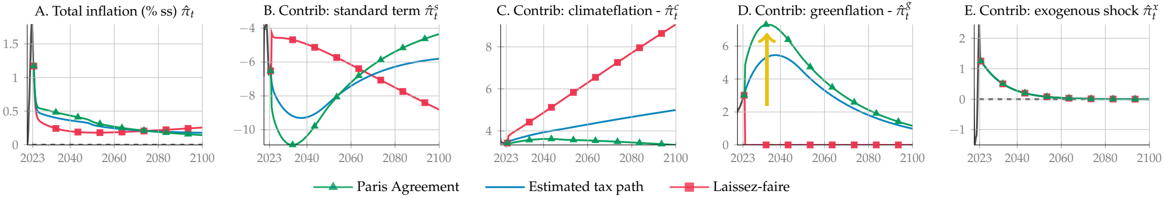
- What drives this gap?

DISSECTING THE PC CURVE



- Under Paris Agreement:
  - The immediate increase in carbon tax fuels inflation.
  - But increasing abatement expenditures reduces both consumption and in turn the wealth effect on the labor supply.
  - Reducing emissions also stabilizes damages and inflation.

DISSECTING THE PC CURVE



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  - The immediate increase in carbon tax fuels inflation.
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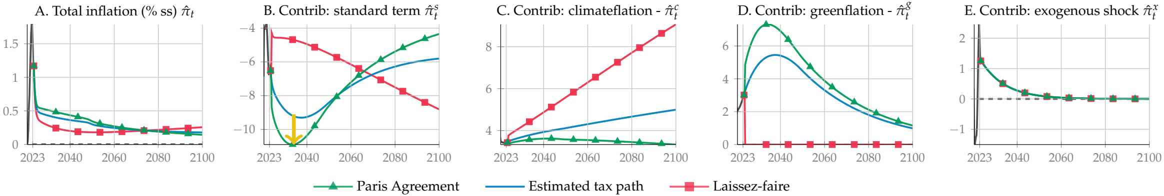
  - Reducing emissions also stabilizes damages and inflation.

Dissecting the PC curve


A. Total inflation (% ss) $\hat{\pi}_t$

B. Contrib: standard term $\hat{\pi}_t^s$

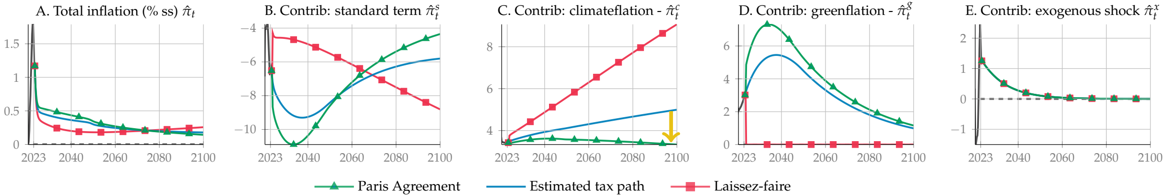
C. Contrib: climateflation - $\hat{\pi}_t^c$

D. Contrib: greenflation - $\hat{\pi}_t^g$

E. Contrib: exogenous shock $\hat{\pi}_t^x$

- Under Paris Agreement:
  - The immediate increase in carbon tax fuels inflation.
  - But increasing abatement expenditures reduces both consumption and in turn the wealth effect on the labor supply.
  - Reducing emissions also stabilizes damages and inflation.

DISSECTING THE PC CURVE



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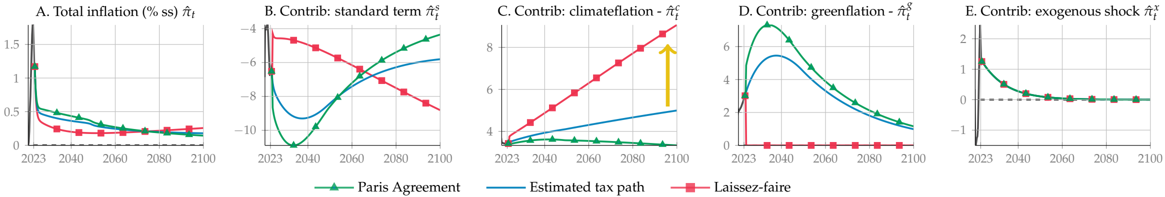
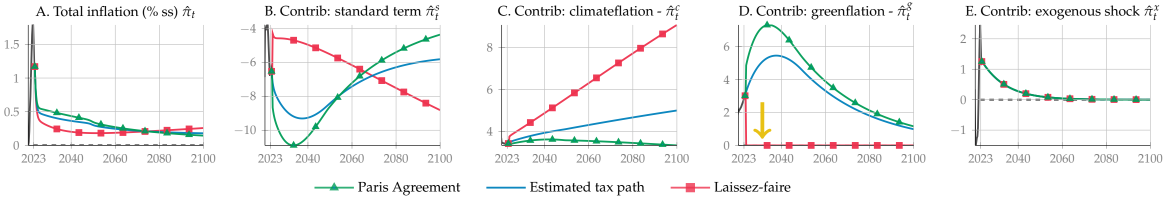


- Under Laissez-faire:
  - The rising damage makes resources scarcer: ever growing inflation as long as planet warms.
  - Disengagement from carbon policy makes carbon price to be zero.
  - Standard term follows the recessionary forces from in-sample inflation, but decreases as climate grows.

DISSECTING THE PC CURVE



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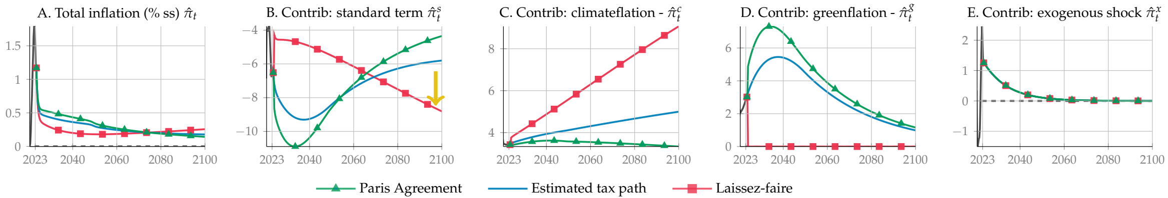

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  - Disengagement from carbon policy makes carbon price to be zero.
  - Standard term decreases as carbon stock grows.

ADDITIONAL RESULTS

- Transition is inflationary, robust to different parametrizations (attenuation, NK slope, AD slope, etc.).
- Taylor output parameter determines if climate damages are in real or nominal terms.
- Short pain from transition (greenflation) against the long terms costs of a warming planet (climateflation).
- From monetary policy perspective, easier to manage green transition than a warming planet.

PLAN

1. Introduction
2. The NKC model
3. Estimation
4. The Anatomy of Green/Climateflation
5. Conclusion

CONCLUSION

- This paper has developed a four-dimensional New Keynesian model with climate externality.
- This framework allows us to identify two phenomena faced by the central bank:
    - The first one is a persistent negative supply shock called *climateflation* that arises from the deleterious effects of climate change itself:
    - The second one is a transitory positive demand shock called *greenflation* that appears following the implementation of a climate mitigation policy;
- Short pain from transition (greenflation) against the long terms costs of a warming planet (climateflation).

Thank you for your attention

Fair, R. and Taylor, J. (1983). Solution and maximum likelihood estimation of dynamic nonlinear rational expectations models. *Econometrica*, 51:1169–1185.

Schnabel, I. (2022). A new age of energy inflation: climateflation, fossilflation and greenflation. In *Remarks at a panel on "Monetary Policy and Climate Change" at The ECB and its Watchers XXII Conference, Frankfurt am Main*, volume 17.