The transition to a green economy: Implications for monetary policy*

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*The view expressed are those of the authors and do not necessarily reflect the official policy or position of the Bank of England and the Deutsche Bundesbank

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Inflationary effects of climate policies?

- In the last years we have observed a sharp increase in inflation, mainly driven by increases in energy prices. Inflation

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- Many people draw parallels between these inflationary pressures and the ones that may arise from ambitious carbon pricing policies.
- While relative price changes between fossil and "green" energy are desirable and intended, they may weigh on inflation and output if firms and households cannot substitute away from fossil fuels.

Motivation II

The optimal monetary policy response

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Motivation II

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- The debate on inflationary effects of climate policy is accompanied by a further debate: *Which inflation measure should be targeted in response to energy supply and climate policy shocks?*
- While headline inflation is the benchmark target, many central banks (CBs) also monitor a set of “core” inflation measures that allow them to “look through” temporary changes in headline.
- Since the macroeconomic effects of carbon taxes and their pass-through on consumer prices are still unclear, the appropriate inflation measure to be stabilized by the CB remains an open question.

Previous Literature I

Are climate policies inflationary?

- It depends on price rigidities (Annicchiarico and Di Dio 2017, Del Negro et al., 2023).
- It depends on expectations and central bank credibility (Annicchiarico et al. 2022).
- Core inflation largely unaffected by carbon taxes (Moessner, 2022; Kanzig, 2022) or slightly negative affected (Diluiso et al. 2021; McKibbin et al, 2021; Konradt and Di Mauro, 2023; Olovsson and Vestin, 2023).

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So far:

- no focus on welfare performance of different inflation measures
- no clear distinction between the effects of a temporary increase in climate policy stringency and a gradual transition.

Previous literature II

What is the optimal inflation target in response to energy supply shocks?

- Core inflation would be the optimal choice when energy prices are flexible (e.g. Aoki 2001).
- Stabilizing core performs better in terms of welfare than stabilizing headline (e.g. Bodenstein et al 2008).

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So far:

- no climate features
- above results based on the assumption of unit elasticity between energy and labor and between energy consumption and core consumption.

This Paper: Research Questions

- What are the macroeconomic impacts of a rise in carbon taxes?
  - How do they differ when the carbon price rises gradually over a transition period instead of increasing suddenly?
- Which inflation measure should monetary policy target in response to it?
  - Should it focus on stabilizing core inflation only or should it also account for relative price movements in the energy sector?

This Paper: Approach

- An environmental New Keynesian model:
  - Perfectly competitive energy sectors (green and fossil)
  - Monopolistically competitive production sector
  - Distinction between core and headline inflation
  - Imperfect complementarity/substitutability in production and consumption
  - Wage and price rigidities (Calvo, 1983)
  - Climate change feedback effects (impact level damages)

- A model-based welfare function to identify welfare-relevant policy trade-offs

- Headline vs core inflation targeting in response to:
  - sudden increase in the carbon tax
  - gradual increase in the carbon tax over ten years

This Paper: Preview of the Results

- When there are imperfect complementarities in consumption and production, welfare is negatively affected by movements in relative prices.
- In terms of welfare, a monetary policy targeting headline inflation performs as well as a policy targeting core inflation.
- A sudden increase in carbon taxes transmits as a negative supply shocks.
- A gradually increase in carbon taxes mostly materializes with a contraction in economic activity.

The Model

Households' utility

Household h maximizes utility out of consumption C_t and labor N_t:

$$U_0 = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{1}{1-\zeta} C\left(h\right)_t^{1-\zeta} - \chi \frac{N\left(h\right)_t^{1+\varphi}}{1+\varphi} \right),$$

subject to:

$$P_{C,t} C\left(h\right)_t + B_t = W_t N\left(h\right)_t + D_t + R_{t-1} B_{t-1} + T_t,$$

where B_t are one-period risk-free bonds, D_t dividends, T_t lump-sum transfers, W_t nominal wage and $P_{C,t}$ the consumption price index.

The Model

Households' wage setting

Each household has some monopoly power in the labor market and posts the wage at which it is willing to supply labor.

The aggregator's demand for each household's labor is equal to the sum of firms' demands in the three sectors:
$N_t = N_{Y,t} + N_{F,t} + N_{G,t}$.

Following Calvo (1983), each period only a fraction $1 - \theta_W \in (0,1)$ of households can re-optimizes its posted nominal wage. The optimal wage W_t^* is:

$$W_t^{*\,1+\varphi\sigma_{W,t}} = \frac{\sigma_{W,t}}{\sigma_{W,t}-1} \frac{\mathbb{E}_0 \sum_{k=0}^{\infty} (\theta_W \beta)^k \chi W_{t+k}^{\sigma_{W,t}(1+\varphi)} N_{t+s}^{(1+\varphi)}}{\mathbb{E}_0 \sum_{k=0}^{\infty} (\theta_W \beta)^k \lambda_{t+k} W_{t+k}^{\sigma_{W,t}} N_{t+s}}.$$

Households' consumption basket is defined as a CES aggregate of energy goods $C_{E,t}$ and core consumption goods $C_{Y,t}$:

$$C_t = \left[\varpi_{CE}^{\frac{1}{\sigma_C}} C_{E,t}^{\frac{(\sigma_C - 1)}{\sigma_C}} + (1 - \varpi_{CE})^{\frac{1}{\sigma_C}} C_{Y,t}^{\frac{(\sigma_C - 1)}{\sigma_C}} \right]^{\frac{\sigma_C}{(\sigma_C - 1)}},$$

where $\sigma_C \in (0, 1)$.

The energy bundle includes fossil (F) and green (G) energy:

$$C_{E,t} = \left[\varpi_{CF}^{\frac{1}{\sigma_E}} C_{EF,t}^{\frac{(\sigma_E - 1)}{\sigma_E}} + (1 - \varpi_{CF})^{\frac{1}{\sigma_E}} C_{EG,t}^{\frac{(\sigma_E - 1)}{\sigma_E}} \right]^{\frac{\sigma_E}{(\sigma_E - 1)}},$$

where $\sigma_E > 1$.

The Model

Sticky-price intermediate good sector

Output $Y_{j,t}$ is produced by monopolistically competitive firms using labor $N_{Y,j,t}$ and a bundle of energy inputs $M_{E,j,t}$:

$$Y_{j,t} = \left[\varpi_Y^{\frac{1}{\varepsilon_Y}} \left(\Delta_t A_{Y,t} N_{Y,j,t} \right)^{\frac{(\varepsilon_Y - 1)}{\varepsilon_Y}} + (1 - \varpi_Y)^{\frac{1}{\varepsilon_Y}} \left(M_{E,j,t} \right)^{\frac{(\varepsilon_Y - 1)}{\varepsilon_Y}} \right]^{\frac{\varepsilon_Y}{(\varepsilon_Y - 1)}},$$

where $\varepsilon_Y \in (0, 1)$. Δ_t denotes the level impact damages due to climate change climate block

The energy composite is an aggregate of green and fossil energy:

$$M_{E,j,t} = \left[\varpi_{MG}^{\frac{1}{\varepsilon_E}} M_{EG,j,t}^{\frac{(\varepsilon_E - 1)}{\varepsilon_E}} + (1 - \varpi_{MG})^{\frac{1}{\varepsilon_E}} M_{EF,j,t}^{\frac{(\varepsilon_E - 1)}{\varepsilon_E}} \right]^{\frac{\varepsilon_E}{(\varepsilon_E - 1)}}.$$

where $\varepsilon_E > 1$.

The Model

Sticky-price intermediate good sector

Marginal costs are a function of wage W_t and the producer energy price index $P_{ME,t}$:

$$MC_t = \varpi_Y^{(1-\varepsilon_Y)} \frac{W_t}{\Delta_t A_{Y,t}} + (1-\varpi_Y)^{(1-\varepsilon_Y)} P_{ME,t}.$$

Following Calvo (1983), only a fraction $1-\theta_Y \in (0,1)$ of firms can change prices in period t, choosing an optimal price $P^*_{CY,t}$ such that:

$$\frac{P^*_{CY,t}}{P_{CY,t}} = \frac{\sigma_t}{\sigma_t - 1} \frac{\mathbb{E}_t \sum_{k=0}^{\infty} \theta_Y^k Q_{t,t+k} \frac{MC_{t+k,t}}{P_{CY,t+k}} \left(\frac{P_{CY,t+k}}{P_{CY,t}}\right)^{\sigma_t} Y_{t+k}}{\mathbb{E}_t \sum_{k=0}^{\infty} \theta_Y^k Q_{t,t+k} \left(\frac{P_{CY,t+k}}{P_{CY,t}}\right)^{\sigma_t - 1} Y_{t+k}},$$

where $P_{CY,t}$ is the sectoral price of core goods.

The Model

Flexible-price energy sectors: The fossil sector

Fossil energy is produced using labor $N_{F,t}$ and fossil resources O_t:

$$E_{F,t} = \left[\varpi_O^{\frac{1}{\varepsilon_F}} \left(\Delta_t A_{F,t} N_{F,t} \right)^{\frac{(\varepsilon_F - 1)}{\varepsilon_F}} + (1 - \varpi_O)^{\frac{1}{\varepsilon_F}} O_t^{\frac{(\varepsilon_F - 1)}{\varepsilon_F}} \right]^{\frac{\varepsilon_F}{(\varepsilon_F - 1)}},$$

where $\varepsilon_F \in (0, 1)$. Emissions are equal to the amount of fossil resources used in production.

Firms in this sector are perfectly competitive. Marginal costs are equal to:

$$MC_t^F = \varpi_O^{(1-\varepsilon_F)} \frac{W_t}{\Delta_t A_{F,t}} + (1 - \varpi_O)^{(1-\varepsilon_F)} P_{O,t}.$$

where $P_{O,t}$ is the price of fossil fuels.

The Model

Flexible-price energy sectors: The green sector

Green energy is produced using labor $N_{G,t}$:

$$E_{G,t} = \Delta_t A_{G,t} N_{G,t}.$$

Firms in this sector are perfectly competitive. Marginal costs are equal to:

$$MC_t^G = \frac{W_t}{\Delta_t A_{G,t}}$$

Monetary Policy

Monetary policy is conducted according to the following rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\iota_R} \left[\left(\frac{\Pi_{C,t}}{\Pi_C}\right)^{\iota_\pi} \left(\frac{Y_t}{Y_t^*}\right)^{\iota_y}\right]^{1-\iota_R},$$

where Y_t^* is output under flex prices and wages and R and Π_C are steady state values for interest rate and **headline inflation**, defined as:

$$\Pi_{C,t} = \left[\varpi_{CE}\left(\frac{\Pi_{CE,t}}{\Pi_{C,t}}\frac{P_{CE,t-1}}{P_{C,t-1}}\right)^{1-\sigma_C} + (1-\varpi_{CE})\left(\frac{\Pi_{CY,t}}{\Pi_{C,t}}\frac{P_{CY,t-1}}{P_{C,t-1}}\right)^{1-\sigma_C}\right]^{\frac{1}{1-\sigma_C}},$$

where $\Pi_{CE,t}$ is energy inflation rate and $\Pi_{CY,t}$ is **core inflation**.

Calibration

	Description	Value
Preferences Parameters		
β	Discount factor	0.99
ζ	Risk aversion coefficient	1.5
φ	Inverse of Frisch elasticity	0.7
Price and Wage Setting		
θ_Y	Calvo's price parameter	0.75
θ_W	Calvo's wage parameter	0.75
μ_p	Steady state price markup	1.2
μ_w	Steady state wage markup	1.2
Consumption		
σ_C	Elasticity between C and C_E	0.4
σ_{CE}	Elasticity between C_{EG} and C_{EF}	2
ϖ_{CE}	Weight of energy in consumption	0.06
ϖ_{CF}	Weight of fossil energy in consumption	0.80
Production		
ε_Y	Elasticity between N_Y and M_E	0.4
ε_E	Elasticity between M_{EG} and M_{EF}	2
$1-\varpi_Y$	Weight of energy in production	0.08
ϖ_{MG}	Weight of clean energy in production	0.20
ε_F	Elasticity between N_F and O	0.3
$1-\varpi_O$	Weight of fossil resources in production	0.53
Monetary Policy		
ι_π	Inflation coefficient of the Taylor rule	1.5
ι_R	Smoothing parameter of the Taylor rule	0
ι_y	Output gap coefficient of the Taylor rule	0

Welfare Function I

A 2^{nd} order approx. of household h's utility around the steady state, $\int_0^1 \left(U_t(h) - U\right) dh / (U_C C)$ yields:

$$\left(\widehat{c}_t - (\zeta - 1)\frac{\widehat{c}_t^{\,2}}{2}\right) - \chi \frac{N^{1+\varphi}}{C^{1-\zeta}}\left(\widehat{n}_t + (1+\varphi)\frac{\widehat{n}_t^{\,2}}{2} + \varphi \sigma_W^2 \frac{var(\widehat{w}_t(h))}{2}\right).$$

Using the aggregate demand relationships we can define:

$$\begin{aligned}\widehat{c}_t + \frac{1-\zeta}{2}\widehat{c}_t^{\,2} \quad = \quad & \widehat{y}_{C,t}^{net} - \frac{\zeta - 1}{2}(\widehat{y}_{C,t}^{net})^2 \\ & - \varpi_{CE}(1 - \varpi_{CE})(1 - \sigma_C)\sigma_C \frac{(\widehat{p}_{CE,t} - \widehat{p}_{CY,t})^2}{2} \\ & + \varpi_{CE}\varpi_{CF}(1 - \omega_{CF})(\sigma_E - 1)\sigma_E \frac{(\widehat{p}_{F,t} - \widehat{p}_{G,t})^2}{2}.\end{aligned}$$

Energy and final goods are complements, $\sigma_C < 1$:
HHs dislike variability in relative price movements between goods

Fossil and green energy are substitutes, $\sigma_E > 1$:
HHs can switch towards the relatively cheaper energy good.

Welfare Function II

The disutility from providing labor to the final good sector and energy sectors $\widehat{n}_t + (1+\varphi)\left(\widehat{n}_t{}^2\right)/2$ is proportional to:

$$\sigma_W^2 \frac{var(\widehat{w}_t(h))}{2} + \frac{N_Y}{N}\frac{\sigma^2}{\varpi_Y}\frac{var(\widehat{P_C}_t(j))}{2} + \widehat{n}_{Y,t}^{gross} + cov(\widehat{n}_{Y,t}^{gross})$$

$$+\varpi_Y(.)\frac{N_Y}{N}\frac{(1-\varepsilon_Y)\varepsilon_Y}{\varpi_Y}\frac{(\widehat{mc}_{Y,t} - (\widehat{p}_{ME,t} - \widehat{p}_{CY,t}))^2}{2}$$

$$+\varpi_o(.)\frac{(1-\varepsilon_F)\varepsilon_F}{\varpi_o}\frac{N_F}{N}\frac{(\widehat{mc}_{F,t} - (\widehat{p}_{O,t} - \widehat{p}_{F,t}))^2}{2}.$$

The last two terms reflect the effects that relative price changes have on the production side.

Energy and labor are complements in production, $\varepsilon_Y < 1$ and so are fossil fuels and labor, $\varepsilon_F < 1$.

A higher variability of prices changes relative to marginal costs induces a higher disutility of labor.

Scenarios

Policy shock:

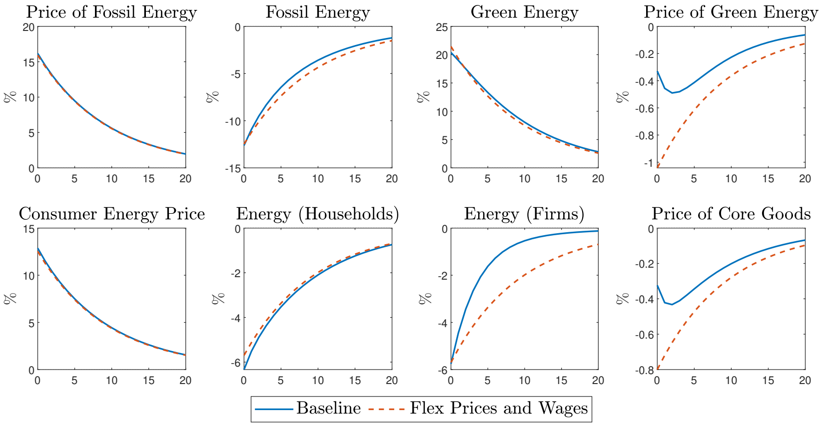
25% sudden increase in the carbon tax

- Role of price and wage rigidities
- Role of elasticity of substitution
- **Headline Inflation Targeting vs Core Inflation Targeting**

Transition:
Carbon tax announced in the first period and linearly increasing over 40 quarters

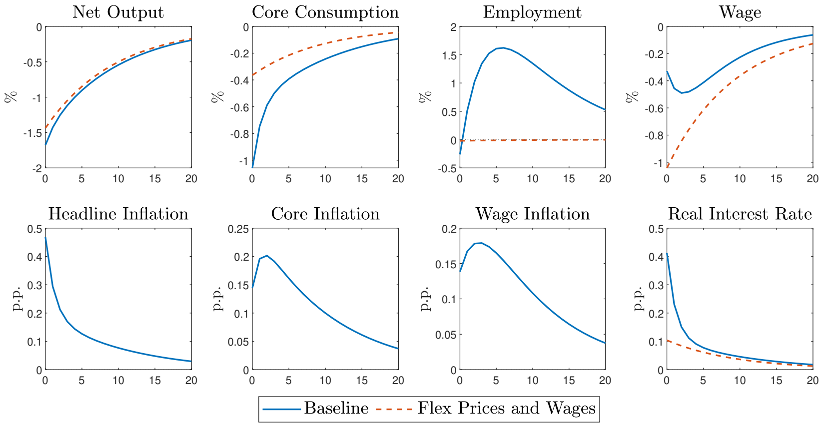
- **Headline Inflation Targeting vs Core Inflation Targeting**

Role of Price and Wage Rigidities



Note: IRFs to a 25% increase in the carbon tax. Results in % deviations from the steady state. Time in quarters.

Role of Price and Wage Rigidities



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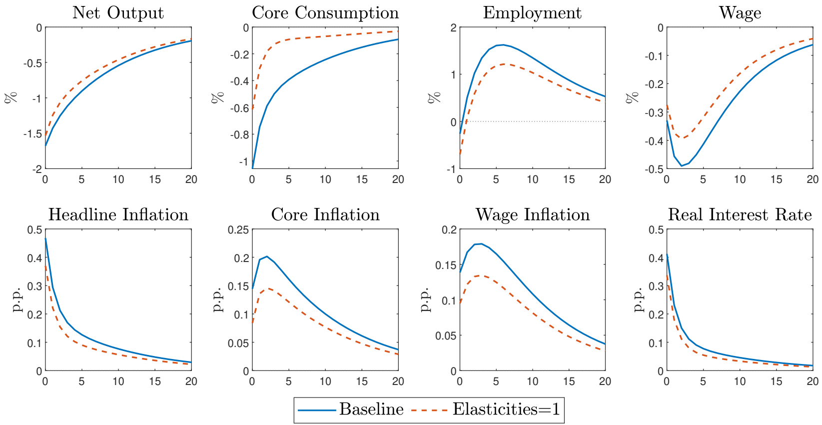
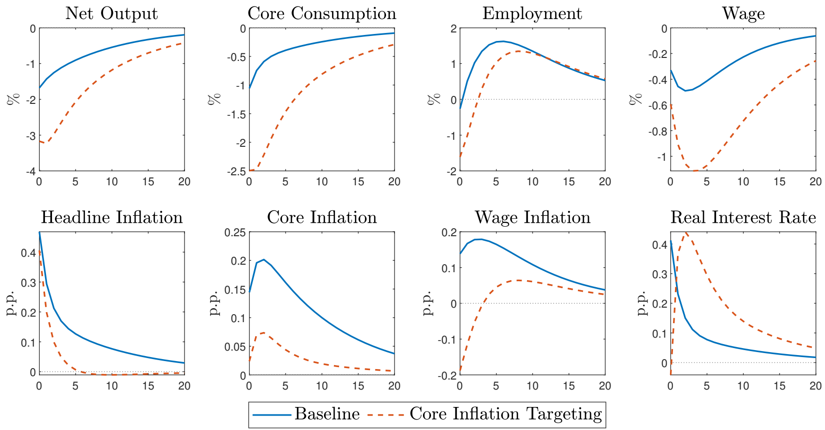
Role of Elasticity of Substitution



Note: IRFs to a 25% increase in the carbon tax. Dashed red line: $\varepsilon_Y = 1$ and $\sigma_C = 1$. Results in percentage deviations (%) and percentage point deviations (p.p.) from the steady state. Time in quarters.

additional variables

Policy Shock: Headline vs Core



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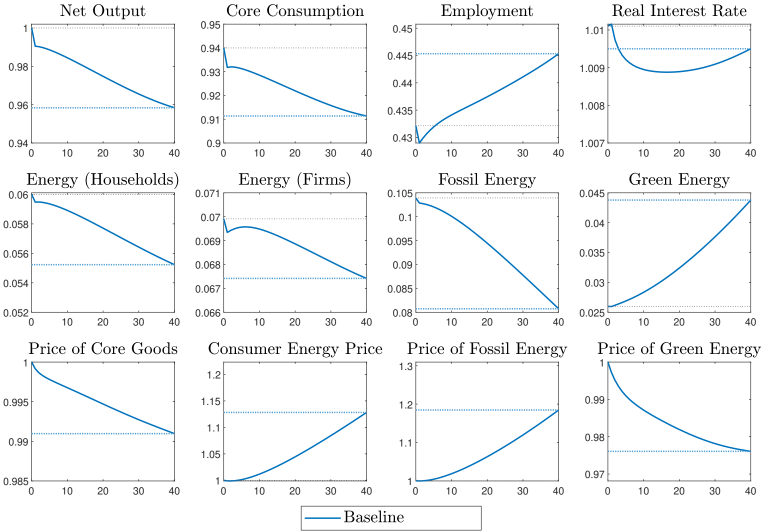

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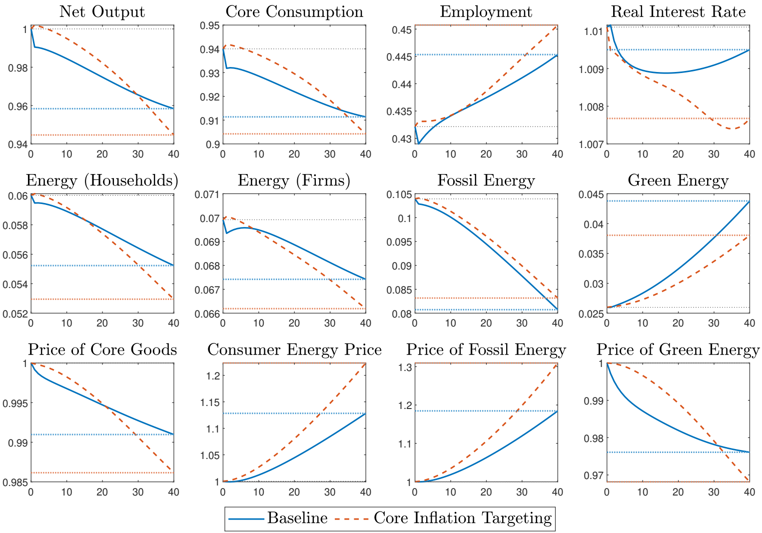

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Conclusions

- The size of adjustments to climate policy shocks and the best monetary policy response depend on the elasticity of substitution across production inputs and consumption goods.
- Stabilizing headline inflation performs as well as stabilizing core inflation, since it allows to reduce the volatility in relative prices coming from imperfect complementarity.
- A gradual transition does not necessarily result in higher prices but entails significant real adjustments.

Next Steps

- Compute the optimal (welfare maximizing) monetary policy and compare the performance of alternative monetary rules using it as a benchmark.
- Extend the analysis to dual mandate Taylor rules.
- Equip the model with features needed to make the transition exercise more robust:
  - endogenous sectoral shares
  - growth trends
  - different elasticities in the short and medium run.
- Estimate the model.

Thank you

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Appendix

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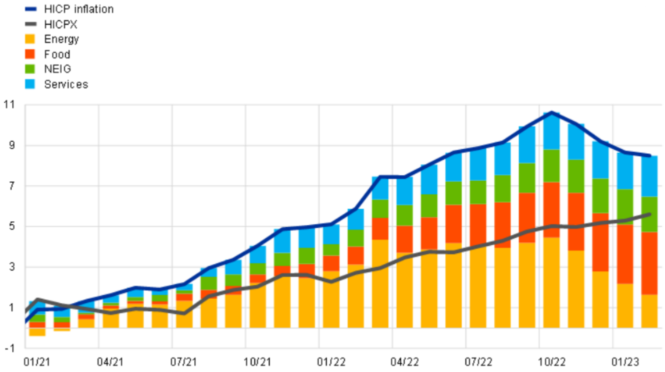
Recent Inflation Developments

Headline inflation and its main components

(annual percentage changes; percentage point contributions)



Sources: Eurostat and ECB calculations.
Notes: HICP stands for Harmonised Index of Consumer Prices. HICPX stands for HICP inflation excluding energy and food. NEIG stands for non-energy industrial goods. The latest observations are for February 2023 (flash estimate).

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The Model

Climate module

Following Golosov et al. (2014), global warming affects firms' productivity via a damage factor Δ_t :

$$\Delta_t = \exp\left(-\eta(Z_t - \overline{Z})\right), \quad \eta > 0$$

The stock of emissions in the atmosphere Z_t evolves as:

$$Z_t - \overline{Z} = (1 - \delta_Z)\left(Z_{t-1} - \overline{Z}\right) + O_t + O_t^{RoW}$$

where $\overline{Z}$ is the pre-industrial concentration of pollutant, $\delta_Z \in (0,1)$ is the natural decay rate and O_t^{RoW} are emissions from the rest of the world.

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Calibration II

	Description	Value
Steady state ratios and values		
$P_{CE}C_E/P_C C$	Energy share in consumption	0.06
$P_{ME}M_E/P_Y Y$	Energy share in production	0.07
$E_F/(M_E+M_E)$	Fossil energy share on total energy	0.80
$(N_G+N_F)/N$	Share of labor in energy sectors	0.024
$O/(O+O^{row})$	Share of Euro Area emissions	0.073
Δ	Climate damages	0.002438
Environmental Parameters		
$\bar{Z}$	Pre-industrial concentration of carbon	581
δ_z	Decay rate of greenhouse gases	0.0021
η	Damage function parameter	7.86e-06

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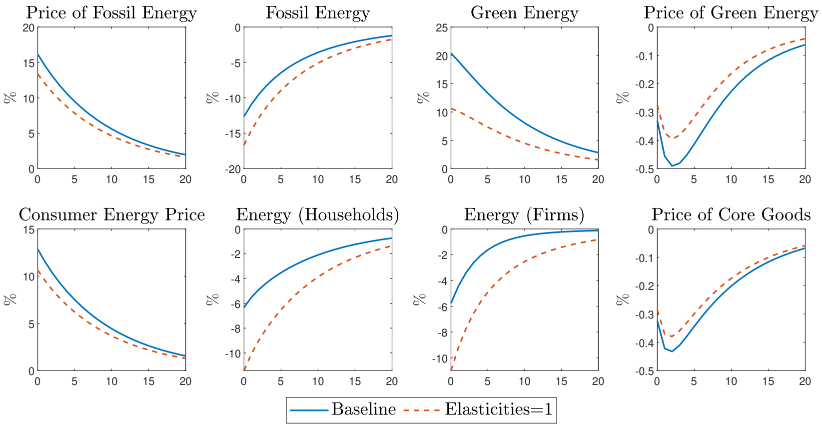
Role of Elasticity of Substitution



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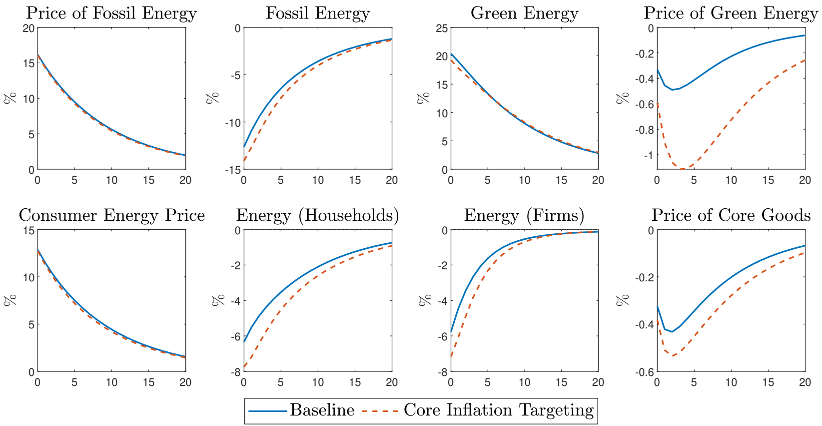
Policy Shock: Headline vs Core



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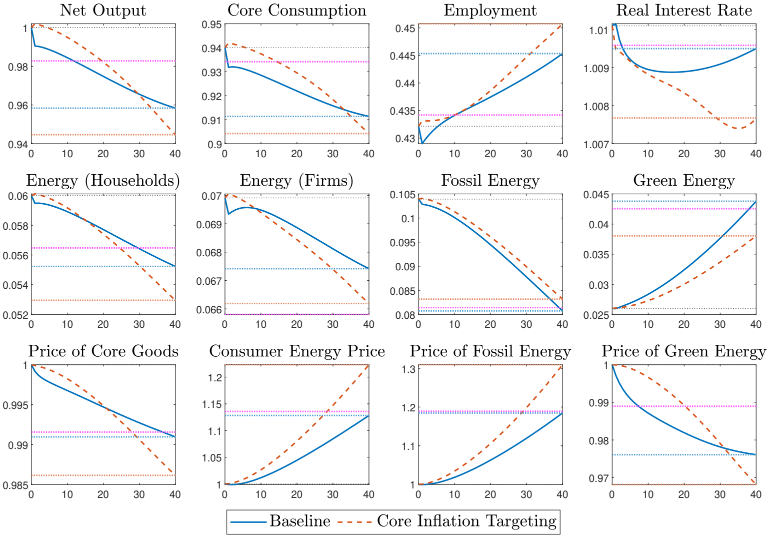
Transition: Headline vs Core vs Flex



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