Carbon Pricing and Monetary Policy in an Estimated Macro-Climate Model*

Sofia Semik†

February 12, 2025

Abstract

I develop and estimate a New Keynesian macro-climate model with energy that accounts for the response of the euro area economy to carbon policy shocks. Using data from the EU emission trading system, I identify three key features of carbon price increases: a gradual reduction of emissions, an immediate surge in headline inflation and a significant drop in economic activity. To account for the gradual decline in emissions, I introduce fossil energy adjustment costs into the model, capturing constraints in reducing fossil energy use. In addition, a low substitutability between green and fossil energy allows the model to replicate the sharp increase in headline inflation and the fall in economic activity. The estimated model suggests that monetary policy can substantially mitigate GDP losses from carbon pricing by focusing on core rather than headline inflation, making a Taylor rule with core inflation targeting a welfare-improving strategy in this context.

JEL Codes: E52,H23,Q43,Q58

Keywords: Carbon pricing, monetary policy, emissions, Bayesian estimation

*I'm grateful for the comments and suggestions I received from colleagues, the participants of the 2nd International Conference on the Climate-Macro-Finance Interface, Diego Känzig and especially for the feedback I received from my supervisor Mathias Trabandt.

†Goethe University Frankfurt am Main, semik@em.uni-frankfurt.de

1 Introduction

Climate change has become an increasingly urgent global challenge, prompting governments to implement ambitious policies to transition toward a low-carbon economy. As carbon pricing policies expand, a growing body of research has developed environmental DSGE models to assess their macroeconomic implications (see for instance Annicchiarico and Di Dio (2015), Diluiso et al. (2021), Coenen et al. (2024), Sahuc et al. (2025)). However, there remains significant uncertainty regarding the actual effects of carbon price increases on the macroeconomy, particularly in light of concerns about "greenflation"—the inflationary pressures resulting from higher energy costs (Schnabel, 2022). To effectively design and evaluate monetary policy responses to macroeconomic dynamics caused by carbon policy initiatives, it is crucial to have a model that accurately captures the empirical effects of carbon pricing.

In this paper, I develop and estimate a two-agent New Keynesian macro-climate model with energy that accounts for macroeconomic effects of carbon price increases in the euro area observed in the data. I assess the macroeconomic impact of carbon price increases on the EU Emission Trading System (EU ETS) carbon market using local projections. For this I use the carbon policy shock series constructed by Känzig (2023), which identifies unexpected changes in ETS emission allowance future prices. My findings suggest that carbon policy shocks effectively reduce GHG emissions, though the reduction is not immediate. Instead, emissions decline gradually, likely due to technological constraints and infrastructure limitations that prevent an instantaneous shift away from fossil energy. However, the emission reduction comes at an economic cost for the euro area. The carbon policy shock triggers a sharp increase in energy prices, which is then passed on to consumer prices, leading to an immediate rise in headline inflation. Higher energy costs raise production expenses for firms and increase households' energy bills, causing a decline in economic activity. The fall in wages, stemming from firms' higher energy-related costs, further reduces household income, amplifying the drop in consumption and aggregate demand. This downturn is potentially exacerbated by monetary policy tightening, as central banks respond to inflationary pressures by raising interest rates.

To accurately capture these empirical dynamics, I estimate my model using Bayesian impulse response matching. This methodology involves minimizing the distance between the dynamic responses of my model to a carbon policy shock and analog objects in the data obtained from the local projections. My model accounts well for the key features of the estimated impulse response functions: a gradual decline in emissions, an immediate surge in headline inflation and a significant drop in economic activity. The following parameter specifications are key features for the success of the model fit:

The first non-standard feature of my model is the introduction of quadratic adjustment costs for fossil energy producers, preventing an immediate reduction in fossil energy use following a carbon price shock. The posterior mode of the adjustment cost parameter suggests that these costs are significantly positive. These frictions reflect real-world technological constraints and infrastructure limitations, ensuring that the delayed decline in emissions observed in the data is replicated in the model. Second, the estimated elasticity of substitution between green and fossil energy is below unity in my model, indicating that these energy sources are complements rather than substitutes. This contrasts with much of the literature, where substitution elasticities typically range between 1.8 and 3. The low substitutability in my model is essential to capturing the strong pass-through from fossil energy prices to aggregate energy prices. Higher substitutability would imply a weaker inflationary response, leading to an underestimation of the observed rise in consumer prices and the associated decline in aggregate demand. Third, there is very strong complementarity of energy in production and consumption. The model assumes that energy is a crucial input for both firms and households, making it difficult to substitute away from energy consumption. This amplifies the economic effects of carbon price shocks, as it makes households and firms more vulnerable to higher energy prices following carbon policy shocks.

Having a model that accurately accounts for the macroeconomic effects of carbon policy shocks is essential for meaningful policy analysis. I assess the role of monetary policy in mitigating the economic costs of carbon pricing. Specifically, I evaluate how different monetary policy rules influence the macroeconomic response to a large and permanent carbon price shock, consistent with expected future increases in EU ETS prices. The results suggest that a monetary policy rule targeting core inflation instead of headline inflation can significantly reduce GDP losses from carbon price shocks. By focusing on core inflation, the central bank effectively "looks through" the temporary surge in energy inflation, avoiding excessive monetary tightening. While this approach leads to a somewhat larger initial increase in headline inflation, this effect is not persistent. In contrast, the mitigation of GDP losses is substantial, making core inflation targeting a welfare-improving policy choice. However, this policy trade-off comes with a small reduction in the effectiveness of carbon pricing in lowering emissions.

This paper contributes to the growing literature on macro-climate DSGE models by providing an empirically grounded framework for assessing the macroeconomic effects of carbon pricing in the euro area. As climate policies become more ambitious, understanding these dynamics is crucial for designing effective policy frameworks, especially with regard to the design of monetary policy in response to inflationary pressures and GDP losses caused by carbon policy initiatives.

Related Literature. This papers contributes to both empirical and theoretical literature on the macroeconomic effects of climate change mitigation policies and potential implications for monetary policy. First, my paper is related to a growing strand of empirical literature assessing the macroeconomic effects of carbon price increases. The empirical part is closely related to Känzig (2023). Känzig uses high-frequency identification of regulatory events on the European carbon market to construct a carbon policy surprise shock series and study the effects on the euro area economy and on emissions. His findings suggest that an increase in the EU ETS carbon price is effective in reducing emissions, but entails economic costs as it creates inflationary pressures and a fall in employment and real activity. Metcalf and Stock (2023) analyze the macroeconomic implications of European carbon taxes. Interestingly, they find that while carbon taxes reduce emissions, they do not lead to a significant reduction in GDP. Similarly, Konradt and Weder di Mauro (2023) do not find evidence for significant inflationary pressures caused by carbon taxes using data from European and Canadian carbon tax regimes.

I contribute to this literature by assessing the impact of EU ETS carbon price increases on emissions and the macroeconomy and using these results to estimate a New Keynesian macro-climate model with energy using Bayesian impulse response matching. Gagliardone and Gertler (2023) use a similar methodology to estimate a model to match the impulse responses to an oil shock. Their findings suggest that strong complementarity of oil in production and consumption are key to account for the macreconomic dynamics following an oil price increase. Sahuc et al. (2025) estimate a simple New Keynesian climate model without an explicit energy sector to analyze long-term transition scenarios under different climate policy regimes.

The second related strand of literature focuses on developing New Keynesian models with energy to assess the impact of carbon price increases on inflation and the conduct of monetary policy. Coenen et al. (2024) extend the ECB's New Area-Wide Model with a disaggregated energy sector to assess the impact of different carbon transition paths on the euro area economy. Their results suggest an increase in headline inflation and a fall in aggregate demand during the transition due to the increase in energy prices. Similarly, Olovsson and Vestin (2023) find that it is optimal for euro area monetary policy to see through increasing energy prices and focus on stabilizing core inflation, which leads to an increase in headline inflation. However, their results suggest that this increase is modest as long as the carbon tax path is pre-announced. Del Negro et al. (2023) develop a two-sector model to study how the green transition affects the central bank's trade-off between keeping prices stable and closing the output gap. Nakov and Thomas (2023) study Ramsey optimal monetary policy in a model with climate externalities and how it is affected by different environmental policy regimes. I estimate a model with energy that is able to account for the gradual response in emissions, inflationary pressures and the significant fall in economic activity following a carbon policy shock to assess the implications of climate change mitigation for the macroeconomy and monetary policy.

Structure. The remainder of the paper is structured as follows: Section 2 presents empirical evidence on the macroeconomic effects of a carbon policy shock in the euro area. Section 3 introduces the New Keynesian macro-climate model with energy. Section 4 outlines the estimation methodology, presents the results and discusses key parameter specifications. Section 5 evaluates the impact of alternative monetary policy rules on the macroeconomic implications of carbon policy shocks. Section 6 concludes.

2 Empirical Analysis

In this section, I assess the macroeconomic implications of an increase in the EU ETS carbon price in the euro area. The EU ETS operates as a carbon market where a fixed number of emission allowances are issued, granting firms the right to emit greenhouse gases (GHGs) into the atmosphere. Firms can buy, sell, and trade these allowances, creating a market-driven price for carbon emissions. To identify changes in the ETS price, I rely on the carbon policy shock series developed by Känzig (2023), which captures unexpected variations in emission allowance futures prices using high-frequency surprise changes. It is a monthly shock series that spans from 1999 to 2019. I estimate the effects using simple local projections:

$$y_{i,t+h} = \beta^i_{h,0} + \gamma^i_h CPShock_t + \beta^i_{h,1} y_{i,t-1} + ... + \beta^i_{h,p} y_{i,t-p} + \epsilon_{i,t,h}, \tag{1}$$

where $CPShock_t$ is the ETS carbon policy shock series. Thus, γ^i_h captures the effect of a carbon policy shock on variable i at horizon h. I use quarterly euro area data from 1999Q1 to 2019Q4 to asses the impact of carbon price increases on prices, GHG emissions and real activity. Specifically, I use the following set of variables:

$$y_t^{12\times 1} = \begin{pmatrix} \log(\text{real fossil energy price}_t) \\ \text{HICP energy inflation (annualized)}_t \\ \text{HICP inflation (annualized)}_t \\ \text{HICP inflation excluding energy (annualized)}_t \\ \text{EONIA}_t \\ \log(\text{GHG emissions}_t) \\ \log(\text{real GDP}_t) \\ \log(\text{real consumption}_t) \\ \log(\text{real investment}_t) \\ \log(\text{real wages}_t) \\ \log(\text{hours}_t) \\ \text{capacity utilization}_t \end{pmatrix}.$$

The real fossil energy price is constructed as a weighted bundle of the Brent crude oil price and the HICP component for gas, deflated by headline HICP. The EONIA interbank interest rate is used as a proxy for the ECB policy rate, since the interest rate has been at the zero lower bound for a large part of the sample. As data on GHG emissions is only available at an annual frequency, I construct a quarterly measure of emissions using code from Quilis (2024) on Chow-Lin temporal disaggregation with indicators. As quarterly indicators I use the energy component of HICP and industrial production, following Känzig (2023). I aggregate the monthly carbon policy shock series up to a quarterly frequency to match the frequency of the data. I use three lags of the dependent variables as controls in the local projections ($p = 3$).

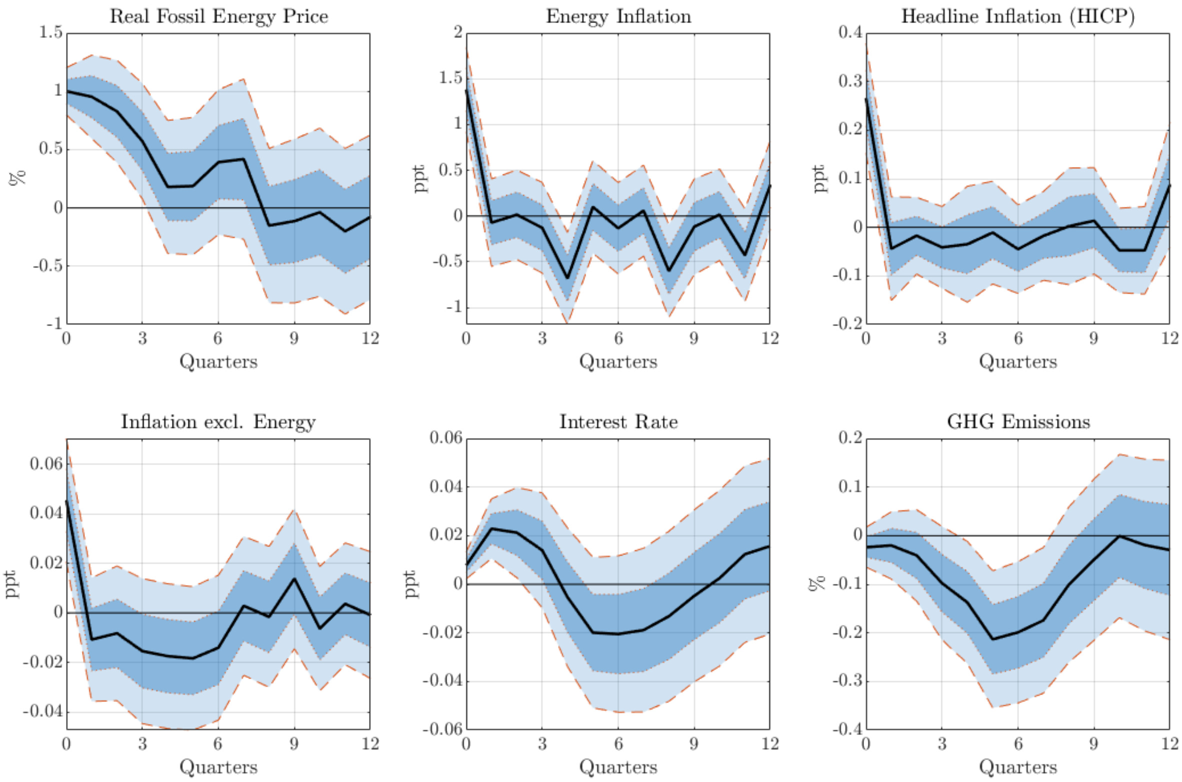

Figure 1: Impulse responses of prices and emissions

The solid line is the point estimate, the dark and light shaded areas are 68 and 95 % confidence bands. The shock is normalized to increase the real fossil energy price by 1%.

Figure 1 presents the impulse responses to a carbon policy shock for the first set of variables, prices and GHG emissions. The shock is normalized to increase the real price of fossil energy by 1% on impact. The confidence bands are computed using the lag-augmentation approach from Montiel Olea and Plagborg-Møller (2021). The carbon policy shock leads to an immediate increase in fossil energy prices, and therefore also in aggregate energy prices. Energy inflation increases by almost 1.5 percentage points on impact. The pass-through of energy prices to consumer prices appears to be strong, as headline inflation increases by about 0.25 percentage points on impact. Higher energy prices also lead to a small increase in inflation excluding energy on impact, since they also increase the production costs of firms, which is passed on to consumers. The nominal interest rate increases by about 2 basis points at its peak during the first year following the shock, which implies that monetary policy seems to react these inflationary pressures. Finally, the carbon price increase appears to be effective in reducing emissions. The shock leads to a peak reduction in GHG emissions by about 0.2 percent. Interestingly, this reaction does not happen immediately with the increase in fossil fuel prices, but the peak is only reached after almost two years. In terms of both direction and magnitude, these results are consistent with Känzig (2023) as well as previous evidence on different energy price shocks, such as oil shocks (Känzig (2021), Baumeister and Hamilton (2019)).

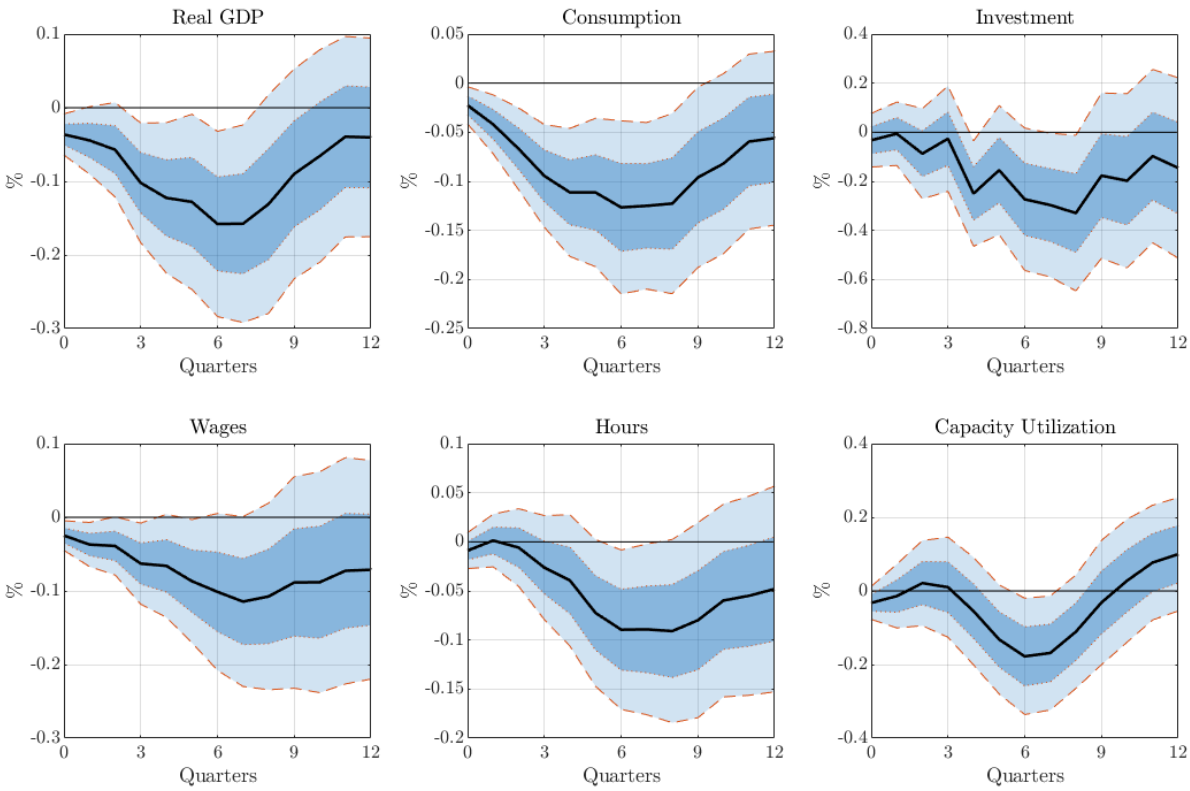

Figure 2: Impulse responses of macroeconomic aggregates

The solid line is the point estimate, the dark and light shaded areas are 68 and 95 % confidence bands. The shock is normalized to increase the real fossil energy price by 1%.

The above results indicate a strong pass-through from fossil energy to consumer prices. Figure 2 displays the response of several macroeconomic aggregates to the same carbon price shock to understand its macroeconomic implications. The shock leads to a significant decline in real GDP with a peak reduction of about 0.15 %, driven by a fall in both consumption and investment. Moreover, the shock leads to a decline in real wages, hours worked and capacity utilization in production. Higher energy prices from carbon policy innovations directly impact disposable income of households and firms, leading to a decline in consumption and investment expenditure. This in turn leads to lower output, which provides an incentive for firms to lower their labor costs. This can be seen from the delayed but significant decline of wages and hours worked in figure 2. The resulting reduction in labor income leads to an additional decrease in aggregate demand. Contractionary monetary policy in response to the inflationary pressures from higher energy prices poses another possible channel impacting the decline in aggregate demand. According to Känzig (2023), these indirect general equilibrium effects account for over 2/3 of the aggregate effect on consumption, explaining the significant response of the real economy to the carbon policy shock. The decline of capacity utilization in response to the carbon policy shock indicates that firms cut down production since they face higher costs for their energy use.

3 The Model

The model is a two-agent New Keynesian (TANK) framework extended by an energy sector. The economy is populated by ricardian and hand-to-mouth households, final good producers, intermediate good producers as well as producers of green and fossil energy. The production of fossil energy generates carbon emissions, while green energy production is carbon-neutral. A bundle of green and fossil energy is used for both intermediate goods production and final consumption of households. Carbon policy is modeled as a surcharge on the price of fossil energy. The model also features a climate change externality, such that carbon emissions negatively affect total factor productivity.

3.1 Households

The model features two types of households: Ricardian agents, denoted by subscript R, and hand-to-mouth agents, denoted by subscript H. R agents perform intertemporal optimization, have access to financial markets and supply capital. Their preferences are specified as:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \log(c_{t,R} - bc_{R,t-1}) - \frac{h_{t,R}^{1+\varphi}}{1+\varphi} \right\}, \tag{2}$$

where $c_{t,R}$ represents final consumption, $h_{t,R}$ represents hours worked, $\beta \in (0,1)$ is the discount factor, b controls the degree of habit formation and ϕ is the inverse Frisch elasticity.

The R household's budget constraint is defined as follows in nominal terms:

$$\sum_j P_t c_{t,R} + P_t^I i_t^j + B_{t+1} = W_t h_{t,R} + (R_t^{k,j} u_t^j - a(u_t^j) P_t^I) K_{t-1}^j + R_{t-1} B_t + T_{t,R} + \Pi_t. \tag{3}$$

Here, P_t is the price of final consumption goods and P_t^I is the price of investment goods $i_t^j, j \in (Y, G, B)$. Investment is allocated across three different sectors: capital goods for intermediate goods production k_t^Y, green energy production k_t^G and fossil energy production k_t^B. R_t^k is the nominal rental rate of capital and $u_t^j K_t^j$ denotes the household's supply of capital services in the given period, where u_t^j is the capacity utilization rate. $a(u_t^j)$ denotes cost of capacity utilization in units of investment goods. R households can invest in one-period risk-free bonds B_{t+1}, where $R_{t-1}B_t$ denotes the revenue from holding bonds. $W_t h_{t,R}$ is household R' labor income, $T_{t,R}$ are lump-sum transfers directed towards R agents and Π_t are firm profits.

Following Christiano et al. (2005), R households face quadratic adjustment costs in investment, so that investment is smoothed over time. This results in the following capital law of motion for each sector:

$$k_t^j = (1-\delta)k_{t-1}^j + \left[1 - \frac{\kappa_I}{2}\left(\frac{i_t^j}{i_{t-1}^j} - 1\right)^2\right] i_t^j, \quad j \in (Y, G, B) \tag{4}$$

where κ_I denotes the investment adjustment cost parameter.

Labor supplied by individual households is differentiated, which yields the following expression for aggregate labor supply:

$$h_{t,R} = \left(\int_0^1 h_{t,R}(i)^{\frac{\varepsilon_W - 1}{\varepsilon_W}} di\right)^{\frac{\varepsilon_W}{\varepsilon_W - 1}}, \tag{5}$$

where ε_W is the elasticity of substitution between individual varieties.

Ricardian households are assumed to set wages in a Calvo-style staggered fashion. Each period household i is able to reoptimize its nominal wage rate with probability $1 - \theta_W$. The remaining fraction of households cannot reoptimize, such that $W_t(i) = W_{t-1}(i)$ with probability θ_W.

The second type of households are hand-to-mouth, meaning they do not perform intertemporal optimization and have no access to financial markets, but instead consume all disposable income in a given period. Their budget constraint reads as follows:

$$P_t c_{t,H} = W_t h_{t,H} + T_{t,H},$$

where $T_{t,H}$ are transfer payments directed towards H households. For simplicity, I assume that H agents have no bargaining power and do not optimize their hours worked, but instead work the same hours as R agents, $h_{t,H} = h_{t,R}$ to earn economy-wide wage W_t following Erceg et al. (2024). Including hand-to-mouth agents is crucial to account for potentially large demand-side effects of energy price shocks (see Auclert et al. (2023), Chan et al. (2024), Känzig (2023)).

To capture the energy consumption of households, final consumption $c_{t,j}$ is modeled as a CES bundle of energy ($c_{t,j}^E$) and the manufactured good from final good production

$(c^X_{t,j})$, such that

$$c_{t,j} = \left(\gamma_c^{\frac{1}{\varrho_c}} (c^E_{t,j})^{\frac{\varrho_c - 1}{\varrho_c}} + (1-\gamma_c)^{\frac{1}{\varrho_c}} (c^X_{t,j})^{\frac{\varrho_c - 1}{\varrho_c}} \right)^{\frac{\varrho_c}{\varrho_c - 1}}, \; j \in \{H, R\}. \tag{6}$$

Here, γ_c determines the share of energy in final consumption[1] and ϱ_c is the elasticity of substitution between energy and the manufactured good. The resulting demand equations for energy and the manufactured consumption good are:

$$c^E_{t,j} = \gamma_c \left(\frac{P^E_t}{P_t} \right)^{-\varrho_c} c_{t,j}, \tag{7}$$

$$c^X_{t,j} = (1-\gamma_c) \left(\frac{P^X_t}{P_t} \right)^{-\varrho_c} c_{t,j}, \tag{8}$$

where P^E_t and P^X_t are their respective prices. The CPI can therefore be defined such that it captures both goods and energy prices:

$$P_t = \left(\gamma_c (P^E_t)^{1-\varrho_c} + (1-\gamma_c)(P^X_t)^{1-\varrho_c} \right)^{\frac{1}{1-\varrho_c}}. \tag{9}$$

This specification makes it possible to explicitly define a measure for core inflation π^X_t, which, in contrast to headline inflation π_t, excludes fluctuations in energy prices:

$$\pi^X_t = \frac{p^X_t}{p^X_{t-1}} \pi_t, \tag{10}$$

where p^X_t denotes the manufactured good price in terms of domestic CPI.
Similarly, energy inflation is defined as follows:

$$\pi^E_t = \frac{p^E_t}{p^E_{t-1}} \pi_t. \tag{11}$$

3.2 Final good firms

The representative final-good firm uses the following CES bundle to produce the final good y_t:

$$y_t = \left(\int_0^1 y_t(i)^{\frac{\varepsilon - 1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon - 1}}, \tag{12}$$

[1]For now I assume that the share of energy in the households' final consumption expenditure is identical between ricardian and hand-to-mouth agents. Although there is evidence that low income households spend a larger fraction of their aggregate expenditure on essential goods like energy, Känzig (2023) shows that this channel is of secondary importance regarding the distributional consequences of energy price shocks. The heterogeneous income incidence of these households is the key driver of the consumption response to energy price increases. However, I am working on introducing households with heterogeneous energy expenditure shares.

where $y_t(i)$ is an intermediate good produced by intermediate good firm i and ε is the elasticity of substitution between intermediate goods. The profit maximization problem of the final good firm reads as follows:

$$\max_{y_t,\{y_t(i)\}_{i\in[0,1]}} P_t^X y_t - \int_0^1 P_t^X(i) y_t(i) di \tag{13}$$

$$\text{s.t.} \quad y_t = \left(\int_0^1 y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}. \tag{14}$$

Here, $P_{H,t}(i)$ is the price of the intermediate good produced by firm i in the home country. The problem yields the following intermediate input demand:

$$y_t(i) = \left(\frac{P_t^X(i)}{P_t^X} \right)^{-\varepsilon} y_t. \tag{15}$$

3.3 Intermediate good firms

A continuum of intermediate goods $y_t(i)$ is produced by price setting firms that are optimizing under monopolistic competition. The production function of these firms is a CES aggregator in energy and value added from a Cobb-Douglas bundle of capital and labor, following Hassler et al. (2021):

$$y_t(i) = A_t^Y \left[(1-\gamma_Y)^{\frac{1}{\varrho_Y}} \left((u_t^Y k_{t-1}^Y(i))^{\alpha} (h_t^Y(i))^{1-\alpha} \right)^{\frac{\varrho_Y - 1}{\varrho_Y}} + (\gamma_Y)^{\frac{1}{\varrho_Y}} \left(e_t^Y(i) \right)^{\frac{\varrho_Y - 1}{\varrho_Y}} \right]^{\frac{\varrho_Y}{\varrho_Y - 1}}, \tag{16}$$

where $e_t^Y(i)$, $u_t^Y k_{t-1}^Y(i)$ and $h_t^Y(i)$ respectively is the energy, effective capital and labor demanded by firm i, α is the capital share in the value added from capital and labor, γ_Y is the energy share in intermediate goods production and ϱ_Y is the elasticity of substitution between energy and the capital-labor bundle.

Firms set their price P_t^X and choose input factors capital, labor and energy to maximize profits subject to their production technology (16) and the demand of the final good firm (15).The firms set prices in Calvo-style staggered contracts, such that each firm faces a constant probability $1-\theta_P$ of being able to adjust its price. The remaining firms that are not able to reoptimize set their price according to $P_t^X(i) = P_{t-1}^X(i)$.

3.4 Energy sector

A representative energy firm combines two different energy sources, green energy e_t^G and brown (fossil) energy e_t^B, to provide energy services to households and for intermediate goods production. The energy inputs are bundled using the following CES aggregator:

$$e_t = \left((1-\zeta)^{\frac{1}{\xi}} (e_t^G)^{\frac{\xi-1}{\xi}} + \zeta^{\frac{1}{\xi}} (e_t^B)^{\frac{\xi-1}{\xi}} \right)^{\frac{\xi}{\xi-1}}, \tag{17}$$

where ξ is the elasticity of substitution between green and fossil energy and ζ determines the share of fossil energy in energy production.

Both energy inputs are produced using a Cobb-Douglas bundle of sector-specific capital and labor services k_t^j and h_t^j, $j \in \{B, G\}$:

$$e_t^j = A_t^j (u_t^j k_{t-1}^j)^{\alpha_E} (h_t^j)^{1-\alpha_E}, \quad j \in \{B, G\}, \tag{18}$$

where u_t^j is the sector-specific rate of capacity utilization.
Fossil energy production generates carbon emissions m_t, such that:

$$m_t = \vartheta e_t^B, \tag{19}$$

where ϑ determines the carbon content of fossil energy production.
The profits of the energy firm are defined as follows:

$$\Pi_t^E = p_t^E e_t - p_t^B (1+\tau_t) e_t^B - p_t^G e_t^G - \Phi \left(\frac{e_t^B / e_t}{e_{t-1}^B / e_{t-1}} \right) p_t^E e_t, \tag{20}$$

where the carbon policy rate τ_t is modeled as a surcharge on the price of fossil energy. I choose to model carbon policy as a carbon tax for simplicity, because both carbon taxes and cap-and-trade systems like the EU ETS increase the price of fossil fuel use to reduce emissions. The carbon tax rate follows an AR(1) process:

$$\log(\tau_t) = (1-\rho_\tau) \log(\overline{\tau}) + \rho_\tau \log(\tau_{t-1}) + \epsilon_t^\tau, \tag{21}$$

where ϵ_t^τ is an exogenous carbon policy shock and $\overline{\tau}$ is the steady state carbon tax rate. Furthermore, energy producers face quadratic adjustment costs in the share of fossil energy, similar to the adjustment cost function defined in Coenen et al. (2024):

$$\Phi \left(\frac{e_t^B / e_t}{e_{t-1}^B / e_{t-1}} \right) = \frac{\kappa_E}{2} \left(\frac{e_t^B / e_t}{e_{t-1}^B / e_{t-1}} - 1 \right)^2. \tag{22}$$

These costs are crucial to account for the slow adjustment of fossil energy use following a carbon price increase, for instance due to long-term contracts with fossil fuel providers or the lack of appropriate infrastructure to switch to renewable energy sources. This cost implies a trade-off for energy firms. Higher carbon prices create an incentive for energy firms to reduce fossil fuel use to lower production costs. However, the firms face adjustment costs, preventing large and abrupt cuts in fossil energy use.

3.5 Monetary and fiscal policy

The fiscal authority levies the carbon tax on energy firms and rebates the revenues to households via lump-sum transfers. This seems to be the most neutral assumption for revenue use, as the revenues from the EU ETS are supposed to either finance environmental projects or be rebated to households. I abstract from the existence of public debt and assume the fiscal authorities run a balanced budget at all times. The government budget constraint takes the following form:

$$\tau_t p_t^B e_t^B = T_t + p_t^X g, \tag{23}$$

where government spending g is assumed to be constant.

The central bank follows a Taylor rule to set the nominal interest rate r_t:

$$\frac{r_t}{r} = \left(\frac{r_{t-1}}{r}\right)^{\rho_r} \left[\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{gdp_t}{gdp}\right)^{\phi_y} \left(\frac{gdp_t}{gdp_{t-1}}\right)^{\phi_{\Delta y}}\right]^{(1-\rho_r)}, \tag{24}$$

In the baseline analysis, the central bank is assumed to respond to deviations in headline HICP inflation, GDP and GDP growth.

3.6 Climate change

I introduce a climate change externality as in Golosov et al. (2014) into my model to capture negative effects of increasing atmospheric carbon on the economy. The externality creates a two-way interaction between the economy and climate change. In the benchmark model, fossil energy production generates carbon emissions, which feed into the stock of atmospheric carbon. The stock of atmospheric carbon evolves according to the following process:

$$S_t = (1-\delta_S)S_{t-1} + (m_t + m^{row}), \tag{25}$$

where $\delta_{S,0}$ is the depreciation rate of carbon dioxide from the atmosphere and $\delta_{S,1}$ is the percentage of carbon emissions that enter the atmosphere. The global stock of atmospheric carbon is fueled by domestic euro area emissions m_t and emissions from the rest of the world m^{row}, which is constant over time, because I assume no climate policy action in the rest of the world.

The extended model now introduces a feedback effect, such that the environmental damage from higher atmospheric carbon reduces total factor productivity.[2]. Following

[2] Antoher approach of some environmental DSGE models is to include the pollution externality directly into the utility function of households (see Acemoglu et al. (2012), Benmir et al. (2020), Barrage (2020)). However, Nordhaus (2008) and Heutel (2012) argue that such a modeling choice would be more appropriate for conventional pollutants that directly affect health rather than greenhouse gases.

Golosov et al. (2014), total factor productivity in each production sector is then modeled as follows:

$$A_t^i = a_t^i e^{-\psi S_t}, \qquad i \in \{Y, G, B\}, \tag{26}$$

where ψ is the damage parameter that determines the size of the externality and $a_t^i, i \in \{Y, G, B\}$ is the total factor productivity that would prevail in each sector without the environmental externality.[3]

3.7 Market clearing and functional forms

The labor and energy market clear such that:

$$h_t = h_t^Y + h_t^B + h_t^G, \tag{27}$$

$$e_t = \lambda c_{t,H}^E + (1-\lambda) c_{t,R}^E + e_t^Y, \tag{28}$$

where λ denotes the share of hand-to-mouth agents.
Aggregate investment is defined as follows:

$$i_t = i_t^Y + i_t^B + i_t^G. \tag{29}$$

Aggregating firm profits implies:

$$\Pi_t = \Pi_t^Y + \Pi_t^F + \Pi_t^G. \tag{30}$$

The resource constraint of the economy is then obtained by plugging the government budget constraint and the profit functions of intermediate goods firms and energy producers into the weighted sum of household budget constraints:

$$p_t^X y_t = p_t^X c_t^X + p_t^I i_t + p_t^X g + \sum_j a(u_t^j) k_{t-1}^j + \Phi\left(\frac{e_t^B / e_t}{e_{t-1}^B / e_{t-1}}\right) p_t^E e_t, \quad j \in \{Y, B, G\}. \tag{31}$$

Real GDP is measured as follows:

$$gdp_t = c_t + p_t^I i_t + p_t^X g, \tag{32}$$

where aggregate consumption is defined as:

$$c_t = \lambda c_{t,H} + (1-\lambda) c_{t,R}. \tag{33}$$

[3]For simplicity, this is set to $a_t^i = 1$ in each sector.

The capacity utilization adjustment cost function is defined as:

$$a(u) = \frac{1}{2}\sigma_0\sigma_a u^2 + \sigma_0(1-\sigma_a)u + \sigma_0\left(\frac{1}{2}\sigma_a - 1\right), \tag{34}$$

where σ_0 is set such that $a(1) = a'(1) = 0$ in steady state. The parameter σ_a controls the curvature of the adjustment cost function, such that a higher σ_a indicated larger costs for changing capacity utilization.

A full set of equilibrium equations as well as the steady state of the model is listed in appendix A.

4 Estimation Results

I estimate the key parameters of the model by matching the dynamic responses to a carbon policy shock in the model with the estimated impulse responses from the data presented in section 2 using Bayesian impulse response matching. First, I calibrate a set of parameters and then estimate the remaining parameters conditional on the set of calibrated parameters.

4.1 Estimation methodology

For the estimation I follow the limited information Bayesian methodology developed in Christiano et al. (2010) that minimizes the distance between the dynamic impulse responses to the carbon policy shock ϵ_τ in the model and the analog responses in the data. The impulse responses from the data are estimated using local projections in section 2. I use ten of the variables considered in the local projections for the estimation procedure: real fossil energy prices, energy inflation, headline inflation, nominal interest rate, emissions, real GDP, real consumption, real investment, real wages and capacity utilization.

The estimation procedure relies on the assumption that the structural model correctly describes the data-generating process. Let θ_0 denote the true values of the model parameters, and let $\psi(\theta)$ represent the mapping from the parameter space to the model-implied impulse responses. Then, $\psi(\theta_0)$ corresponds to the true impulse responses, which are estimated from the data as $\hat{\psi}$. Under standard asymptotic sampling theory, when the number of observations T is large, the empirical impulse responses satisfy:

$$\sqrt{T}\left(\hat{\psi} - \psi(\theta_0)\right) \overset{d}{\sim} N(0, W(\theta_0, \zeta_0)). \tag{35}$$

Here, θ_0 represents the true values of the model parameters, while ζ_0 denotes the true values of shocks that are not explicitly estimated. The vector $\hat{\psi}$ includes the contemporaneous and 11 lagged responses of the 10 variables used for the estimation. The asymptotic distribution of $\hat{\psi}$ can be rewritten as:

$$\hat{\psi} \overset{d}{\sim} N(\psi(\theta_0), V), \tag{36}$$

where $V = W(\theta_0, \zeta_0)/T$. In practice, I use a consistent estimator for V, considering only diagonal elements, as suggested by Christiano et al. (2010).

To estimate the model parameters, I treat $\hat{\psi}$ as observed data and specify prior distributions for θ. Using Bayes' theorem, I compute the posterior distribution of θ given $\hat{\psi}$ and V. The likelihood function for $\hat{\psi}$ given θ is approximated by:

$$f(\hat{\psi}|\theta, V) = (2\pi)^{-N/2}|V|^{-1/2} \exp\left[-0.5(\hat{\psi} - \psi(\theta))' V^{-1}(\hat{\psi} - \psi(\theta))\right]. \tag{37}$$

Maximizing this function provides an approximate maximum likelihood estimator for θ. The likelihood function is derived from the asymptotic distribution of the impulse responses and accounts for estimation uncertainty. I obtain parameter estimates by maximizing the posterior density and use a Markov Chain Monte Carlo (MCMC) algorithm to sample from the posterior distribution.

4.2 Calibrated parameters

Table 1: Calibrated parameters

Parameter	Description	Value	Source
$\omega_{e,c}$	Energy share in consumption bundle	0.1	Eurostat, HICP weight
$\omega_{e,y}$	Energy share in production	0.07	Coenen et al. (2024)
ζ	Green energy share	0.15	Eurostat
β	Discount factor	0.995	Standard value
π	Steady-state inflation rate	1.005	ECB target 2% annual rate
φ	Inverse Frisch elasticity	1	Standard value
α	Capital share in production	0.3	Standard value
α^E	Capital share in energy production	0.3	Standard value
δ	Depreciation rate	0.025	Standard value
μ_P	Price mark-up	1.2	Standard value
μ_W	Wage mark-up	1.2	Standard value
λ	Share of HtM households	0.25	Dossche et al. (2021)
δ_S	Decay rate of atmospheric carbon	0.9983	Hassler et al. (2020)
ψ	Damage coefficient	0.00002698	Hassler et al. (2020)
ϑ	Carbon content of fossil energy	1	Hassler et al. (2020)

The model is calibrated to the euro area at a quarterly frequency. All calibrated parameter values are shown in table 1.

The quarterly discount factor is set to $\beta = 0.995$, which implies an annual steady-state real interest rate of 2%. The steady-state inflation rate is calibrated to match an annual inflation of 2% for both core and headline inflation. The substitution elasticity between intermediate goods is set to $\varepsilon = 6$, which is a standard value in New Keynesian models, implying a price mark-up of $\mu_P = \frac{\varepsilon}{\varepsilon - 1} = 1.2$. The wage mark-up is also set to $\mu_W = 1.2$. The capital share in production is set to $\alpha = 0.3$ and capital depreciates at a rate of $\delta = 2.5\%$ each quarter. The inverse Frisch elasticity is set to $\varphi = 2$. The share of hand-to-mouth agents is set to $\lambda = 25\%$ following the estimates from Dossche et al. (2021) for the euro area.

The energy-related parameters are calibrated to match euro area data in steady state. The share of energy in the consumption bundle $\omega_{e,c}$ is calibrated to match the weight of energy expenditure in euro area HICP, which is approximately 10%. The distribution parameter γ_c is then calibrated to ensure this expenditure share of every value of p^E and ϱ_c in steady state:

$$\gamma_c = \omega_{e,c}(p^E)^{\varrho_c - 1}. \tag{38}$$

Similarly, $\omega_{e,y}$ matches the share of energy in production of about 7% in the euro area following Coenen et al. (2024). such that:

$$\gamma_c = \omega_{e,y}\left(\frac{p^E}{p^X}\right)^{\varrho_y - 1}. \tag{39}$$

The share of green energy in aggregate energy production is set to $\zeta = 15\%$, reflecting the average value for the euro area for the sample period of 1999 to 2019.

Finally, for the calibration of the climate module, I follow the estimates from Hassler et al. (2020). The damage function coefficient ψ is estimated to specifically capture damages from carbon-induced temperature increases in Europe.

4.3 Estimated parameters and results

Conditional on the calibrated parameters, I then estimate the remaining sixteen model parameters. Table 3 reports the prior and posterior distributions of the estimated parameters. This section discusses the estimated parameter values and their implications, with a particular focus on the energy-related parameters.

First, the results imply strong complementarity between energy and other inputs in production as well as energy and non-energy goods in consumption. This complementarity is a standard assumption in macro climate models with energy with values usually ranging between 0.2 and 0.5 (Hassler et al. (2021), Coenen et al. (2024), Diluiso et al. (2021)). My estimates are lie slightly below this range with $\varrho_c = 0.13$ and $\varrho_y = 0.06$. The 90% interval is also on the lower end of estimates in the literature. Such a high degree of complementarity makes households and firms very vulnerable to carbon policy shocks, because the sharp increase in energy prices will increase their energy bills, leading

Table 2: Priors and Posteriors of Parameters

Parameter	Prior	Posterior	
	$\mathcal{D}$, Mean [5-95%]	Mode	Mean [5-95%]
Energy complementarity firms, ϱ_y	$\mathcal{G}$, 0.5 [0.13 1.07]	**0.06**	0.08 [0.01 0.16]
Energy complementarity households, ϱ_c	$\mathcal{G}$, 0.5 [0.13 1.07]	**0.13**	0.16 [0.07 0.26]
Substitution green and fossil energy, ξ	$\mathcal{G}$, 2 [0.89 3.47]	**0.72**	0.80 [0.49 1.11]
Fossil energy adjustment cost, κ_E	$\mathcal{U}$, 50 [5 95]	**35.27**	40.23 [28.56 70.39]
Habit persistence, b	$\mathcal{B}$, 0.6 [0.34 0.83]	**0.50**	0.47 [0.29 0.66]
Calvo wage stickiness, θ_w	$\mathcal{B}$, 0.6 [0.34 0.83]	**0.87**	0.88 [0.80 0.96]
Investment adjustment costs, κ_I	$\mathcal{G}$, 5 [1.27 10.73]	**1.92**	2.69 [0.79 4.55]
Capacity utilization adjustment costs, σ_a	$\mathcal{G}$, 1 [0.15 2.46]	**0.40**	0.66 [0.03 1.29]
Calvo price stickiness, θ_p	$\mathcal{B}$, 0.6 [0.34 0.83]	**0.72**	0.67 [0.46 0.81]
Taylor rule inflation coefficient, ϕ_π	$\mathcal{G}$, 1.6 [1.14 2.12]	**1.76**	1.78 [1.29 2.27]
Taylor rule output coefficient, ϕ_y	$\mathcal{G}$, 0.1 [0.01 0.26]	**0.005**	0.01 [0 0.03]
Taylor rule output growth coefficient, $\phi_{\Delta y}$	$\mathcal{G}$, 0.1 [0.01 0.26]	**0.08**	0.13 [0.01 0.27]
Interest rate smoothing, ρ_r	$\mathcal{B}$, 0.8 [0.62 0.94]	**0.96**	0.96 [0.94 0.98]
Autocorr. carbon shock, ρ_τ	$\mathcal{U}$, 0.5 [0.05 0.95]	**0.85**	0.86 [0.82 0.90]
Std.Dev. carbon shock, σ_τ	$\mathcal{G}$, 0.2 [0.09 0.41]	**0.27**	0.27 [0.23 0.31]

Notes: Posterior mode and parameter distributions are based on a standard MCMC algorithm with a total of 500,000 draws (5 chains, 50 percent of draws used for burn-in, acceptance rate about 27%). $\mathcal{B}, \mathcal{G}$ and $\mathcal{U}$ denote beta, gamma and uniform distribution, respectively.

to a significant drop in consumption and investment expenditure. These results are in line with Gagliardone and Gertler (2023) who estimate strong complementarities of oil in production and consumption using an oil price shock.

Second, the posterior mode of the substitution elasticity between green and fossil energy is $\xi = 0.72$. As this value is below unity, this suggests that green and fossil energy sources are complements rather than substitutes in aggregate energy production. In addition, the 90% confidence interval suggest an upper bound of 1.1. The estimation results therefore suggest that green and fossil energy are complements or weak substitutes. Standard values for this parameter usually range from 1.8 to 3, suggesting higher substitutability (Papageorgiou et al. (2017), Coenen et al. (2024)). The substitution elasticity is a key parameter for determining the effectiveness of carbon pricing policies.

Finally, the posterior mode of the fossil energy adjustment cost parameter is significantly positive with $\kappa_E = 35.3$. These types of adjustment costs are non-standard in New Keynesian climate models, implying a value of $\kappa_E = 0$. My results suggest that including adjustment costs in the share of fossil energy is crucial to match the lagged response of emissions following an increase in the ETS carbon price. Section 4.4 provides a detailed analysis of the implications of the parameter estimates for ξ and κ_E.

The remaining parameters, that are not directly related to the energy sector, fall within a reasonable range for standard macroeconomic models. The degree of price stickiness suggests that prices are adjusted every four quarters on average, while wages remain unchanged for about eight quarters on average. Habit persistence $b = 0.5$ is close to the estimate of the New Area Wide Model (Coenen et al. (2018), henceforth NAWM II). Investment and capacity utilization adjustment costs are a little lower than suggested by the NAWM II. The estimated Taylor rule coefficients suggest a high degree of interest rate smoothing and a small coefficient on output growth, while the output gap coefficient is close to zero, which is also in line with the NAWM II. The persistence of the carbon policy shock is approximately $\rho_\tau = 0.85$.

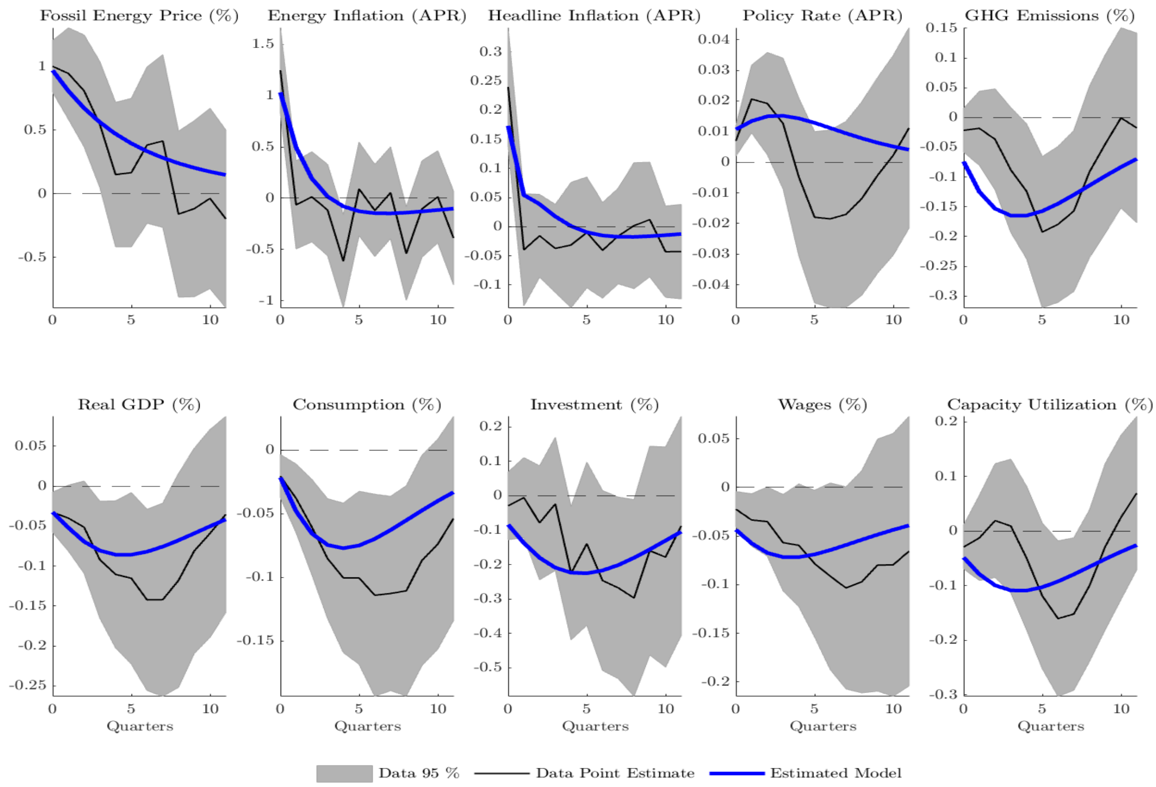

Figure 3: Impulse responses to carbon policy shock: Model vs. Data

Figure 3 compares the dynamic impulse responses from the model, depicted by the blue line, to the responses estimated from the data in section 2, depicted by the black line. The grey areas are the 95% confidence intervals from the local projections. The model adequately captures the dynamics observed in the data following a carbon policy shock. As aggregate energy prices are a bundle of fossil and green energy prices, the carbon price increase leads to a surge in energy inflation. This leads to a rise in headline inflation, both due to a direct increase in households' energy expenditure and due to firms passing on higher production costs to consumers. Higher energy bills directly lead to lower consumption and investment expenditure. The increase in production costs of firms leads to a decline in wages and capacity utilization. Lower wages in turn further decrease aggregate demand. The negative effects on aggregate demand are amplified by the rise in real interest rates as monetary policy leans against inflationary pressures.

4.4 Counterfactual analysis

This section highlights the the crucial role of two key parameters—the substitution elasticity between green and fossil energy ξ and the fossil energy adjustment cost parameter κ_E in accurately capturing the economy's response to a carbon policy shock. These parameters govern how flexibly firms and households can adjust their energy consumption and how smoothly the economy transitions away from fossil energy in response to policy changes. To demonstrate how these two parameters are identified, I fix all estimated model parameters at their posterior mode (as reported in table 3) and simulate two counterfactual scenarios: (i) the absence of fossil energy adjustment costs ($\kappa_E = 0$) (ii) higher substitutability between green and fossil energy ($\xi = 3$). Figure 4 compares the resulting impulse responses to the baseline responses in figure 3.

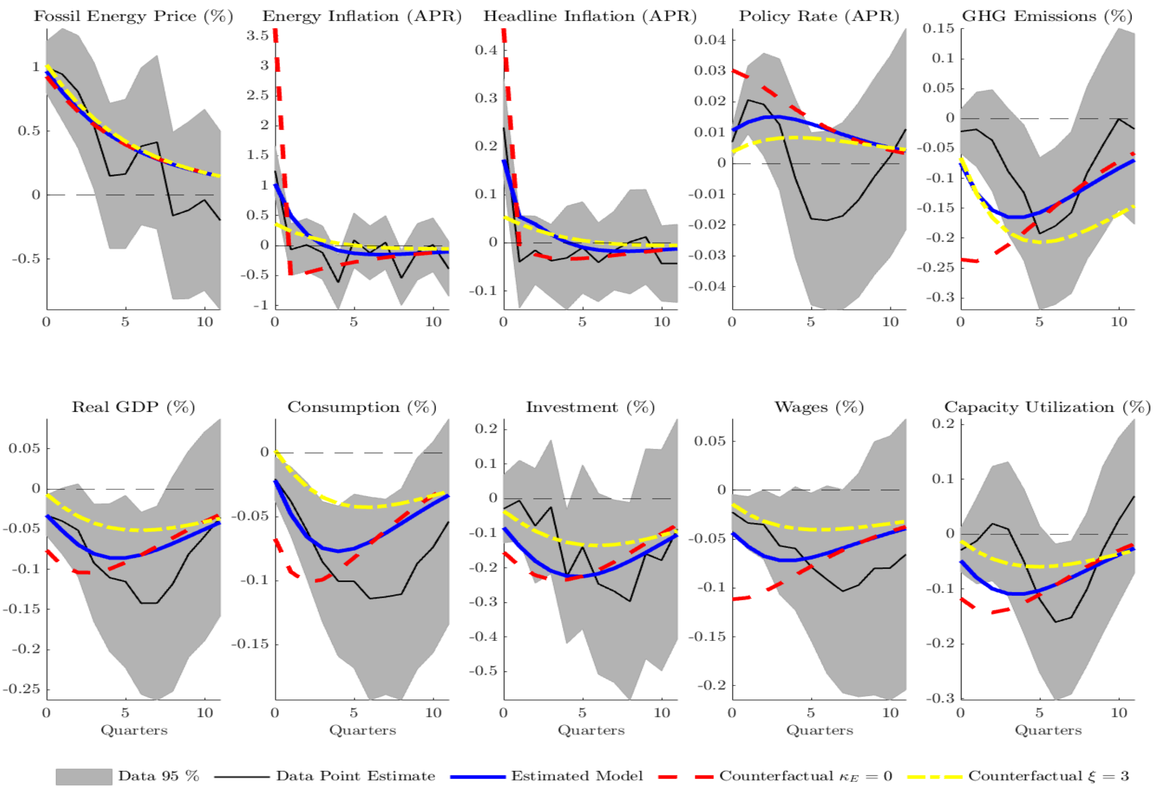

Figure 4: Impulse responses to carbon policy shock: Counterfactual analysis

Scenario (i) is depicted by the dashed red line. The most pronounced effect is observed in aggregate energy prices, with energy inflation surging nearly 4 percentage points on impact, which is more than twice the estimated response from the data. This short-run spike in energy prices transmits directly to headline inflation, which rises by nearly 0.5 percentage points on impact, amplifying the economy-wide cost pressures. Consequently, household real income declines sharply, as higher energy prices directly increase energy expenditures. The resulting strong demand contraction prevents the model from capturing the more gradual decline in consumption observed in the data. Furthermore, since firms can immediately substitute away from fossil energy, emissions drop sharply on impact. However, this implies that the model fails to reproduce the observed gradual decline in emissions following a carbon policy shock. In reality, infrastructure limitations, supply constraints, and technological adoption barriers slow the transition away from fossil fuels, making the emission response less immediate and more persistent.

The dash-dotted yellow line depicts scenario (ii). A higher value for ξ implies that energy producers can more easily substitute away from fossil energy, which mutes the strong impact response of aggregate energy inflation. Consequently, the surge in headline inflation is notably dampened, easing the burden of higher energy costs on households. This results in a considerably smaller contraction in consumption compared to the baseline estimated model. Additionally, greater substitutability accelerates the transition to green energy, leading to a more pronounced decline in emissions than observed in the data following a carbon policy shock.

5 Monetary Policy

The transition to a low-carbon economy poses important challenges for monetary policy. While central banks do not play a direct role in climate change mitigation, they must respond to the inflationary pressures and GDP losses that result from rising carbon prices. This section analyzes how different monetary policy rules influence the macroeconomic effects of a carbon policy shock. While the estimation analysis is based on a small and transitory shock, future carbon price increases under the EU ETS are likely to be large and permanent, reflecting the EU's commitment to ambitious climate targets. Understanding how monetary policy should respond to such shocks is therefore crucial.

Figure 7 presents the impulse responses to a permanent carbon price increase, which leads to a 5% increase in real fossil energy prices. The figure compares the outcomes under two different monetary policy frameworks: the baseline scenario (solid blue line) and an alternative scenario in which the central bank targets core inflation instead of headline inflation (dashed red line). In the baseline scenario, the carbon price shock leads to a gradual and persistent reduction in emissions, with a peak reduction of 2%. However, this reduction comes at a cost: the rise in fossil energy prices induces a sharp increase in headline inflation, as energy costs directly feed into consumer prices. Core inflation also increases, but to a much smaller extent, as firms face rising marginal costs. In response, the central bank raises interest rates, leaning against inflationary pressures. However, this monetary tightening amplifies the decline in real GDP.

The dashed red line in Figure 7 illustrates an alternative policy: the central bank targets core inflation instead of headline inflation in the Taylor rule. Under this framework, the central bank effectively "looks through" the rise in energy prices. As a result, the nominal interest rate does not increase as aggressively, which strongly mitigates the fall in aggregate demand. The contraction in GDP is almost halved at peak compared to the baseline scenario. The increase in core inflation becomes larger and more persistent, leading to a headline inflation spike that is approximately 0.3 percentage points higher on impact. However, despite this stronger initial rise, headline inflation does not remain persistently elevated. One year after the shock, the inflation dynamics under both scenarios are nearly identical, suggesting that the long-term inflationary consequences of targeting core inflation are limited.

By mitigating the economic downturn, targeting core inflation constitutes a welfare improvement relative to targeting headline inflation[4]. The more moderate contraction in GDP means that household income and consumption decline less, reducing the welfare costs associated with the carbon price shock. However, there is a trade-off in terms of emissions reduction: the peak decline in emissions is somewhat smaller under core inflation targeting, reaching 1.5% at peak instead of 2% in the baseline. This is because the milder economic contraction leads to relatively higher production and consumption, slightly offsetting the emissions reduction induced by the carbon price increase.

As a robustness check I re-estimate the model with a Taylor rule that targets core instead of headline inflation, leaving the rest of the model unchanged. The results are presented in Appendix B The estimation with the alternative Taylor rule results in a similar model fit as the baseline estimation, and does not change the implications of this exercise.

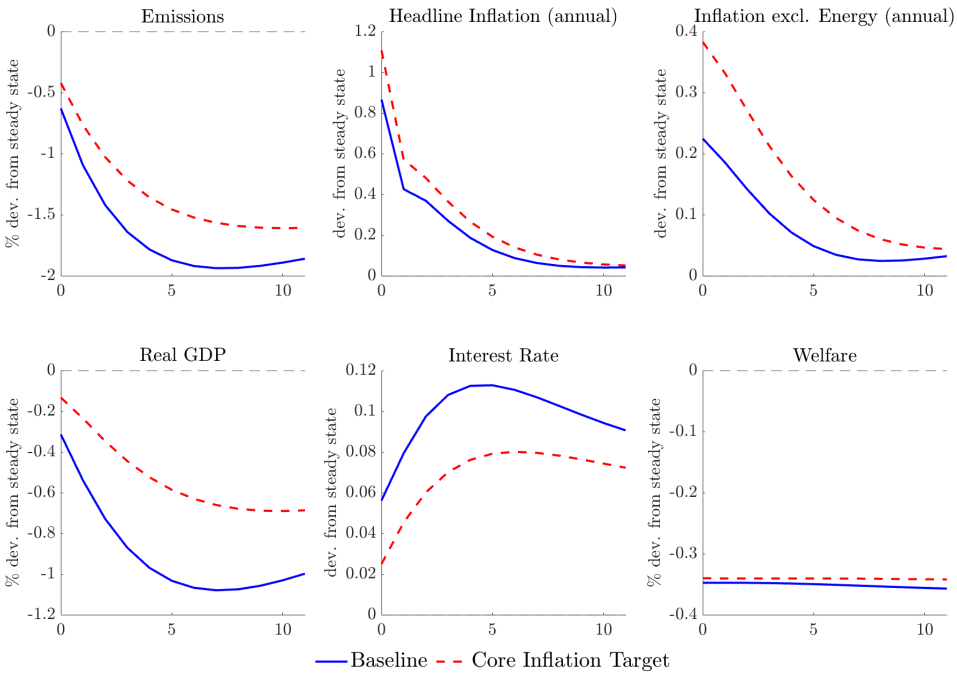

Figure 5: Impulse responses to a permanent carbon policy shock: Headline vs. core inflation stabilization

[4]Social welfare is defined as the population weighted average of Ricardian and hand-to-mouth households' utility and specified in consumption equivalent terms.

6 Conclusion

In this paper, I develop and estimate a New Keynesian macro-climate model that successfully captures the macroeconomic effects of carbon price shocks in the euro area. Using local projections, I document three key empirical responses to carbon price increases: a gradual decline in emissions, a sharp rise in headline inflation, and a significant drop in economic activity. To replicate these dynamics, I introduce two non-standard features into the model, fossil energy adjustment costs and low substitutability between green and fossil energy, both of which are essential for matching the observed responses. The estimated model closely aligns with the data, providing a robust empirical framework for analyzing the economic trade-offs of carbon pricing. With this empirically grounded framework, I assess the role of monetary policy in shaping macroeconomic outcomes following carbon price shocks. My results show that a central bank focusing on core rather than headline inflation can significantly reduce GDP losses following a permanent carbon price shock. These insights contribute to the macro-climate modeling literature by providing a framework that accurately captures the macroeconomic effects of carbon policy. This framework could also be used in future research to evaluate optimal monetary policy responses to carbon shocks or to analyze how carbon pricing interacts with standard macroeconomic fluctuations and monetary policy transmission. As carbon pricing becomes an increasingly central policy tool, models that accurately reflect these dynamics will be essential for designing effective economic and monetary policies.

References

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous (2012). "The environment and directed technical change". In: *American economic review* 102.1, pp. 131–166.

Annicchiarico, Barbara and Fabio Di Dio (2015). "Environmental policy and macroeconomic dynamics in a new Keynesian model". In: *Journal of Environmental Economics and Management* 69, pp. 1–21.

Auclert, Adrien, Hugo Monnery, Matthew Rognlie, and Ludwig Straub (2023). *Managing an energy shock: Fiscal and monetary policy.* Tech. rep. National Bureau of Economic Research.

Barrage, Lint (2020). "Optimal dynamic carbon taxes in a climate–economy model with distortionary fiscal policy". In: *The Review of Economic Studies* 87.1, pp. 1–39.

Baumeister, Christiane and James D Hamilton (2019). "Structural interpretation of vector autoregressions with incomplete identification: Revisiting the role of oil supply and demand shocks". In: *American Economic Review* 109.5, pp. 1873–1910.

Benmir, Ghassane, Ivan Jaccard, and Gauthier Vermandel (2020). *Green asset pricing.* Tech. rep. ECB Working Paper No. 2477.

Chan, Jenny, Sebastian Diz, and Derrick Kanngiesser (2024). "Energy prices and household heterogeneity: Monetary policy in a gas-tank". In: *Journal of Monetary Economics* 147, p. 103620.

Christiano, Lawrence J, Martin Eichenbaum, and Charles L Evans (2005). "Nominal rigidities and the dynamic effects of a shock to monetary policy". In: *Journal of political Economy* 113.1, pp. 1–45.

Christiano, Lawrence J, Mathias Trabandt, and Karl Walentin (2010). "DSGE models for monetary policy analysis". In: *Handbook of monetary economics.* Vol. 3. Elsevier, pp. 285–367.

Coenen, Günter, Peter Karadi, Sebastian Schmidt, and Anders Warne (2018). "The New Area-Wide Model II: an extended version of the ECB's micro-founded model for forecasting and policy analysis with a financial sector". In.

Coenen, Günter, Matija Lozej, and Romanos Priftis (2024). "Macroeconomic effects of carbon transition policies: an assessment based on the ECB's New Area-Wide Model with a disaggregated energy sector". In: *European Economic Review* 167, p. 104798.

Del Negro, Marco, Julian Di Giovanni, and Keshav Dogra (2023). "Is the Green Transition Inflationary?" In: *FRB of New York Staff Report* 1053.

Diluiso, Francesca, Barbara Annicchiarico, Matthias Kalkuhl, and Jan C Minx (2021). "Climate actions and macro-financial stability: The role of central banks". In: *Journal of Environmental Economics and Management* 110, p. 102548.

Dossche, Maarten, Jiri Slacalek, and Guido Wolswijk (2021). “Monetary policy and inequality”. In: *Economic Bulletin Articles* 2.

Erceg, Christopher, Marcin Kolasa, Jesper Lindé, and Andrea Pescatori (2024). “Can Energy Subsidies Help Slay Inflation?” In.

Gagliardone, Luca and Mark Gertler (2023). “Oil prices, monetary policy and inflation surges”. In.

Golosov, Mikhail, John Hassler, Per Krusell, and Aleh Tsyvinski (2014). “Optimal taxes on fossil fuel in general equilibrium”. In: *Econometrica* 82.1, pp. 41–88.

Hassler, John, Per Krusell, and Conny Olovsson (2021). “Directed technical change as a response to natural resource scarcity”. In: *Journal of Political Economy* 129.11, pp. 3039–3072.

Hassler, John, Per Krusell, Conny Olovsson, and Michael Reiter (2020). “On the effectiveness of climate policies”. In: *IIES WP* 53, p. 54.

Heutel, Garth (2012). “How should environmental policy respond to business cycles? Optimal policy under persistent productivity shocks”. In: *Review of Economic Dynamics* 15.2, pp. 244–264.

Känzig, Diego R (2021). “The macroeconomic effects of oil supply news: Evidence from OPEC announcements”. In: *American Economic Review* 111.4, pp. 1092–1125.

— (2023). *The unequal economic consequences of carbon pricing*. Tech. rep. National Bureau of Economic Research.

Konradt, Maximilian and Beatrice Weder di Mauro (2023). “Carbon taxation and greenflation: Evidence from europe and canada”. In: *Journal of the European Economic Association*, jvad020.

Metcalf, Gilbert E and James H Stock (2023). “The macroeconomic impact of Europe’s carbon taxes”. In: *American Economic Journal: Macroeconomics* 15.3, pp. 265–286.

Montiel Olea, José Luis and Mikkel Plagborg-Møller (2021). “Local projection inference is simpler and more robust than you think”. In: *Econometrica* 89.4, pp. 1789–1823.

Nakov, Anton and Carlos Thomas (2023). “Climate-conscious monetary policy”. In.

Nordhaus, William (2008). *A question of balance: Weighing the options on global warming policies*. Yale University Press.

Olovsson, Conny and David Vestin (2023). *Greenflation?* Sveriges Riksbank.

Papageorgiou, Chris, Marianne Saam, and Patrick Schulte (2017). “Substitution between clean and dirty energy inputs: A macroeconomic perspective”. In: *Review of Economics and Statistics* 99.2, pp. 281–290.

Quilis, Enrique M. (2024). *Temporal Disaggregation*. Accessed: 30 Oct. 2024. URL: `https://de.mathworks.com/matlabcentral/fileexchange/69800-temporal-disaggregation`.

Sahuc, Jean-Guillaume, Frank Smets, and Gauthier Vermandel (2025). “The New Keynesian Climate Model”. In.

Schnabel, Isabel (2022). *A new age of energy inflation: climateflation, fossilflation and greenflation*. Speech by Isabel Schnabel, Member of the Executive Board of the ECB, at a panel on "Monetary Policy and Climate Change" at The ECB and its Watchers XXII Conference. URL: https://www.ecb.europa.eu/press/key/date/2022/html/ecb.sp220317_2~dbb3582f0a.en.html.

A Model details

This appendix presents the full set of equilibrium conditions. The model is described by a total of 57 equations and 57 endogenous variables $\{c_t, c_{t,R}, c_{t,H}, c^E_{t,R}, c^E_{t,H}, c^X_{t,R}, c^X_{t,H}, \lambda_t, r_t, \pi_t, \pi^X_t, \pi^E_t, r^{k,Y}_t, r^{k,B}_t, r^{k,G}_t, q^Y_t, q^G_t, q^B_t, u^B_t, u^Y_t, u^G_t, i_t, i^Y_t, i^G_t, i^B_t, k^Y_t, k^G_t, k^B_t, h_{t,R}, h_{t,H}, h^Y_t, h^G_t, h^B_t, e_t, e^Y_t, e^G_t, e^B_t, p^X_t, p^{X*}_t, p^E_t, p^I_t, p^G_t, p^B_t, w_t, w^*_t, K_t, F_t, d_t, K^W_t, F^W_t, y_t, mc_t, gdp_t, S_t, A^Y_t, A^G_t, A^B_t\}$ and an exogenous process for τ_t.

Households:

$$\lambda_t = \frac{1}{c_{t,R} - bc_{t-1,R}} - \beta b \frac{1}{c_{t+1,R} - bc_{t,R}} \tag{A.1}$$

$$1 = \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \frac{r_t}{\pi_{t+1}} \tag{A.2}$$

$$q^Y_t = \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} (r^{k,Y}_{t+1} u^Y_{t+1} - a(u^Y_t) p^I_t + (1-\delta) q^Y_{t+1}) \tag{A.3}$$

$$q^G_t = \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} (r^{k,G}_{t+1} u^G_{t+1} - a(u^G_t) p^I_t + (1-\delta) q^G_{t+1}) \tag{A.4}$$

$$q^B_t = \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} (r^{k,B}_{t+1} u^B_{t+1} - a(u^B_t) p^I_t + (1-\delta) q^B_{t+1}) \tag{A.5}$$

$$r^{k,Y}_t = a'(u^Y_t) p^I_t \tag{A.6}$$

$$r^{k,G}_t = a'(u^G_t) p^I_t \tag{A.7}$$

$$r^{k,B}_t = a'(u^B_t) p^I_t \tag{A.8}$$

$$p^I_t = q^Y_t \left[1 - \frac{\kappa_I}{2} \left(\frac{i^Y_t}{i^Y_{t-1}} - 1 \right)^2 - \kappa_I \left(\frac{i^Y_t}{i^Y_{t-1}} - 1 \right) \frac{i^Y_t}{i^Y_{t-1}} \right] + \beta q^Y_{t+1} \left[\frac{\lambda_{t+1}}{\lambda_t} \kappa_I \left(\frac{i^Y_{t+1}}{i^Y_t} - 1 \right) \left(\frac{i^Y_{t+1}}{i^Y_t} \right)^2 \right] \tag{A.9}$$

$$p^G_t = q^Y_t \left[1 - \frac{\kappa_I}{2} \left(\frac{i^G_t}{i^G_{t-1}} - 1 \right)^2 - \kappa_I \left(\frac{i^G_t}{i^G_{t-1}} - 1 \right) \frac{i^G_t}{i^G_{t-1}} \right] + \beta q^G_{t+1} \left[\frac{\lambda_{t+1}}{\lambda_t} \kappa_I \left(\frac{i^G_{t+1}}{i^G_t} - 1 \right) \left(\frac{i^G_{t+1}}{i^G_t} \right)^2 \right] \tag{A.10}$$

$$p^I_t = q^B_t \left[1 - \frac{\kappa_I}{2} \left(\frac{i^B_t}{i^B_{t-1}} - 1 \right)^2 - \kappa_I \left(\frac{i^B_t}{i^B_{t-1}} - 1 \right) \frac{i^B_t}{i^B_{t-1}} \right] + \beta q^B_{t+1} \left[\frac{\lambda_{t+1}}{\lambda_t} \kappa_I \left(\frac{i^B_{t+1}}{i^B_t} - 1 \right) \left(\frac{i^B_{t+1}}{i^B_t} \right)^2 \right] \tag{A.11}$$

$$k^Y_t = (1-\delta) k^Y_{t-1} + \left(1 - \frac{\kappa_I}{2} \left(\frac{i^Y_t}{i^Y_{t-1}} - 1 \right)^2 \right) i^Y_t \tag{A.12}$$

$$k^G_t = (1-\delta) k^G_{t-1} + \left(1 - \frac{\kappa_I}{2} \left(\frac{i^G_t}{i^G_{t-1}} - 1 \right)^2 \right) i^G_t \tag{A.13}$$

$$k^B_t = (1-\delta) k^B_{t-1} + \left(1 - \frac{\kappa_I}{2} \left(\frac{i^B_t}{i^B_{t-1}} - 1 \right)^2 \right) i^B_t \tag{A.14}$$

$$c_{t,H} = w_t h_{t,H} + \lambda \tau_t p_t^B e_t^B \tag{A.15}$$

$$h_{t,H} = h_{t,R} \tag{A.16}$$

$$1 = \left(\gamma_c (p_t^E)^{1-\varrho_c} + (1-\gamma_c)(p_t^X)^{1-\varrho_c} \right)^{\frac{1}{1-\varrho}} \tag{A.17}$$

$$c_{t,R}^E = \gamma_c \left(p_t^E \right)^{-\varrho_c} c_{t,R} \tag{A.18}$$

$$c_{t,R}^X = (1-\gamma_c) \left(p_t^X \right)^{-\varrho_c} c_{t,R} \tag{A.19}$$

$$c_{t,H}^E = \gamma_c \left(p_t^E \right)^{-\varrho_c} c_{t,H} \tag{A.20}$$

$$c_{t,H}^X = (1-\gamma_c) \left(p_t^X \right)^{-\varrho_c} c_{t,H} \tag{A.21}$$

Wage setting:

$$w = \left(\theta_W w_{t-1}^{1-\varepsilon_W} + (1-\theta_W)(w_t^*)^{1-\varepsilon_W} \right)^{\frac{1}{1-\varepsilon_w}} \tag{A.22}$$

$$(w_t^*)^{1+\phi\varepsilon_W} = \frac{\varepsilon_W}{\varepsilon_W - 1} \frac{K_t^W}{F_t^W} \tag{A.23}$$

$$K_t^W = (w_t^{\varepsilon_W} h_{t,R})^{1+\phi} + \theta_W \beta (\pi_{t+1})^{(1+\phi)\varepsilon_W} K_{t+1}^W \tag{A.24}$$

$$F_t^W = w_t^{\varepsilon_W} h_{t,R} \lambda_t + \theta_W \beta (\pi_{t+1})^{(1+\phi)\varepsilon_W - 1} F_{t+1}^W \tag{A.25}$$

Firms:

$$y_t d_t = \left[(1-\gamma_Y)^{\frac{1}{\varrho_Y}} \left((A_t^Y u_t^Y k_{t-1}^Y)^{\alpha} (h_t^Y)^{1-\alpha} \right)^{\frac{\varrho_Y - 1}{\varrho_Y}} + (\gamma_Y)^{\frac{1}{\varrho_Y}} \left(e_t^Y \right)^{\frac{\varrho_Y - 1}{\varrho_Y}} \right]^{\frac{\varrho_Y}{\varrho_Y - 1}} \tag{A.26}$$

$$w_t = mc_t \left((1-\gamma_Y) y_t d_t \right)^{\frac{1}{\varrho_Y}} \left(A_t^Y (u_t^Y k_{t-1}^Y)^{\alpha} (h_t^Y)^{1-\alpha} \right)^{\frac{\varrho_Y - 1}{\varrho_Y}} (1-\alpha) \frac{1}{h_t^Y} \tag{A.27}$$

$$r_t^{k,Y} = mc_t \left((1-\gamma_Y) y_t d_t \right)^{\frac{1}{\varrho_Y}} \left((A_t^Y u_t^Y k_{t-1}^Y)^{\alpha} (h_t^Y)^{1-\alpha} \right)^{\frac{\varrho_Y - 1}{\varrho_Y}} \alpha \frac{1}{u_t^Y k_{t-1}^Y} \tag{A.28}$$

$$e_t^Y = \left(\frac{p_t^E}{mc_t} \right)^{-\varrho_Y} \gamma_Y y_t d_t \tag{A.29}$$

Price setting:

$$p_t^X = \left(\theta_P (p_{t-1}^X)^{1-\varepsilon} + (1-\theta_W)(p_t^{X*})^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} \tag{A.30}$$

$$p_t^{X*} = \frac{\varepsilon}{\varepsilon - 1} \frac{K_t}{F_t} p_t^X \tag{A.31}$$

$$K_t = y_t mc_t + \theta_P \beta \frac{\lambda_{t+1}}{\lambda_t} (\pi_{t+1}^X)^{\varepsilon_W} K_{t+1} \tag{A.32}$$

$$F_t = y_t p_t^X + \theta \beta \frac{\lambda_{t+1}}{\lambda_t} (\pi_{t+1}^X)^{\varepsilon - 1} F_{t+1} \tag{A.33}$$

$$d_t = (1-\theta_P)\left(\frac{p_t^{X*}}{p_t^X}\right)^{-\varepsilon} + \theta_P(\pi_t^X)^\varepsilon d_{t-1} \tag{A.34}$$

$$\pi_t^X = \frac{p_t^X}{p_{t-1}^X}\pi_t \tag{A.35}$$

Energy firms:

$$e_t = \left((1-\zeta)^{\frac{1}{\xi}}(e_t^G)^{\frac{\xi-1}{\xi}} + \zeta^{\frac{1}{\xi}}(e_t^B)^{\frac{\xi-1}{\xi}}\right)^{\frac{\xi}{\xi-1}} \tag{A.36}$$

$$p_t^B(1+\tau_t) = p_t^E\left(\left(\zeta\frac{e_t}{e_t^B}\right)^{\frac{1}{\xi}} - \Phi'\left(\frac{e_t^B/e_t}{e_{t-1}^B/e_{t-1}}\right)\right) \tag{A.37}$$

$$e_t^G = (1-\zeta)\left(\frac{p_t^G}{p_t^E}\right)^{-\xi} e_t \tag{A.38}$$

$$e_t^B = A_t^B(u_t^B k_{t-1}^B)^{\alpha_E}(h_t^B)^{1-\alpha_E} \tag{A.39}$$

$$e_t^G = A_t^G(u_t^G k_{t-1}^G)^{\alpha_E}(h_t^G)^{1-\alpha_E} \tag{A.40}$$

$$(1-\alpha_E)p_t^B e_t^B = w_t h_t^B \tag{A.41}$$

$$(1-\alpha_E)p_t^G e_t^G = w_t h_t^G \tag{A.42}$$

$$\alpha_E p_t^B e_t^B = r_t^{k,B} u_t^B k_{t-1}^B \tag{A.43}$$

$$\alpha_E p_t^G e_t^G = r_t^{k,G} u_t^G k_{t-1}^G \tag{A.44}$$

$$\pi_t^E = \frac{p_t^E}{p_{t-1}^E}\pi_t \tag{A.45}$$

Climate change:

$$S_t = (1-\delta_S)S_{t-1} + (m_t + m^{row}), \tag{A.46}$$

$$A_t^Y = a_t^Y e^{-\psi S_t} \tag{A.47}$$

$$A_t^B = a_t^B e^{-\psi S_t} \tag{A.48}$$

$$A_t^G = a_t^G e^{-\psi S_t} \tag{A.49}$$

Aggregation, Market clearing and policy:

$$\frac{r_t}{r} = \left(\frac{r_{t-1}}{r}\right)^{\rho_r}\left[\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi}\left(\frac{gdp_t}{gdp}\right)^{\phi_y}\left(\frac{gdp_t}{gdp_{t-1}}\right)^{\phi_{\triangle y}}\right]^{(1-\rho_r)}, \tag{A.50}$$

$$(1-\lambda)h_{t,R} + \lambda h_{t,H} = h_t^Y + h_t^B + h_t^G \tag{A.51}$$

$$i_t = i_t^Y + i_t^B + i_t^G \tag{A.52}$$

$$e_t = e_t^Y + \lambda c_{t,H}^E + +(1-\lambda)c_{t,R}^E \tag{A.53}$$

$$c_t = \lambda c_{t,H} + (1-\lambda)c_{t,R} \tag{A.54}$$

$$p_t^X y_t = p_t^X c_t^X + p_t^I i_t + p_t^X g + \sum_j a(u_t^j)k_{t-1}^j + \Phi\left(\frac{e_t^B/e_t}{e_{t-1}^B/e_{t-1}}\right) p_t^E e_t, \quad j \in \{Y, B, G\} \tag{A.55}$$

$$gdp_t = c_t + p_t^I i_t + p_t^X g \tag{A.56}$$

$$p_t^I = p_t^X \tag{A.57}$$

Exogenous processes:

$$\log(\tau_t) = (1-\rho_\tau)\log(\overline{\tau}) + \rho_\tau \log(\tau_{t-1}) + \epsilon_t^\tau \tag{A.58}$$

B Robustness

To assess the robustness of my results, I re-estimate the model with an alternative Taylor rule, in which the central bank target core instead of headline inflation:

$$\frac{r_t}{r} = \left(\frac{r_{t-1}}{r}\right)^{\rho_r} \left[\left(\frac{\pi_t^X}{\pi^X}\right)^{\phi_\pi} \left(\frac{gdp_t}{gdp}\right)^{\phi_y} \left(\frac{gdp_t}{gdp_{t-1}}\right)^{\phi_{\Delta y}} \right]^{(1-\rho_r)}. \tag{B.1}$$

The results of this estimation suggest a similar model fit as in the baseline version, also implying that the central bank can mitigate GDP loss following carbon policy shocks by targeting core instead of headline inflation, as discussed in section 5.

Table 3: Priors and Posteriors of Parameters

Parameter	Prior	Posterior	
	$\mathcal{D}$, Mean [5-95%]	Mode	Mean [5-95%]
Energy complementarity firms, ϱ_y	$\mathcal{G}$, 0.5 [0.13 1.07]	**0.06**	0.09 [0.01 0.19]
Energy complementarity households, ϱ_c	$\mathcal{G}$, 0.5 [0.13 1.07]	**0.13**	0.16 [0.06 0.28]
Substitution green and fossil energy, ξ	$\mathcal{G}$, 2 [0.89 3.47]	**0.74**	0.81 [0.47 1.18]
Fossil energy adjustment cost, κ_E	$\mathcal{U}$, 50 [5 95]	**39.29**	46.35 [32.62 77.51]
Habit persistence, b	$\mathcal{B}$, 0.6 [0.34 0.83]	**0.51**	0.47 [0.25 0.69]
Calvo wage stickiness, θ_w	$\mathcal{B}$, 0.6 [0.34 0.83]	**0.86**	0.86 [0.75 0.96]
Investment adjustment costs, κ_I	$\mathcal{G}$, 5 [1.27 10.73]	**1.64**	1.95 [0.31 4.15]
Capacity utilization adjustment costs, σ_a	$\mathcal{G}$, 1 [0.15 2.46]	**0.60**	0.86 [0.03 1.99]
Calvo price stickiness, θ_p	$\mathcal{B}$, 0.6 [0.34 0.83]	**0.70**	0.68 [0.49 0.80]
Taylor rule inflation coefficient, ϕ_π	$\mathcal{G}$, 1.6 [1.14 2.12]	**1.78**	1.87 [1.29 2.49]
Taylor rule output coefficient, ϕ_y	$\mathcal{G}$, 0.1 [0.01 0.26]	**0.02**	0.03 [0 0.05]
Taylor rule output growth coefficient, $\phi_{\Delta y}$	$\mathcal{G}$, 0.1 [0.01 0.26]	**0.09**	0.11 [0.02 0.22]
Interest rate smoothing, ρ_r	$\mathcal{B}$, 0.8 [0.62 0.94]	**0.89**	0.86 [0.74 0.96]
Autocorr. carbon shock, ρ_τ	$\mathcal{U}$, 0.5 [0.05 0.95]	**0.86**	0.86 [0.82 0.91]
Std.Dev. carbon shock, σ_τ	$\mathcal{G}$, 0.2 [0.09 0.41]	**0.27**	0.27 [0.23 0.32]

Notes: Posterior mode and parameter distributions are based on a standard MCMC algorithm with a total of 500,000 draws (5 chains, 50 percent of draws used for burn-in, acceptance rate about 27%). $\mathcal{B}, \mathcal{G}$ and $\mathcal{U}$ denote beta, gamma and uniform distribution, respectively.

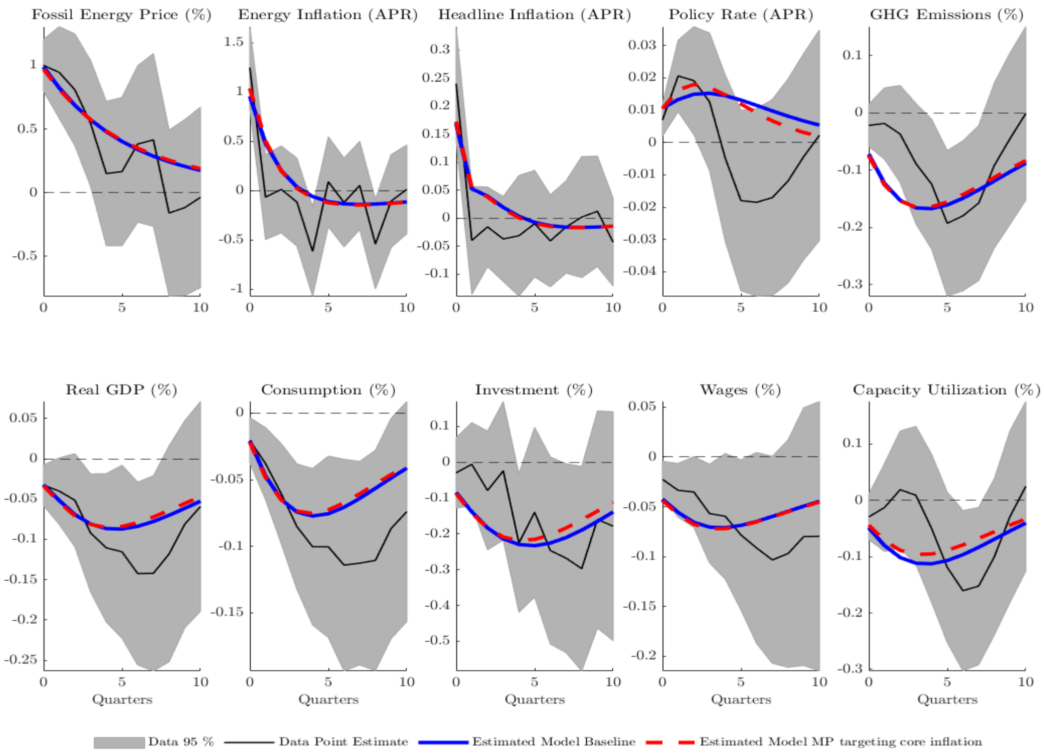

Figure 6: Impulse responses to carbon policy shock: Model vs. Data

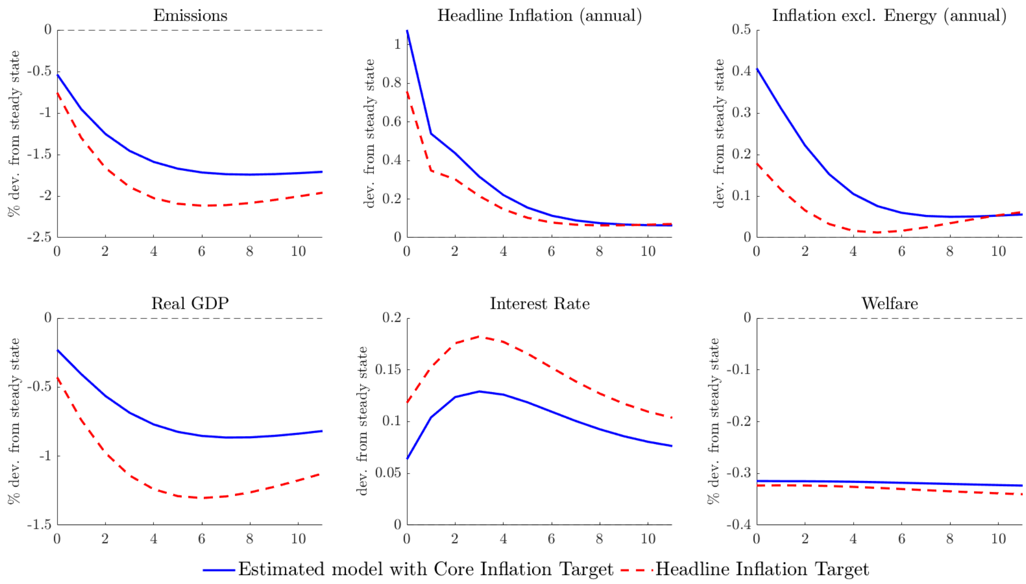

Figure 7: Impulse responses to a permanent carbon policy shock: Core vs. headline inflation stabilization in model estimated on Taylor rule with core inflation