Energy price shocks, monetary policy and inequality

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Abstract

We study how monetary policy shapes the aggregate and distributional effects of an energy price shock. Based on the observed heterogeneity in consumption exposures to energy and household wealth, we build a quantitative small open-economy HANK model matching salient features of Euro Area data. Our model features energy as both a consumption good for households with non-homothetic preferences as well as a factor input into production with input complementarities. Independently of policy, energy price shocks always lead to a reduction in aggregate consumption. Lower income households are more adversely affected through both a decline in labor income as well as negative direct price effects. "Active" monetary policy raising rates in response to rising energy prices amplifies aggregate outcomes through a reduction in aggregate demand but speeds up the recovery by enabling households to rebuild wealth through higher returns on savings. However, low income households are adversely affected by active monetary policy because they have little savings to rebuild wealth and instead loose further due to further declining labor income.

Keywords: energy prices, open economy model, heterogeneous agents, monetary policy, non-homothetic preferences.

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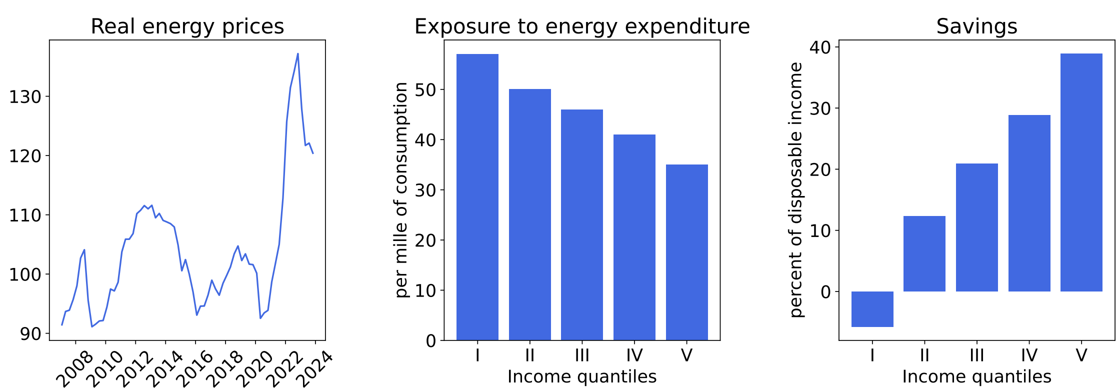
1 Introduction

Energy prices have reached historical heights, starting their rise in mid-2021 after most economies reopened from Covid lock-downs and being catalysed early 2022 by the Russian invasion of Ukraine. Figure 1 (left panel) shows that real energy prices in the Euro Area have risen by 60 percent from their lows in 2020 and by 30 percent compared to their average over the past 20 years. At the same time, monetary policy makers around the globe have reacted to this energy price surge by raising rates at unprecedented speed, despite most economies being energy importers facing an exogenous shock. The rise in energy prices and subsequent policy response naturally have heterogeneous effects on households with low income households likely being affected the most for a variety of reasons. First, lower income households typically spend a larger fraction of their income on energy-related goods and are therefore more exposed to energy prices through the consumption basket (1, middle panel). Second, lower income households have usually little savings making it difficult for them to smooth their consumption in response to temporary price increases (1, right panel). Third, households starkly differ in their sources of income with low income households often solely relying on labor income, whereas higher income households often benefit from returns on their savings.

Figure 1: Energy prices and households' consumption and savings exposures across the income distribution



Note: The "real energy price" indicates the ratio between the energy component of the HICP and the overall HICP index. Charts in the middle and right are based on distributional statistics from the "Income, consumption, and wealth" dataset provided by Eurostat.

Based on the observed heterogeneity in household consumption and wealth positions, we build a small open economy heterogeneous agent New Keynesian (HANK) model to study the aggregate and distributional effects of energy price increases and how they are shaped by monetary policy. We show that the initial aggregate effect of an energy price shock is smaller when monetary policy is "neutral" keeping real rates constant. "Active" monetary policy raising real rates exacerbates the initial decline in aggregate demand and amplifies the negative effects of an energy price shock but leads to a faster recovery. The amplification crucially depends on the targeted inflation measure as energy price inflation has a different time profile than domestic inflation. Whereas the former is initially unexpectedly increasing but subsequently turning negative, the latter is always positive albeit declining over time. By decomposing the aggregate consumption response into a direct interest rate effect, an indirect income effect and a price effect, we show that energy price shocks under neutral policy work predominantly through negative income effects with the relative price effect playing an additional important role. In contrast, under active monetary policy the consumption decline is predominantly driven by rising real rates and account for three fourth of the effect. Turning to the distributional effects, we show that low income households are mostly affected by an energy price shock irrespective of the type of policy. Active policies exacerbate the negative effects for low income households, while they benefit high income households in the medium run through positive real rates. In fact, higher returns allow the latter to rebuild their wealth faster, even leading to an increase in their consumption after a few quarters. Lastly we show that forecasting rules that effectively "look through" the energy price increase exhibit the smallest decline in aggregate consumption and output.

In our HANK model energy features as both a consumption good and a factor input to production. All energy used in the domestic economy has to be imported. Households have non-homothetic preferences over energy and non-energy goods modelled as a Stone-Geary utility function. They face idiosyncratic income risk and an occasionally binding borrowing constraint that they can only imperfectly insure against by saving in a mutual fund. Firms produce domestic goods using labor and energy as inputs, which are nearly complements. An energy price increase can therefore not simply be met by employing more labor to produce the same quantity of output. While prices are flexible, we introduce sticky wages through labor unions, which supply labor at a wage rate of their choice but which they can only infrequently change. We model monetary policy as a Taylor rule, which can react either to contemporaneous inflation measures or their forecasts. These measures include headline inflation, defined as the change in the aggregate price level, core inflation, defined as the change in domestic goods prices, and energy price inflation. We contrast these rules to a "neutral" policy that looks through energy price increases by keeping the real rate constant.

We calibrate our model to data from the Euro Area in order to quantify the aggregate and distributional effects of an energy price shock. While we calibrate most model parameters to standard values in the literature, we take particular care in matching the heterogeneity observed in household consumption baskets. In particular we use Eurostat's "Income, wealth and consumption statistics" (ICWS) to match the average households' expenditure on energy of around 9 percent and match the degree of non-homotheticity to target higher energy expenditures of the lowest income quintile of around 13 percent. Additionally, we target an average aggregate marginal propensity to consume of around 0.3 delivering substantial income and wealth heterogeneity. On the firm side, we calibrate the degree of complementarity between factor inputs to estimates recently laid out in Bachmann et al. (2022) and additionally take into account data from input-output tables indicating that the use of energy in production is almost twice the size than in consumption.

We start our analysis by discussing how non-homothetic preferences and input complementarities in production shape the aggregate and individual consumption and income response to an energy price shock under a baseline with neutral monetary policy. These are important drivers of aggregate effects as non-homotheticity imposes a constraint on low income households, while consumption and production elasticities of substitution govern the ability of agents to respond to the shock in relative prices. We show that low income households suffer a larger consumption expenditure shock compared to high income households, thereby further increasing their already elevated marginal propensity to consume (MPC). When the elasticity of substitution across consumption goods is large, the energy price shock is less severe for all households as they are able to substitute away from more expensive energy goods towards domestic goods. Similarly, a high elasticity of substitution in the production function allows firms to decrease their demand for energy and therefore imply a smaller drop in labor demand, predominantly benefitting low income households.

Turning to the aggregate effects of an energy price shock we show the strong dependence of its effects on monetary policy. We contrast a baseline in which monetary policy is neutral and looks through the shock by keeping real rates constant to various "active" policy rules, which react either to contemporaneous or forecast measures of inflation. In our open economy model the aggregate effects of an energy price shock are generally negative, independently of policy, because the benefits from higher energy prices solely acrue to the foreign economy. We find that active policy responding to either headline or core inflation leads to higher real interest rates. These in turn induce a strong decline in consumption and output that is four times bigger than in case of "neutral" monetary policy. However, while the initial recession is stronger under an active rule, the subsequent recovery is also faster. A policy rule responding to energy prices has remarkably different implications. Under such a policy the real rate increase is the highest with an initial suppression of energy and headline inflation. However, this comes at the cost of a strong recession that is initially twice as deep as under a headline or core rule. The initial restraint of inflation rates in the short term comes notably at the cost of higher medium-term inflation, when a speedy recovery of domestic goods demand together with rising foreign demand ultimately raises core and headline inflation. Forecast rules reacting to either headline or core inflation effectively "look through" the energy price increase. Therefore, the real rate increase under these is considerably smaller thereby alleviating most of the negative effects on aggregate demand. In turn, the decline in both consumption and labor income is relatively less pronounced compared to a neutral rule with otherwise very similar implications.

Decomposing aggregate consumption into three partial effects we analyze the different drivers of neutral versus active policy. We decompose the consumption response into a direct effect arising from changes in the real interest rate, an indirect effect arising from changes in labor income and a relative price effect. The latter captures a decline in consumption arising from an increase in energy prices, which lead to higher expenditures on subsistence consumption leaving a smaller share of income for consumption beyond the subsistence level. Under a neutral policy rule three fourth of the consumption decline is due to indirect income effects with one fourth driven by the relative price effect. This implies that the adverse effects of an energy price shock works predominantly through a reduction in real income with an additional margin for rising costs of the consumption basket. In stark contrast, under an active police rule three fourth of the decline in consumption are accounted for by the direct real rate effect.

Finally, we investigate the distributional implications of a foreign energy price shock associated with different monetary policy conducts. In general, low-income households bear the brunt of the energy price shock, irrespective of the reaction of monetary policy. However, active monetary policies, by exacerbating the decline in aggregate demand and labor income, further adversely impact low-income households through an additional decline of consumption. High income households on the other hand, while suffering more in the initial period when the energy price unexpectedly occurs, ultimately benefit from active policies. Higher real rates allow these households with considerable savings to enjoy higher returns. Ultimately, these households even exhibit a positive consumption response to an energy price shock.

Related literature We relate to three main strands of the literature investigating the aggregate and distributional effects energy shocks in open economy models, including the implications and propagation mechanisms under different monetary policy conducts. The core analysis builds on an established body of literature which focuses on the transmission of oil price shocks in open-economy representative-agent models (Mendoza (1995), Kose (2002) and more recently Baqaee and Farhi (2019)) including the appropriate monetary policy response (Bodenstein et al. (2011), Natal (2012)). Blanchard and Gali (2007) study the propagation of oil prices in an open economy representative agent model, including oil in the production function in order to account for the role of intermediate production factors. Bernanke et al. (1997) conduct counterfactual monetary policy simulations and conclude that monetary policy significantly influences the transmission of oil price shocks in the economy. Bodenstein et al. (2011) use a New Keynesian model with oil in consumption and production to examine the effects of different monetary policies in response to energy shocks, by distinguishing between core and headline inflation. The authors find an optimal response to an adverse energy supply shock involves a persistent rise in core and headline inflation. Bodenstein et al. (2013) using the same model find that the effects of oil shocks on aggregate demand are rather cushioned when monetary policy is constrained by the zero lower bound compared to normal times when monetary policy is unconstrained. Natal (2012) in an optimal policy design argues that policies which perfectly stabilize prices entail significant welfare costs. We add to this literature by studying energy price shocks in a similar open economy setting but with a focus on household heterogeneity which allows us to also study distributional effects of energy price shocks and how they relate to different monetary policy responses.

We also relate to a growing literature analyzing the domestic effects of shocks emerging in foreign economies in the context of open-economy heterogeneous agent (HA) models. de Ferra et al. (2020) quantify the aggregate and distributional effects of capital flow reversals in Hungary, where agents hold different amounts of foreign currency debt. Guo et al. (2020) study the distributional effects of international shocks when agents differ by their sector of work and their financial integration, finding that these sources of heterogeneity can play a major role and create trade-offs in the conduct of monetary policy. Other recent papers studying the redistributive effects of external shocks include Zhou (2020), Oskolkov (2022) and Otten (2021). Cugat (2019) introduce household heterogeneity in an open-economy New Keynesian model and study its role in the transmission of foreign shocks. Auclert et al. (2019) study monetary transmission in an open-economy HANK, providing general conditions under which households' heterogeneity matters emphasizing the presence of a strong real-income channel that can lead to contractionary devaluations. Guntin et al. (2020) show how introducing household heterogeneity can inform macroeconomic theories of aggregate consumption adjustment to sudden stops. We contribute to this literature by explicitly studying energy price shocks and their aggregate and distributional consequences adding monetary policy as a source impacting foreign shocks.

Third, we contribute to an emerging literature studying energy shocks in macroeconomic models with at least some degree of household heterogeneity. Chan et al. (2022) focus on the production side highlighting the demand spillovers arising from input complementary in a two agent New Keynesian model. They show that a higher complementary leads to a stronger decline in labor demand hurting constrained households more and additionally study optimal policy in this setting with limited heterogeneity. While also modelling input complementary, we instead emphasize the demand side heterogeneity in both consumption and income in a fully-fledged HANK model and compare how different monetary policy rules benefit or hurt different households along the income distribution. Gornemann et al. (2023) using a similar two agent model study how supply shortages can lead to self-fulfilling fluctuations and analyze how monetary policy can remove determinacy risks. In a recent paper Olivi et al. (2023) study how monetary policy should react to aggregate and sectoral disruptions in a multi-sector New Keynesian model. They focus on an analytical derivation of two wedges related to heterogeneous consumption expenditures when households have non-homothetic preferences and show that applied to UK data these wedges are quantitatively important. We differ from their paper by explicitly modelling energy and considering shocks to energy prices instead of aggregate productivity which can have vastly different implications as shown by Chan et al. (2022). Additionally, their focus on tractable heterogeneity precludes them to fully study distributional effects as we do in our model. Perhaps the closest papers to ours are Auclert et al. (2023) and

Pieroni (2022). Pieroni (2022) builds a closed economy HANK model to study how a shock to energy supply affects macroeconomic outcomes. We instead employ an open economy model and innovate by explicitly studying different monetary policy rules and how they affect both aggregate an distributional outcomes and explicitly look at welfare effects across the income distribution. Auclert et al. (2023) similarly build an open economy HANK model with differences in the model setup, e.g. abstracting from input complementarities in production. They study how the interaction of fiscal policy and exogenously specified monetary policy can mitigate energy price shocks albeit solely focusing on aggregate effects. We instead explicitly study distributional outcomes and specify monetary policy through a more commonly used Taylor rule that endogenously reacts to either contemporaneous or forecast measures of inflation.

The remainder of the paper is organised as follows. In Section 2 we present our theoretical model and in Section 3 we describe the calibration and steady state of the model. Section 4.1 focuses on the implications of an energy price shock in the context of different monetary policy frameworks, highlighting the role of the elasticities of substitution in consumption and production and studying the aggregate and distributional effects under both a neutral monetary policy and various active policy rules. Section 5 concludes.

2 Model

In this section we introduce a small open economy model with heterogeneous households in the spirit of Auclert et al. (2021c). Energy features as both a consumption good as well as a factor input to production. Households have non-homothetic preferences over non-energy and energy goods with poorer households spending a larger share of their income on energy. Production of non-energy goods requires labor and energy as inputs which cannot be easily substituted. A labor union flexibly supplies labor to firms charging a wage rate that they can only infrequently change, whereas goods prices are perfectly flexible. All energy has to be imported from abroad and we model an energy crisis as an exogenous shock to the foreign price of energy.

2.1 Households

Environment The economy is populated by a continuum of households of measure one. Households are infinitely-lived and time is discrete. The domestic economy is part of a continuum of foreign countries distributed over the unit interval, each populated by a representative foreign agent (à la Gali and Monacelli, 2005). Each domestic household faces idiosyncratic income risk in the form of shocks to labor productivity, which follow a first order Markov process with states $s_t \in \mathcal{S}$ and transition probabilities $\gamma(s_{t+1}|s_t)$. Households can only imperfectly insure against labor income risk by saving in a mutual fund, which yields ex-post return r_t.

A household with assets a and productivity s at time t optimally chooses consumption of domestically produced goods c_h, imported energy goods c_e and savings a' solving the dynamic program

$$V_t(a, s; \Omega, \mathbf{X}) = \max_{c_h, c_e, a'} u(c_h, c_e) - v(N_t) + \beta \mathbb{E}_t \left[\sum_{s' \in \mathcal{S}} \gamma(s'|s) V_{t+1}(a', s'; \Omega', \mathbf{X}') \right]$$

$$\begin{aligned} \text{subj. to} \quad & c + a' = (1 + r_t)a + s w_t N_t \\ & \Omega' = \mathcal{T}(\Omega), \quad c \geq 0, \quad a' \geq \underline{a} \end{aligned} \tag{1}$$

where w_t is the real wage, N_t is labor supply determined by labor unions as described below and $\underline{a}$ is an ad-hoc borrowing limit. $\mathbf{X}$ is a vector of aggregate states specified below and $\Omega = \Omega(a, s)$ the distribution of agents over asset holdings $a \in \mathcal{A}$ and income productivity $s \in \mathcal{S}$.

Preferences Period utility is separable in consumption and labor hours and takes CRRA form

$$u(c_h, c_e) = \frac{c^{1-\sigma}}{1-\sigma}, \qquad v(N) = \psi \frac{N^{1+\varphi}}{1+\varphi}$$

with the consumption basket given by a Stone-Geary aggregator

$$c = \left[(1-\alpha)^{\frac{1}{\eta}} c_h^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} (c_e - \underline{c})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{2}$$

where $\underline{c}$ denotes the subsistence level of energy consumption. Subsistence consumption introduces non-homotheticity in the utility function implying that the expenditure share of energy declines with income. As in the data households therefore do not only differ in the level but also in the composition of spending with poorer households spending a larger share on energy. The parameter σ denotes the inverse elasticity of intertemporal substitution, φ the inverse Frisch elasticity of labor supply, η the elasticity of substitution between energy and non-energy consumption and α measures the share of energy consumption in the overall consumption basket. The consumer price index for these preferences is given by

$$P_t \equiv \left[(1-\alpha) P_{ht}^{1-\eta} + \alpha P_{et}^{1-\eta} \right]^{\frac{1}{1-\eta}} \tag{3}$$

where P_{ht} is the price of domestically produced non-energy goods and P_{et} is the domestic price of imported energy goods. Consumption expenditure minimization implies that a household in state (a, s) with total consumption $c_t(a, s)$ splits purchases between both goods according to

$$c_{h,t}(a, s) = (1-\alpha) \left(\frac{P_{h,t}}{P_t} \right)^{-\eta} c_t(a, s) \tag{4}$$

$$c_{e,t}(a, s) = \alpha \left(\frac{P_{e,t}}{P_t} \right)^{-\eta} c_t(a, s) + \underline{c} \tag{5}$$

The first order conditions of the dynamic program yields a standard Euler equation, which holds with equality whenever the borrowing constraint does not bind

$$1 \geq \mathbb{E}_t \left[\beta \sum_{s_{t+1}} \gamma(s_{t+1}|s_t)(1+r_{t+1}) \left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \right] \tag{6}$$

2.1.1 Labor union

We introduce sticky wages following Erceg et al. (2000) and Auclert et al. (2021c). A competitive labor packer combines labor provided by a continuum of labor unions $k \in [0,1]$ into an aggregate employment service N_t using a constant elasticity of substitution technology $N_t = \left(\int_0^1 N_{kt}^{\frac{\varepsilon_w - 1}{\varepsilon_w}} di \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}}$, where ε_w is the elasticity of substitution between varieties of union labor. The packer sells this labor aggregate at real wage w_t to the intermediary production sector. The demand for union labor is $n_{it} = \left(\frac{W_{it}}{W_t} \right)^{-\varepsilon_w} N_t$.
Each labor union employs all households for an equal number of hours. Unions engage in monopolistic competition and are in charge of setting nominal wages by maximizing welfare of the average household. Wage adjustments are subject to a quadratic cost in terms of household utility. The objective function of union k is then given by

$$\max_{W_{kt}} \quad \sum_{\tau \geq 0} \beta^{t+\tau} \left[\left(\frac{C_{t+\tau}^{1-\sigma}}{1-\sigma} - \int_0^1 \psi \frac{n_{it+\tau}^{1+\varphi}}{1+\varphi} \right) d\Omega_{it+\tau} - \frac{\chi}{2} \left(\frac{W_{t+\tau}}{W_{t+\tau-1}} - 1 \right)^2 \right]$$

In a symmetric equilibrium all unions charge the same wage and employ households for the same number of hours. The dynamics of aggregate nominal wage inflation $1 + \pi_{wt} = W_t / W_{t+1}$ are given by a non-linear New Keynesian wage Philips Curve[1]

$$\pi_t^w (1 + \pi_t^w) = \frac{\epsilon_w}{\chi} \left[\psi N_t^{1+\varphi} - \frac{\epsilon_w - 1}{\epsilon_w} C_t^{-\sigma} \frac{W_t N_t}{P_t} \right] + \beta \mathbf{E}_t [\pi_{t+1}^w (1 + \pi_{t+1}^w)] \tag{7}$$

In the following, we opt for a framework that features sticky nominal wages but fully flexible prices. Our reasons are threefold. First, rigid wages are crucial to capture salient features of micro data on household earnings. As argued by Auclert et al. (2021a), households on average have very small marginal propensities to earn (MPE), which is the labor market equivalent of marginal propensities to consume (MPC). The fact that households do not adjust their labor supply in response to income changes can only be captured if there is some form of wage stickiness. Second, New Keynesian models with sticky prices typically feature countercyclical profits. While this can matter in the case of representative agent models as shown by Broer et al. (2020), it becomes crucial for heterogeneous agent models, where the distribution of dividends plays an important role

[1] Appendix A cotains further details on the derivation of the NKPC-W.

for aggregate dynamics. Third, assuming sticky prices would be at odds with the observed evolution of markups during the recent inflation surge both in the US and the Euro Area. With sticky prices, an increase in marginal cost would lead to a decrease in markups as firms can reset their prices only with a certain probability. Under flexible prices, markups instead remain constant in line with markups empirically having mostly remained constant or even increased. Real wages instead have seen a marked decline consistent with sticky nominal wages but flexible prices.

2.2 Domestic production

Final goods producer A representative final-goods producer aggregates domestic intermediary goods $Y_{j,t}$ with $j \in [0,1]$ through a CES production function $Y_t = \left(\int_0^1 Y_{j,t}^{\frac{\varepsilon_f - 1}{\varepsilon_f}} dj \right)^{\frac{\varepsilon_f}{\varepsilon_f - 1}}$, where ε_f denotes the elasticity of substitution between intermediate goods. Cost minimization yields the producer demand for intermediate good j given by $Y_{j,t} = \left(\frac{p_{j,t}}{P_{h,t}} \right)^{-\varepsilon_f} Y_t$ and a domestic final goods price $P_{h,t} = \left(\int_0^1 p_{j,t}^{1-\varepsilon_f} dj \right)^{\frac{1}{1-\varepsilon_f}}$.

Intermediate-good producers A continuum of monopolistically competitive firms produces intermediate goods with a CES production technology

$$Y_{j,t} = \left[\alpha_f^{\frac{1}{\theta}} E_{j,t}^{\frac{\theta-1}{\theta}} + (1-\alpha_f)^{\frac{1}{\theta}} \gamma_t N_{j,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \tag{8}$$

using energy E_t and labor N_t as an input, where γ_t captures labor-augmenting aggregate productivity, θ governs the elasticity of substitution across factor inputs and α_f is the share of imported energy used in production.[2] In a symmetric equilibrium factor demand for imported energy and labor satisfies

$$\frac{P_{e,t}}{P_t} = \frac{\alpha_f}{\mathcal{M}_t} \frac{P_{h,t}}{P_t} \left(\frac{Y_t}{E_t} \right)^{\frac{1}{\theta}} \tag{9}$$

$$\frac{W_t}{P_t} = \frac{1-\alpha_f}{\mathcal{M}_t} \frac{P_{h,t}}{P_t} \gamma_t \left(\frac{Y_t}{N_t} \right)^{\frac{1}{\theta}} \tag{10}$$

where $\mathcal{M}_t$ is the real mark-up. This markup arises from imperfect substitution between intermediate goods due to market power despite prices being fully flexible.

Intermediate goods producers pay real dividends to the mutual fund in the amount of

$$D_t = \frac{P_{h,t} Y_t - P_{e,t} F_t - W_t N_t}{P_t} = \frac{P_{h,t}}{P_t} Y_t \left(1 - \frac{1}{\mathcal{M}_t} \right) \tag{11}$$

[2] For simplicity we abstract from capital in the production function. Our setup is equivalent to assuming a capital stock that is in fixed supply.

Mutual fund A domestic, unconstrained and risk-neutral mutual fund holds an asset portfolio composed of shares in intermediate goods firms as well as nominal domestic and foreign bonds yielding nominal returns i_t and i_t^* respectively. Firm shares pay a return $\frac{D_{t+1}+j_{t+1}}{j_t}$, where j_t is the share price in period t. The fund issues claims to households with aggregate real value A_t and maximizes the ex-post return on these liabilities, r_{t+1}.

Equilibrium non-arbitrage conditions imply a Fisher relation between nominal and real returns, covered interest parity between domestic and foreign bonds and return equalization across all investment opportunities

$$1 + i_t = (1 + r_t^{ante})\frac{P_{t+1}}{P_t} \tag{12}$$

$$1 + r_t = (1 + i_t^*)\frac{Q_{t+1}}{Q_t} \tag{13}$$

$$1 + r_t^{ante} = 1 + r_{t+1} = \frac{D_{t+1} + j_{t+1}}{j_t} \tag{14}$$

2.3 International markets and prices

We define e_t as the nominal exchange rate expressed in terms of the domestic price for a unit of foreign currency. An increase of e_t therefore indicates an exchange rate depreciation. The world price of energy P_{et}^* is exogenous in terms of a world currency, where we use an asterisk to denote foreign variables. Assuming that the law of one price holds the domestic price of energy is given by

$$P_{e,t} = e_t P_{e,t}^*$$

The real exchange rate is defined as

$$Q_t = \frac{e_t P_t^*}{P_t} = \frac{P_{e,t}}{P_{e,t}^*}\frac{P_t^*}{P_t} = \frac{P_{e,t}}{P_t} \Big/ \underbrace{\frac{P_{e,t}^*}{P_t^*}}_{\equiv \mathcal{P}_t^*} \tag{15}$$

Without loss of generality, we normalise the foreign price level P_t^* to one. Although there is full pass-through of the world price of energy to domestic energy prices, purchasing power parity (PPP) does not necessarily hold as exogenous variations in $\mathcal{P}_t^*$ generate real exchange rate fluctuations. Domestic prices can be rewritten as a function of the real exchange rate,

$$\frac{P_{h,t}}{P_t} = \left[\frac{1 - \alpha Q_t^{1-\eta} \mathcal{P}_t^{*1-\eta}}{1 - \alpha}\right]^{\frac{1}{1-\eta}} \tag{16}$$

We define the terms of trade as the price of domestic goods over the price of energy

$$\mu_t = \frac{P_{h,t}}{P_{e,t}} = \frac{P_{h,t}}{e_t P^*_{e,t}}$$

Foreign demand for the domestic good depends on the terms of trade and is given by

$$C^*_{h,t} = \left(\frac{P^*_{ht}}{P^*_{e,t}}\right)^{-\lambda} C^* \tag{17}$$

where C^* is a foreign aggregate demand and λ captures the inverse elasticity of foreign demand to the foreign price of domestic goods.

Nominal net exports are the difference between foreign sales of domestic production and energy imports for domestic consumption and production

$$NX_t = P_{h,t}c^*_{h,t} - P_{e,t}c_{e,t} - P_{e,t}E_t \tag{18}$$

The net foreign asset position is defined as $NFA_t = A_t - j_t$ and evolves according to

$$NFA_t = NX_t + (1 + r_{t-1})NFA_{t-1} + (r_t - r_{t-1})(A_{t-1} - j_{t-1}) \tag{19}$$

where the last two terms capture revaluation effects, which are equal to zero in our zero net foreign asset position steady state.

2.4 Monetary Policy

Our main focus is to analyse the effects of monetary policy on the transmission of energy price shocks. The monetary authority sets the nominal interest rate according to a Taylor rule

$$i_t = r_{ss} + \phi_{\pi_k}\pi_{k,t} \qquad k \in \{cpi, h, e\} \tag{20}$$

This specification nests several special cases. In our baseline, monetary policy keeps the real rate constant, $\phi_{\pi_k} = 0$. In alternative scenarios policy can also react to headline, core or energy price inflation, defined as $\pi_{cpi,t} = P_t/P_{t-1}$, $\pi_{h,t} = P_{ht}/P_{ht-1}$ and $\pi_{e,t} = P_{et}/P_{et-1}$ respectively. We also study forecast rules and allow for policy to react to the inflation forecast, $\mathbb{E}_t\pi_{k,t}$ instead of contemporaneous measures of inflation.

2.5 Equilibrium

Given a sequence of foreign energy prices $\{P^*_{e,t}\}$, an initial wealth distribution $\Omega_0(a, z)$ and an initial portfolio allocation for the mutual fund, an equilibrium is a path of value and policy functions $\{V_t(a,z), a'_t(a,z), c_{h,t}(a,z), c_{e,t}(a,z)\}$, distributions $\{\Omega_t(a,z)\}$, prices $\{r_{h,t}, r_t, i_{h,t}, i_{f,t}, Q_t$ $w_t, \pi_{w,t}, P_{e,t}, P_{h,t}, P_t\}$ and aggregate quantities $\{Y_t, E_t, N_t, A_t, D_t, j_t, C^*_{h,t}, NX_t, NFA_t\}$ such that all agents optimize and market clearing holds for asset markets, $A_t = \int a'(a,z)d\Omega_t$, and the domestic goods market, $Y_t = C_{h,t} + C^*_{h,t}$, where $C_{h,t} = \int c_h(a,z)d\Omega_t$. The aggregate state is given by the distribution function $\Omega_t(a,z)$ and $\mathbf{X}_t = \{r_{t-1}, w_{t-1}\}$.

3 Calibration and steady state

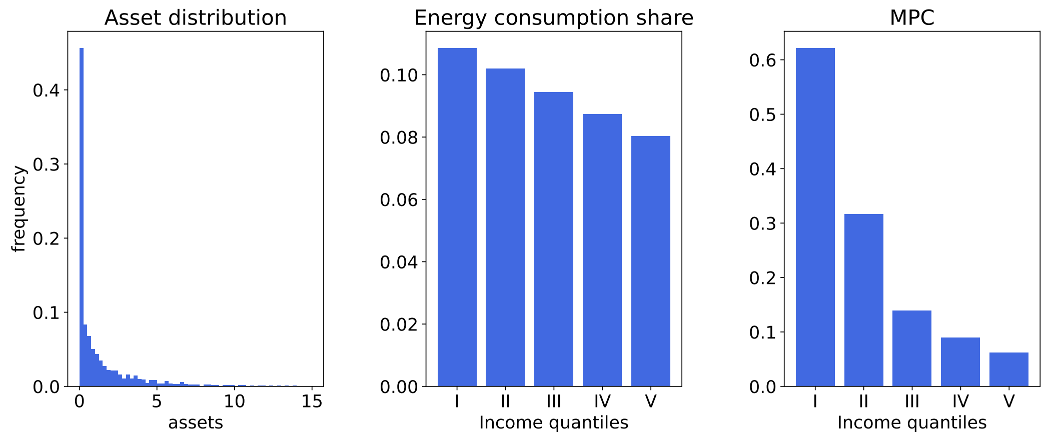
We calibrate the model at a quarterly frequency for the Euro Area and list key model parameters in table 1. We chose some parameters relying on standard values in the literature and match others to target empirical moments from data on household and firm exposure to imported energy, the heterogeneous consumption exposure of households across the income distribution, and aggregate marginal propensities to consume based on data from Eurostat and available empirical estimates. We calibrate the discount factor β to 0.968 to target an annualized nominal interest rate of two percent in steady state in line with recent estimates by Best et al. (2020). We assume an intertemporal elasticity of substitution σ equal to one consistent with King-Plosser-Rebelo preferences and a balanced growth path along the steady state. We calibrate the inverse Frisch elasticity of labor supply $\varphi = 2$ within the standard range of values reported in Chetty et al. (2011). For the idiosyncratic productivity process we follow typical estimates and assume an AR(1) process with persistence of 0.92 and cross-sectional standard deviation of 0.6. We set the borrowing constraint $\underline{a} = 0$. We assume an elasticity of substitution between varieties of labor of 19 implying a wage markup of roughly 5% and set adjustment costs to 190 to yield a Philips curve slope of 0.1. Following Chan et al. (2022) and Auclert et al. (2021c) we calibrate the foreign demand elasticity λ to 1/3. We set the consumption elasticity of substitution between energy and non-energy goods η to 0.4. For the elasticity of substitution in production we chose a value of 0.5. Both parameters are well within the range reported by Bachmann et al. (2022).

Table 1: Calibration

Parameter	Definition	Value	Source/Target
Households			
β	Household discount factor	0.968	Annual nominal rate 2%
σ	Household risk aversion	1	Literature
α	Energy share in consumption	0.051	Eurostat $c_f/c = 0.09$
$\underline{c}$	Subsistence level energy consumption	0.037	Eurostat $c_f^{Q1}/c^{Q1} = 0.13$
η	Elasticity of substitution consumption	0.4	Bachmann et al. (2022)
φ	Inverse Frisch elasticity	2	Literature
ψ	Utility weight of labor	0.543	$\pi = 0$
Labor Unions			
ε_w	Elasticity of substitution labor	19	Wage markup of 5%
χ	Wage adjustment cost	190	NKPC slope of 0.1
Firms			
α_f	Energy share in production	0.201	Eurostat $E = 0.16$
θ	Elasticity of substitution production	0.5	Acurio (2015)
$\mathcal{M}$	Price markup	1.007	Carroll et al. (2017)
World Trade			
C^*	Foreign demand level	0.181	$NX = 0$
λ	Foreign demand elasticity	0.5	Auclert et al (2021)

To calibrate the rest of the household and firm parameters we jointly target four moments from the data. From Eurostat's "Income wealth and consumption statistics" (IWCS) we use the fact that household expenditure on energy is around 9%. The IWCS also shows that the bottom quintile of the income distribution has higher expenditures on energy of around 13% pointing to strong non-homotheticity in the consumption basket. Input-output tables from Eurostat furthermore show that the use of imported energy in production is almost twice the size than the use for consumption. Finally, we also target an average MPC of 0.32 as reported in Carroll et al. (2017). These targets jointly determine the energy share of consumption α and production α_f, the subsistence level of energy consumption $\underline{c}$ and the size of firm markups μ. Lastly, we chose the utility weight of labor ψ and the foreign demand level C^* such that inflation in steady state is zero and the economy initially has zero net foreign assets. We solve the model by solving the household problem relying on the endogenous gridpoint method developed by Carroll (2006), approximating the continuous distribution on a discrete grid as suggested by Young (2010). We compute dynamics using the sequence space approach as developed by Auclert et al. (2021b).

Figure 2: Steady state wealth distribution, consumption composition and MPCs



Note: The left graph shows the histogram over assets choices a'. The middle graph shows the expenditure on energy by income quintile. The right graph shows marginal propensities to consume out of an additional dollar of income.

Our steady state captures salient facts on household heterogeneity as displayed in figure 1 quite well. There is substantial wealth inequality in our economy. Around 20 percent of households are financially constrained with zero savings and unable to smooth shocks to their income or changing prices of their consumption basket. Almost half of all households have only very little savings and therefore are substantially exposed to energy prices. The energy share of low income households is substantially higher than the energy share of high income households. For example, the lowest income quantile spends roughly 3 percentage points more on energy than the highest income quantile. The substantial wealth heterogeneity and hence unequal ability to self-insure against shocks is also reflected in a wide dispersion of marginal propensities to consume (MPCs). Low income households, defined as those in the bottom quintile of the income distribution, spend on average 60 percent of an additional euro on consumption. High income households, defined as the top quintile of the income distribution, instead behave close to the permanent income hypothesis and only spend around 7 percent of an additional euro in response to a transitory income change.

4 Energy price shocks and monetary policy

Our main exercise of interest is to simulate an energy price shock comparable to the one that hit the Euro Area in the beginning of 2022. We thus consider a 30 percent increase in the imported price of energy, roughly matching the magnitude of the rise in energy prices as compared to the past 20 years average level, as shown in figure 1. More precisely, we assume a standard AR(1) process with a persistence of 0.8 for the shock.[3]

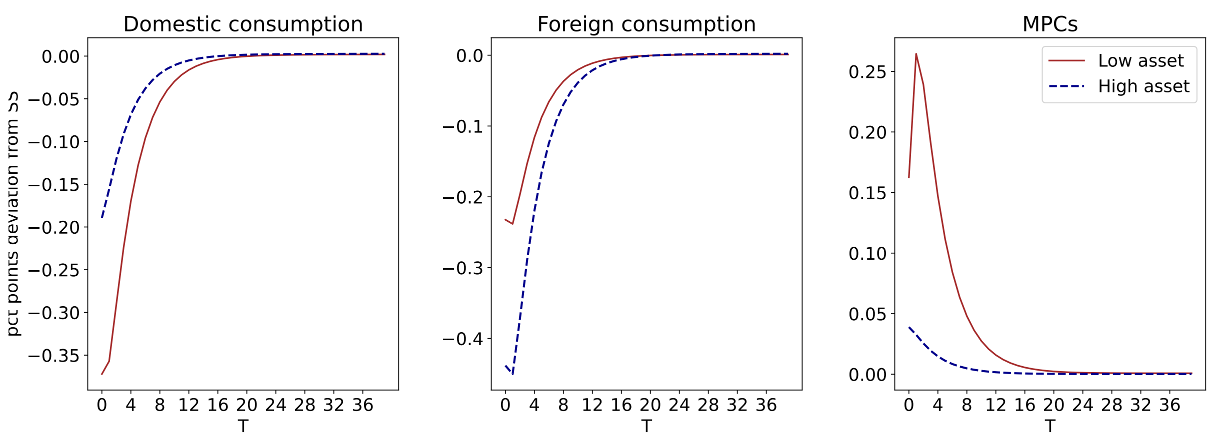
[3] Without loss of generality, we normalize the foreign price level to one in the steady state and assume that it does not change in response to the shock, implying that the energy price increase is to exported energy.

In this section we first illustrate the main transmission mechanism in our model, discussing the role of the elasticity parameters. We then turn to discuss aggregate effects of an energy price shock and how they are shaped by the monetary policy response. Finally, we look at the distributional effects of a foreign energy price shock associated with different monetary policies. Throughout, we contrast "active" rules raising real interest rates with a "neutral" policy rule keeping the real rate constant.

4.1 Elasticities of substitution and main transmission mechanisms

We start by illustrating how non-homotheticity in consumption and input complementarity in production affect the consumption response to an energy price shock across households. These are important drivers of aggregate effects – focusing on them allows to understand the main transmission mechanism in general equilibrium.

Figure 3: Transmission channel of non-homothetic preferences



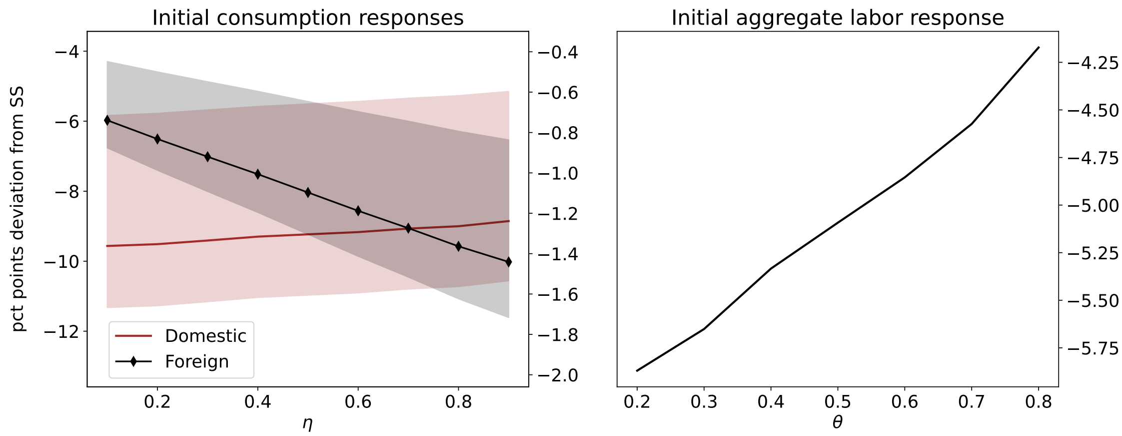
Note: The plots show equilibrium "price" effects, capturing only relative price changes as described in appendix B. The shock is a 30% increase in foreign energy prices. Monetary policy implements a Taylor headline rule. The red line correspond to the average consumption response of the second lowest income quintile, while the dashed line corresponds to the average consumption response of the second highest income quintile.

Following the increase in the price of foreign energy, there are two main channels at play in the transmission of the energy shock through aggregate demand: *i*) the direct consumption expenditure channel and *ii*) the indirect general equilibrium income effect. Figure 3 gives insights for the former effect, as it plots the effect of an increase in the foreign good price on the optimal consumption basket as well as MPCs by quintiles of the wealth distribution. As the foreign good becomes more expensive, households want to substitute away from it but are constrained by the subsistence level of energy consumption. In fact, low income households are not able to decrease their foreign good consumption as much as high income households, as is illustrated in the middle panel. In turns, this implies that low income households suffer a relatively larger consumption expenditure increase following the shock. Moreover, since they cannot insure against this income shock, their domestic consumption drops by relatively more (left panel). MPCs for low income households increase by relatively more, mirroring the larger consumption expenditure shock they are subject to. These partial equilibrium forces are important drivers of general equilibrium responses, as is also visible from comparing the heterogeneous agent economy to a representative agent economy (see section C for more details).

The magnitude of the consumption expenditure effect is governed by the elasticity of substitution across foreign and domestic goods. On the left panel, figure 4 plots the initial consumption response to the foreign price shock for different values of the elasticity of substitution parameter. In particular, we vary the consumption elasticity of substitution η from a very low degree of substitutability ($\eta = 0.1$), where energy and non-energy goods are almost complements, to both goods having a very high degree of substitutability ($\eta = 0.9$) being almost perfect substitutes. Foreign consumption declines by less when η is low, as households cannot substitute consumption of foreign goods by purchasing more domestic goods. This also imposes a larger negative income shock to households, as they cannot mitigate the energy price increase, thereby decreasing their domestic good consumption by relatively more. The response of consumption across the wealth distribution is illustrated with shaded areas and highlights large differences across income quintiles. When substitutability is high, the differences are exacerbated because low income households are constrained by the subsistence level of energy consumption.

The right panel of figure 4 shows the initial response of aggregate labor under different calibration of the production function elasticity of substitution across labor and energy goods. As firms are increasingly able to substitute energy (going from low to high θ), they demand relatively more labor to mitigate the rise in energy input costs. Higher labor demand also raises real wages and overall sustains labor income. A high degree of substitutability between factor inputs therefore somewhat allows to mitigate the effects of an energy price shock. It also benefits low income households, which predominantly rely on labor income.

Figure 4: Role of elasticity of substitution in consumption and production

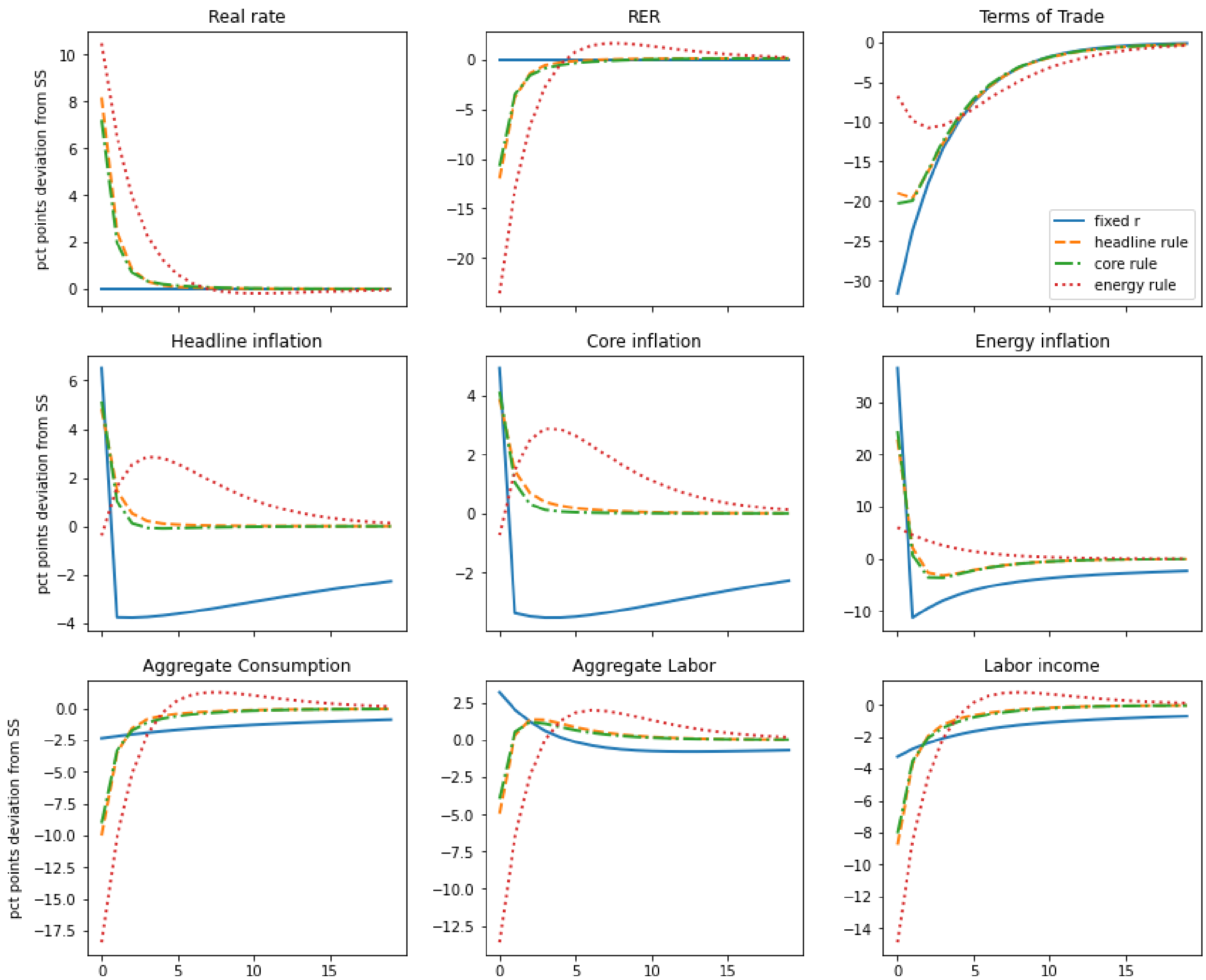


Note: The shock is a 30% increase in foreign energy prices, points correspond to time 0 responses. Monetary policy implements a Taylor headline rule. The shaded areas correspond to the difference from the second poorest to second richest quintiles of the distribution. Foreign consumption responses correspond to the right axis in the left panel.

4.2 Aggregate effects

To gauge the aggregate effects of an energy price shock and their dependence on monetary policy, we contrast a "neutral" policy rule that keeps the real interest rate fixed (our baseline) with policy rules reacting to contemporaneous or forecast measures of inflation. Figure 5 shows impulse responses for selected aggregate variables contrasting the baseline with contemporaneous rules. Under the baseline rule, the energy price shock leads to an initial strong increase in inflation that quickly subsides and turns negative after a few quarters. To keep real rates constant, the Fisher equation implies that the nominal rate is set as the sum of the real rate and *future* inflation. This leads to an initial large increase of nominal rates followed by a quick decline similar to the one of inflation. Despite the large increase in inflation and an initial large increase in nominal rates the baseline rule leads to the lowest decline in consumption and output. The reason is, that household consumption-savings decisions are based on the *real* interest rate. A fixed real rate rule is highly accommodating in response to the energy shock and keeps real rates substantially below rates arising from other policies. In addition, high inflation rates combined with flexible prices lead to a strong real wage decline. This decrease in wages is more than compensated for by an increase in labor demand overall leading to a relatively muted impact on labor income. Domestic aggregate demand is also supported through the open economy channel. Because domestic real rates do not change, they do not differ from foreign real rates implying a constant real exchange rate through the uncovered interest parity condition. Together with a much more pronounced fall in the terms of trade due to an initial high pass-through of energy inflation, households and firms substantially move towards domestic products.

Figure 5: Effects of an energy price shock under contemporaneous monetary policy rules



Note: Impulse response of aggregate variables to a 30 percent increase in foreign energy prices contrasting a rule that keeps real rates fixed with rules reacting to a contemporaneous measure of inflation as described in section 2.

Alternatively, we consider three monetary policy rules reacting to contemporaneous measures of inflation as follows: *i)* headline inflation, defined as the aggregate price inflation; *ii)* core inflation, defined as the domestic price inflation and *iii)* energy inflation.

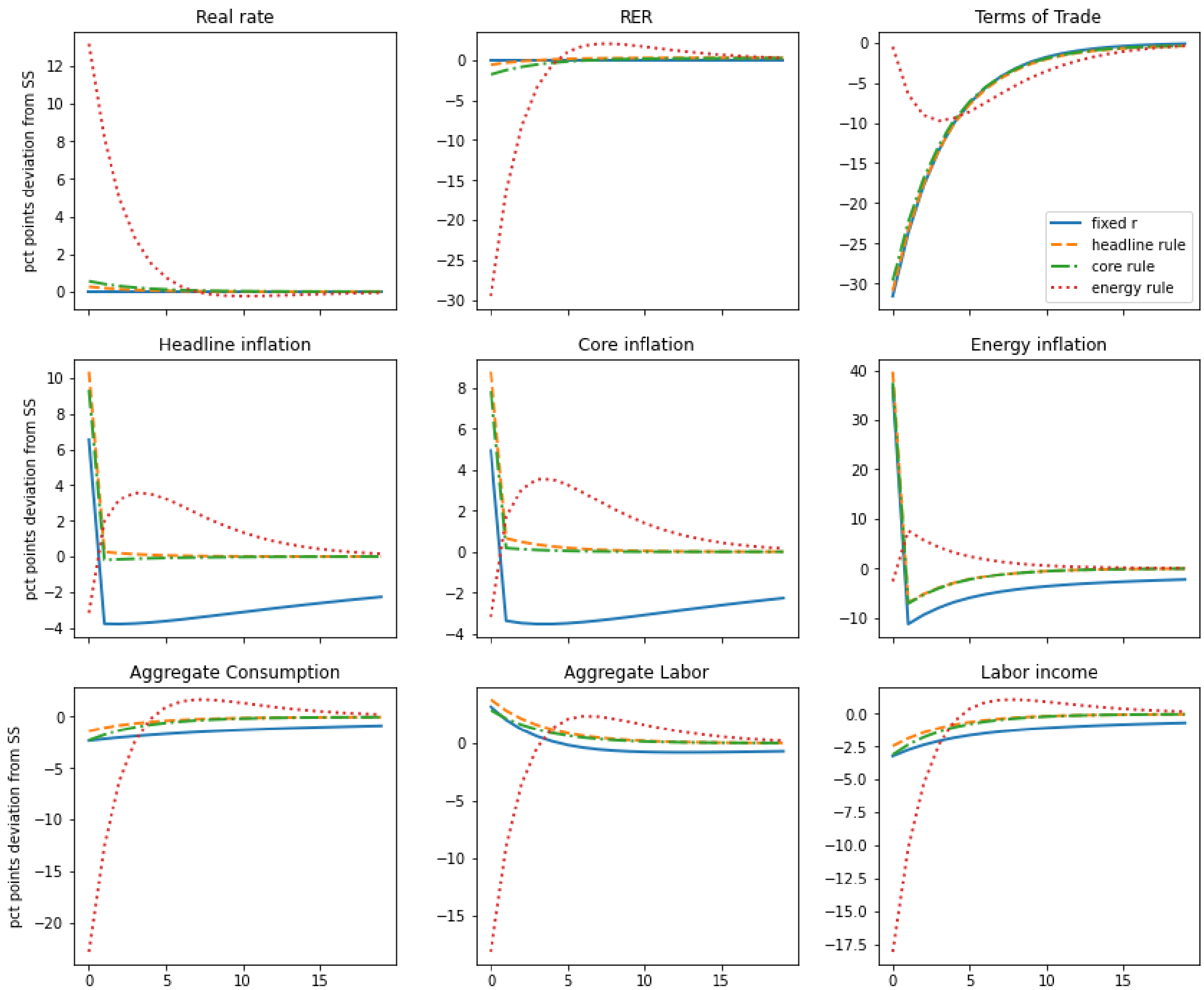
Any of these alternative active policy rule would raise real rates by responding to an energy price shock with rising nominal rates. A headline rule would raise nominal rates around 1.5 percentage points more than a core interest rate rule (around 8 percentage points), whereas an energy rule would raise nominal rates by around 12 percentage points in total. The differences between a headline and a core inflation rule in terms of real rates and inflation outcomes are hardly noticeable though with a core rule leads to slightly higher inflation rates. Given substantially higher real rates, the decline in consumption and output is fourfold compared to the baseline rule. As households consume less domestic goods the decrease in demand for domestic goods amplifies negative effects on labor hours.

A policy rule reacting to energy prices has a substantial recessionary effect containing inflation rates in the short run at the expense of medium-term inflation. Real interest rates are highest under an energy price rule and therefore exert a substantial negative effect on domestic goods demand initially turning core inflation negative and containing energy price inflation. However, in subsequent periods core inflation turns strongly positive while energy inflation remains elevated compared to other policy rules. This medium-term effect arises from two channels. First, reacting solely to energy price inflation is overly restrictive and severely hampers aggregate demand leading to a rise in real rates that has to be quickly reverted with a similar strong reversion in labor demand and labor income. Second, the strong increase in real rates leads to a strong real exchange rate appreciation as foreign interest rates do not move. Since initial inflation is contained, the real exchange rate movement translates almost one-to-one into an exchange rate appreciation with subsequent depreciations as inflation rates turn positive. While the initial appreciation leads to a strong initial decline in production, subsequent depreciations raise foreign demand for domestic goods adding to the recovering domestic demand.

Reacting to different *measures* of inflation is not equivalent to varying the *strength* of the reaction to an energy price shock. From the impulse response in the baseline case it is clear that, absent any policy reaction, an initial increase of energy prices would lead to positive energy inflation in the initial period. However, the subsequent autoregressive decline of (elevated) energy prices, as is the case for our AR(1) shock, implies negative energy inflation rates in the periods following the shock. As the energy price increase leads to substitution effects towards domestic goods in consumption and towards labor in production, core inflation rates initially increase. Since the share of energy goods in the consumption basket is roughly 10 percent, the path of core inflation also heavily influences the path of headline inflation explaining why differences between a core and a headline rule are rather mute. An energy rule however leads to a hump-shaped inflation profile due to an initial suppression and subsequent fast catch-up of demand for domestic goods.

Impulse responses for forecasting rules starkly differ from rules reacting to contemporaneous measures of inflation. In figure 6 we plot impulse responses of aggregate variables for forecast rules. Since energy inflation is only positive in the initial period but receding subsequently, forecast rules reacting to either headline or core inflation are in fact "looking through" the energy price increase. The real rate increase is strongly muted thereby mitigating the negative effects on aggregate demand. In fact, both the decline in consumption as well as labor income are somewhat smaller than under a fixed rate rule with otherwise very similar implications.

Figure 6: Effects of an energy price shock under forecast rules



Note: Impulse response of aggregate variables to a 30 percent increase in foreign energy prices contrasting a rule that keeps real rates fixed with rules reacting to a forecast measure of inflation as described in section 2.

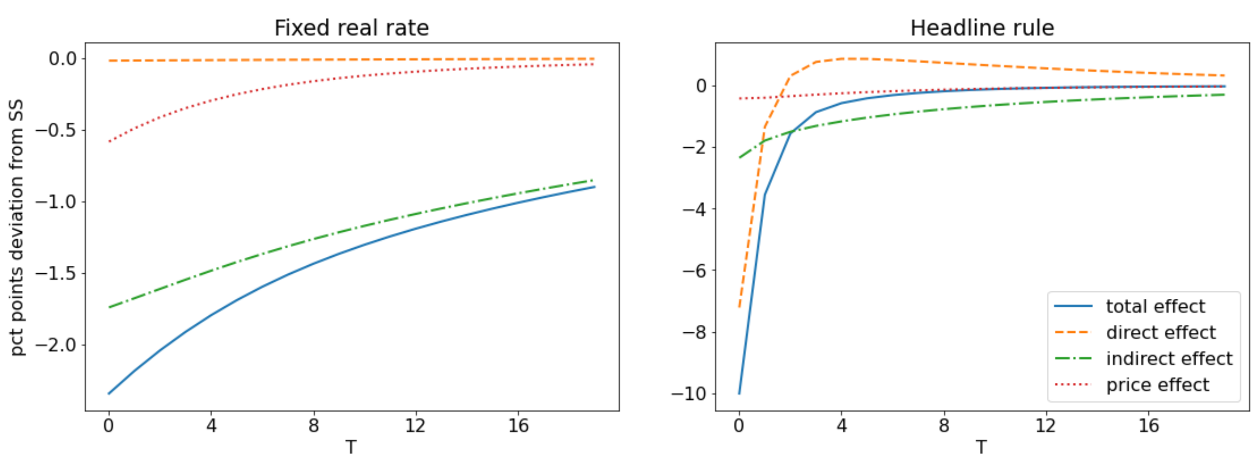
Only the forecast rule relying on energy as an inflation measure amplifies the effects compared to its contemporaneous counterpart. In particular, despite a positive shock to foreign energy prices, domestic inflation rates for energy are initially negative before strongly increasing. Because high real rates induce a severe recession with substantial declines in aggregate consumption and labor, the initial price level even falls. Simultaneously, the real exchange rate substantially appreciates which implies an even higher appreciation of nominal exchange rates due to initially falling prices. The initially elevated exchange rate prevents a pass-through of rising energy prices to the domestic economy. However, this comes at the cost of substantial negative quantity adjustments on the real side. Moreover, as energy prices in subsequent periods pass through to the domestic economy and with strongly recovering aggregate demand, inflation rates in the medium term are even higher than under a policy rule responding to contemporaneous energy inflation.

4.3 Decomposition of aggregate consumption response

In figure 7 we show how the key drivers of the total consumption response differ between a baseline neutral policy rule and a rule actively reacting to headline inflation. We decompose the aggregate consumption response into a direct effect arising from changes in the real interest rate, an indirect effect arising from changes in labor income and a price effect. The latter captures a decline in consumption arising from an increase in energy prices, which lead to higher expenditures on subsistence consumption leaving a smaller share of income for consumption beyond the subsistence level. Any increase in the price of the *overall* consumption basket without leading to changes in the relative price of goods instead reduces real income and therefore constitutes an indirect effect.[4]

Under a fixed real rate rule the consumption decline is mostly driven by indirect effects with the relative price increase also playing a substantial role. In the baseline, the energy price shock makes energy goods more expensive than non-energy goods and thereby raises the cost of subsistence consumption. This price effect accounts for one fourth of the total consumption decline with three fourth being driven by indirect effects through falling labor income. The strong decline of consumption through indirect general equilibrium effects is a common feature of New Keynesian models with heterogeneous households that work predominantly through general equilibrium effects. Indeed, given the absence of any real rate response, direct (partial equilibrium) effects are zero.

Figure 7: Consumption decomposition for contemporaneous rules



Note: Decomposition of the aggregate consumption response to an energy price shock. The “direct” effect captures the contribution from a change in the real interest rate, the “indirect” effect captures income effects and the “price” effect captures relative price changes as described in appendix B.

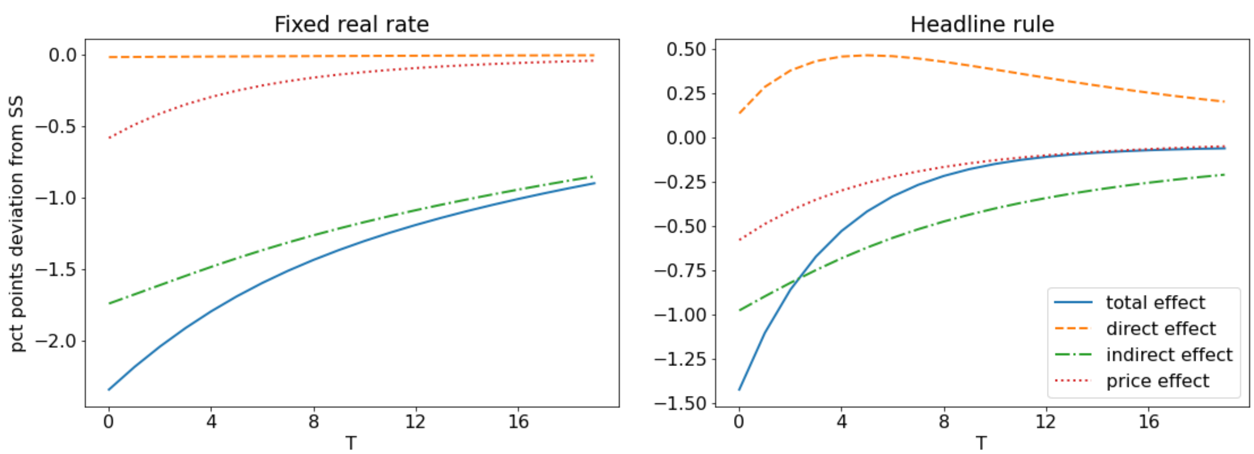
Substantially higher initial inflation rates under the baseline rule, while in itself eroding real income, do nevertheless not imply a stronger consumption decline compared to active policy rules. A fixed real rate rule is sufficiently stimulative to mitigate the erosion of labor income due to higher inflation through a stronger demand for domestic production. Overall, the negative indirect effect

[4] Appendix B contains further details on the decomposition.

on consumption through labor income is about 25 percent smaller compared to active rules. The bulk of the difference however comes from avoiding any negative consumption effects through rising real rates. Therefore, overall the decline in consumption is almost an order of magnitude smaller compared to an active policy rule.

Active policy rules amplify the negative consumption response through increasing real rates. Over three fourth of the consumption decline are due to direct interest rate effects, whereas these were entirely absent in the baseline. Despite the rise in real rates, there is no noticeable reduction in the price effect. However, the restrictive policy is further amplifying indirect effects. Despite containing inflation more strongly than a "neutral" rule, the decline in labor demand through a reduction in aggregate demand leads to substantially falling labor income which adds to the over consumption decline. Nevertheless, an active policy ultimately leads to a faster recovery because of a positive contribution of the direct effect as positive real rates over time help households that hold a sufficient amount of assets rebuild their wealth faster. Appendix B contains further decompositions for the core and energy rule which are quantitatively different but feature the same underlying forces driving the decline in consumption.

Figure 8: Consumption decomposition for forecast rules



Note: Decomposition of the aggregate consumption response to an energy price shock. The "direct" effect captures the contribution from a change in the real interest rate, the "indirect" effect captures income effects and the "price" effect captures relative price changes as described in appendix B.

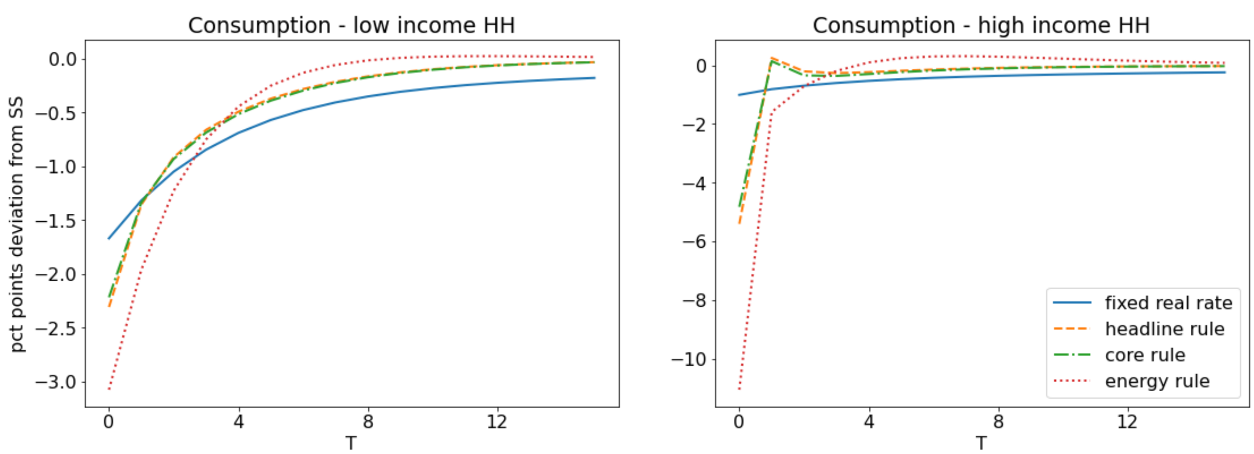
Forecast rules reacting to headline inflation mitigate the consumption decline through positive real rate effects as well as less severe indirect effects. Figure 8 plots the decomposition of aggregate consumption for the headline forecast rule. Compared to the baseline rule, the latter mitigates the aggregate decline in labor income leading to an indirect effect that is almost half. Additionally, the small rise in real rates is insufficient to substantially decrease aggregate demand but instead helps most households rebuild wealth through higher returns on savings ultimately positively contributing to aggregate consumption. As shown in Appendix B, the core forecast rule has similar implications to the headline rule. However, the energy forecast rule exerts a strong negative impact on consumption through the substantial rise in real rates akin to contemporaneous policy rules albeit with larger magnitude.

4.4 Distributional effects

To compare the distributional effects across different monetary policy rules we plot the consumption response of low and high income households in figure 9. Generally, low income households are affected the most by the energy price shock, regardless the monetary policy response, and more so in the in the baseline case. Active monetary policies either through a headline or core rule further amplify this decline in consumption for low income households.

Active monetary policy rules mostly benefit high income households through increasing real rates. Rising real rates leads to higher returns on savings especially in the periods following the energy price shock and benefits high income households who have the highest savings. This positive wealth effect is so strong that high income households even have a *positive* consumption response to the energy price shock beyond the initial period. Only in the initial period is their consumption decline more strongly amplified compared to a fixed rate rule. This initial fall is in part due to declining labor income but predominantly due to the negative ex-post real return arising from unanticipated inflation that lowers the pre-determined nominal rate and thereby savings from the period before the shock occurs.

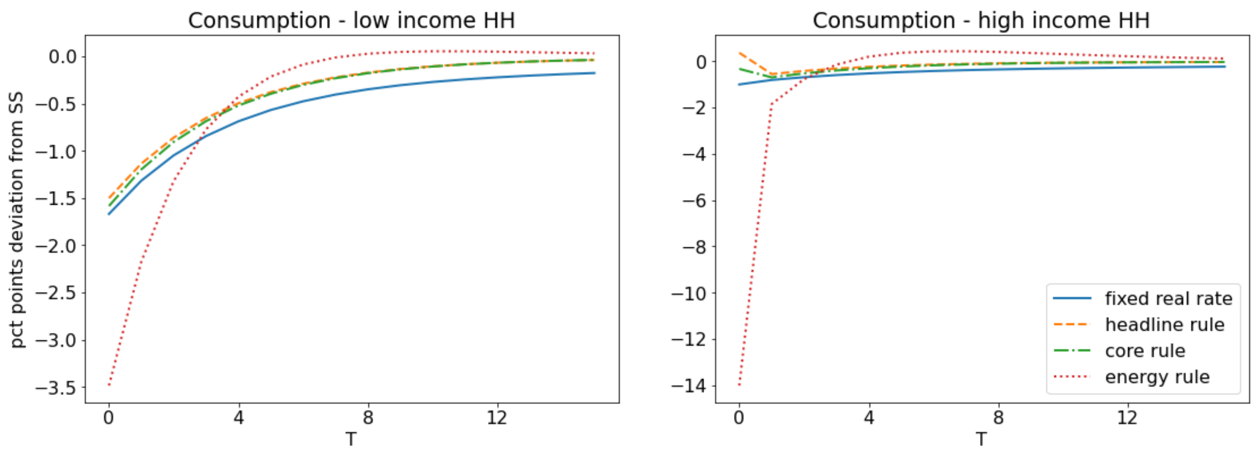
Figure 9: Consumption inequality under contemporaneous rules



Note: Comparison of the consumption response of low and high income households under monetary policy rules reacting to contemporaneous measures of inflation. Low income refers to the lowest wealth quintile whereas high income refers to the second highest wealth quintile.

Forecasting rules reacting to headline or core inflation are beneficial to both low and high income households, albeit for different reasons. Under both forecasting rules, consumption of low income households is still negatively affected by the energy price shock but the effect is reduced compared to the baseline neutral policy. By effectively looking through the transitory nature of the energy price shock both rules achieve a smaller fall in aggregate demand with an associated smaller fall in aggregate labor income which benefits low income households. On the other hand, high income households see a positive consumption response to the energy price shock because the rise in real rates sustains their consumption through higher returns on savings.

Figure 10: Consumption inequality under forecast rules



Note: Comparison of the consumption response of low and high income households under monetary policy rules reacting to forecast measures of inflation. Low income refers to the lowest wealth quintile whereas high income refers to the second highest wealth quintile.

5 Conclusions

The surge in energy prices that began in 2021 has impacted the Euro Area through various channels. Building upon the open economy HANK literature, we introduce non-homothetic preferences in consumption and incorporate energy into production. This framework enables a quantitative assessment of the channels and redistributional effects of the recent energy-induced inflation surge. We particularly focus on studying these implications in both a “neutral” referred to as the baseline, and an “active” monetary policy framework under various rules specifications. Additionally, we explore the distributional consequences of a foreign energy price shock under different monetary policy frameworks.

In what regards the aggregate effects, given significantly higher real rates, we find that in case of either a headline or a core inflation rule, the decline in consumption and output is four times greater compared to the baseline rule. We also find that policy rule reacting to energy prices has a substantial recessionary effect containing inflation rates in the short run at the expense of medium-term inflation. Then, we investigate the implications by employing monetary policy rules reacting to forecast measures of inflation. Model based impulse response functions indicate that forecast rules reacting to either headline or core inflation effectively “look through” the energy price increase. This results in a substantial dampening of the real rate increase, thereby mitigating adverse effects on aggregate demand. Notably, both the decline in consumption and labor income is somewhat less pronounced compared to a fixed rate rule with otherwise similar implications.

Finally, we investigate the distributional effects of the energy prices shock across the different monetary policy rules. In general, low-income households are disproportionately affected by an energy price shock, regardless of the monetary policy response. Active monetary policies, whether headline or core rule based, exacerbate this consumption decline for low-income households. The higher real rates in the "active" policy rules result in favourable returns on savings, benefiting high-income households.

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Appendix

A Derivation of New Keynesian Wage Philips Curve

In this section, we provide the analytical derivation of the wage Phillips Curve. At time t, the union sets its wage to maximize the utility of its average worker:

$$\sum_{\tau\geq 0}\beta^{t+\tau}\left[u(C_{t+\tau})-v(N_{t+\tau})-\frac{\psi_{nr}}{2}(\frac{W_{k,t+\tau}}{W_{k,t+\tau-1}}-1)^2-\frac{\zeta_{BG}}{2}(\epsilon-1)N^{\epsilon}u(C)/\frac{W}{P}(\frac{W_{k,t+\tau}}{P_{t+\tau}}-\frac{W}{P})^2\right]$$

where ψ_{nr} denotes the degree of nominal rigidity and ζ_{BG} denotes the real wage motive. The unions combine individual labor into tasks which face demand $N_{kt}=\left(\frac{W_{kt}}{W_t}\right)^{-\varepsilon_w}N_t$ where $W_t=\left(\int_0^1 W_{k,t}^{1-\varepsilon}dk\right)^{\frac{1}{1-\varepsilon}}$ is the price for aggregate employment services.

Households' real earnings are

$$Z_t=\frac{1}{P_t}\int_0^1 W_{kt}(\frac{W_{kt}}{W_t})^{-\epsilon}N_t d_k$$

Then $\frac{\partial C_t}{\partial W_{kt}}=\frac{\partial Z_t}{\partial W_{kt}}$ where $\frac{\partial Z_t}{\partial W_{kt}}=\frac{1}{P_t}N_{kt}(1-\epsilon)$.

Total hours worked by households (i) are:

$$N_{it}=\int_0^1(W_{kt}/W_t)^{-\epsilon}N_t\,dk$$

Which falls when W_{kt} rises according to

$$\frac{\partial N_t}{\partial W_{kt}}=-\epsilon\frac{N_{kt}}{W_{kt}}$$

Therefore, the union's first order condition gives

$$\left(\frac{W_{k,t}}{W_{k,t-1}}-1\right)\frac{W_{k,t}}{W_{k,t-1}}=\frac{\epsilon}{\psi_{nr}}(N_{kt}v(N_t)^{-\frac{\epsilon-1}{\epsilon}}(N_{k,t}W_{k,t})/(P_t)u(C_t)$$
$$-\zeta_{BG}N^{\frac{\epsilon}{\epsilon-1}}\frac{W}{P}u(C)\frac{W_{k,t}}{P_t}-\frac{W}{P}\frac{W_{k,t}}{P_t})+\beta(\frac{W_{k,t+1}}{W_{k,t}}-1)$$

Define wage inflation as $\pi_w\equiv\frac{W_t}{W_{t-1}}-1$ and the wage markup $\mu_w=\frac{\epsilon}{\epsilon-1}$ yielding A(1) as follows:

$$\pi_{w,t}(1+\pi_{w,t})=(\epsilon/\psi_{nr})[N_tv(N_t)-\frac{1}{\mu_w}Z_tu(C_t)-\frac{\zeta_{BG}}{\mu_w}u(C)\frac{N}{N_t}(\frac{W_t}{P_t}-\frac{W}{P})\frac{W_t}{P_t}\frac{W}{P}]+\beta\pi_{w,t+1}(1+\pi_{w,t+1})$$

In the zero wage inflation steady state

$$v(N) = \frac{1}{\mu_w} u(C) \frac{W}{P}$$

Linearizing A(1) around the steady state yields:

$$d\pi_{w,t} = \epsilon \psi_{nr} N \, dv(N_t) - \frac{1}{\mu_w} du(C_t) \frac{W}{P} - \frac{(1 + \zeta BG)}{\mu_w} u(C) \, d\frac{W_t}{P_t} + \beta \, d\pi_{w,t+1}$$

B Further details on consumption decomposition

In this section we provide further details on the decomposition of the total consumption response to an energy price shock following the approach of Kaplan et al. (2018). Aggregate consumption can be written as a function of the sequence of equilibrium prices and quantities

$$\mathcal{C}_t \left(\{ r_t, w_t, N_t, p_{et} \} \right) = \int c_t(a, z; \{ r_t, w_t, N_t, p_{et} \}) d\Omega_t$$

where $c_t(a, z; \{r_t, w_t, N_t, p_{et}\})$ are the individual policy functions explicitly written as a function of individual states and aggregate prices. Totally differentiating the aggregate consumption function we can decompose the consumption response at each time t as

$$d\mathcal{C}_t \left(\{ r_t, w_t, N_t, p_{et} \} \right) = \underbrace{\sum_{s=0}^{\infty} \frac{\partial \mathcal{C}_{t+s}}{\partial r_{t+s}} dr_{t+s}}_{\text{indirect effect}} + \underbrace{\sum_{s=0}^{\infty} \frac{\partial \mathcal{C}_{t+s}}{\partial w_{t+s}} dw_{t+s} + \frac{\partial \mathcal{C}_{t+s}}{\partial N_{t+s}} dN_{t+s}}_{\text{direct effect}} + \underbrace{\sum_{s=0}^{\infty} \frac{\partial \mathcal{C}_{t+s}}{\partial p_{et+s}} dp_{et+s}}_{\text{price effect}}$$

The direct effect reflects changes in aggregate consumption resulting directly from changes in the path of real interest rates, whereas the indirect effect reflects consumption changes arising from changes in the path of real wages and labor hours. The price effect reflects any changes in consumption arising from a change in relative energy prices that raise the cost of subsistence consumption. To numerically compute each effect we compute the respective partial derivate and multiply it with the equilibrium response arising from the specific monetary policy rule of interest.

Figure A1: Further consumption decomposition for contemporaneous rules

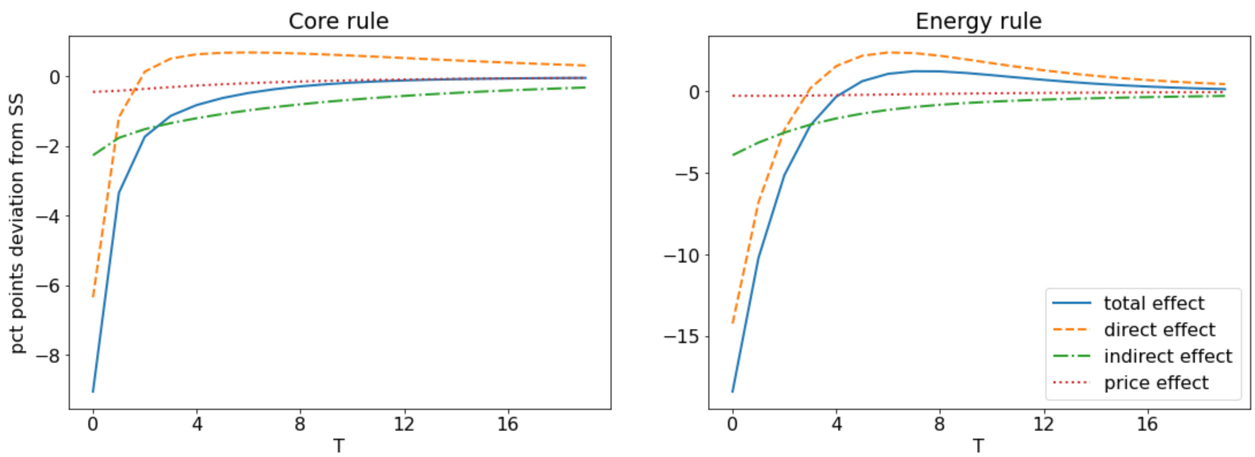


Figure A1 plots the consumption decomposition for the policy rules reacting to contemporaneous core and energy inflation. As was the case for the headline rule in section 4, both rules see a consumption decline predominantly due to increasing real rates. Particularly, the strong decline in consumption under the energy rule is solely driven by the monetary policy response to energy prices.

Figure A2: Further consumption decomposition for forecast rules

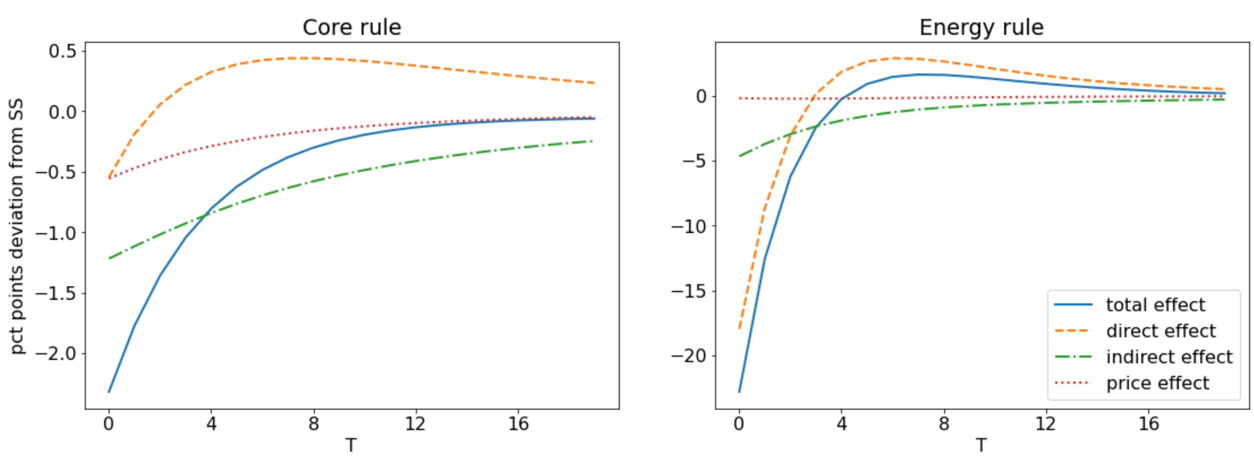
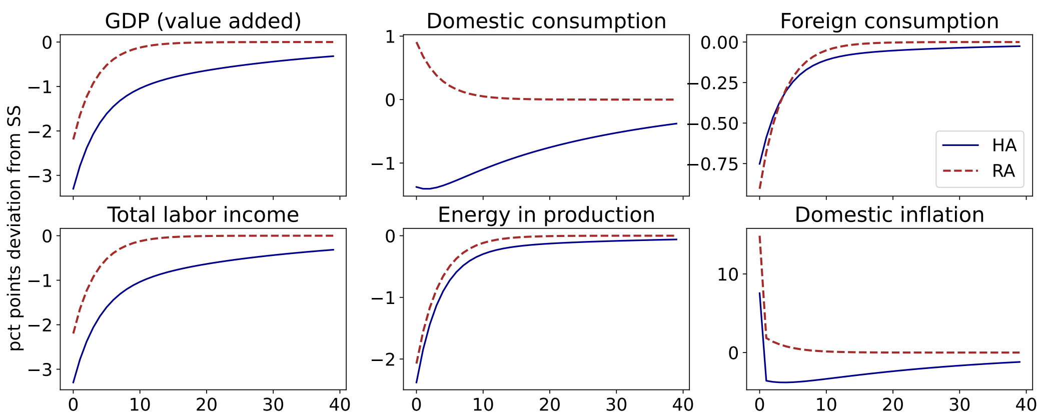


Figure A1 plots the same consumption decomposition for policy rules reacting to the forecast of core or energy inflation. The core forecast rule has similar implications to the headline rule as discussed in the text, except for an initially slightly negative contribution of real rates. However, the energy forecast rule exerts a strong negative impact on consumption through the substantial rise in real rates. It thereby mimics contemporaneous policy rules albeit triggering a consumption decline twice the size.

C Comparison of HANK with RANK model

In this section, we solve a representative agent new Keynesian (RANK) model which we calibrate to be as close as possible to our baseline HANK model with a fixed interest rate monetary policy rule.[5,6] We then simulate the response of these two economies following the same energy price shock as section 4.1, the IRFs are displayed in figure A3.

Figure A3: Comparison of HANK and RANK models



Note: GDP is computed as purchasing power parity adjusted ($\text{GDP}_t = P_{h,t}Y_t/P_t - P_{f,t}E_t/P_t$). The shock is a 30% increase in foreign energy prices. Monetary policy implements a fixed interest rate rule.

GDP drops relatively and significantly more in the HANK model (top left panel). This is due to a strong consumption expenditure channel at play for the poorest agents. On top of having a larger increase in expenditure, those agents are unable to insure because they hold zero or little assets. The aggregate effect of these household is large, as we can infer from the top middle and right panel. General equilibrium are stronger in the HANK model, with labor income and energy in production dropping relatively more than in the RANK model (bottom left and middle panels). Inflation instead reacts stronger on the spot in the RANK, although the shock is short-lived (bottom right panel). A key difference between the economies is that while in RANK the variables go back to steady state relatively quickly, the HANK economy features much more persistence coming through the endogenous asset distribution.

[5]Some caveats need to be considered for the RA representation. Specifically, relevant literature (see Schmitt-Grohe and Uribe (2003)) has indicated that in open economies the RA representation of the random walk nature of the balance of payments makes the model non-stationary, but investigating this aspect goes beyond the scope of this paper.

[6]The only difference between the two model's parameters is the discount factor, which is changed to 0.995 to be consistent with our interest rate calibration.

D Comparison across different supply shocks

E A closed economy setup

F Hump-shaped energy price shock