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Energy price shocks, monetary policy and inequality

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Challenges for Monetary Policy Transmission in a Changing World Network (ChaMP)

This paper contains research conducted within the network "Challenges for Monetary Policy Transmission in a Changing World Network" (ChaMP). It consists of economists from the European Central Bank (ECB) and the national central banks (NCBs) of the European System of Central Banks (ESCB).

ChaMP is coordinated by a team chaired by Philipp Hartmann (ECB), and consisting of Diana Bonfim (Banco de Portugal), Margherita Bottero (Banca d'Italia), Emmanuel Dhyne (Nationale Bank van België/Banque Nationale de Belgique) and Maria T. Valderrama (Oesterreichische Nationalbank), who are supported by Melina Papoutsi and Gonzalo Paz-Pardo (both ECB), 7 central bank advisers and 8 academic consultants.

ChaMP seeks to revisit our knowledge of monetary transmission channels in the euro area in the context of unprecedented shocks, multiple ongoing structural changes and the extension of the monetary policy toolkit over the last decade and a half as well as the recent steep inflation wave and its reversal. More information is provided on its website.

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 that matches salient features of the Euro Area data. Our model incorporates 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 reduce aggregate consumption. Households with little wealth are more adversely affected through both a decline in labor income as well as negative direct price effects. Active policy responses raising rates in response to inflation 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-wealth households are further adversely affected as they have little savings to rebuild wealth from and instead loose due to further declining labor income.

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

JEL-Classification: E52, F41, Q43.

Non-technical summary

In this paper we investigate the aggregate and distributional effects of energy price shocks and how they are shaped by monetary policy. Based on the observed heterogeneity in household consumption exposures to energy and wealth positions, we build a small open economy heterogeneous agent New Keynesian (HANK) model calibrated to Euro Area data. Our model incorporates energy as both a consumption good for households with non-homothetic preferences as well as a factor input into production with input complementarities. All energy used in the domestic economy has to be imported. We contrast "passive" monetary policy responses that keep the real interest rate (nearly) constant with "active" policy responses that react to inflation by strongly raising the real rate.

Our main findings can be summarised as follows. First, energy price increases adversely affect the domestic economy regardless of the monetary policy response. As all energy has to be imported, rising energy prices effectively constitute a transfer of wealth from the domestic to the foreign economy. In contrast to a passive policy response, an active policy reaction raising the real rate to fight inflation implies a four times larger decline in aggregate consumption.

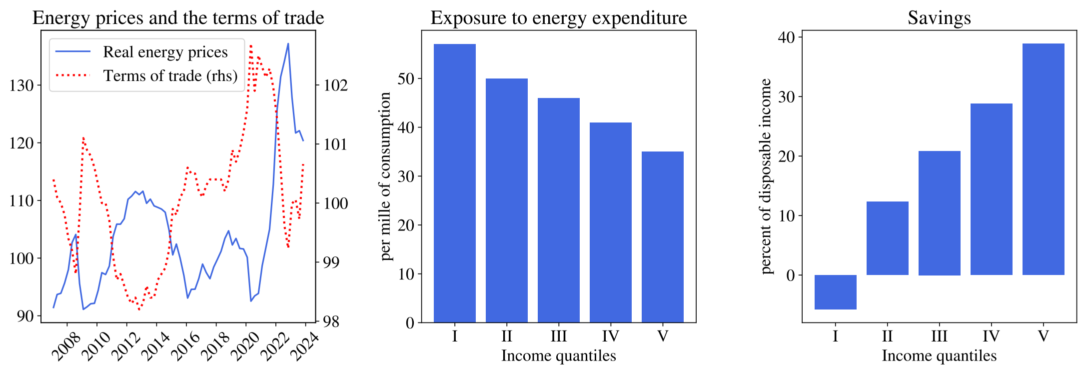
Second, we show that the drivers of the aggregate consumption response differ substantially between active and passive monetary policy responses. We decompose the aggregate consumption response into three components, a direct effect stemming from changes in the real interest rate, an indirect effect resulting from changes in real labor income, and a relative price effect. Under a passive policy response, four-fifths of the consumption decline is attributed to indirect income effects, while the rest is driven by the relative price effect. In stark contrast, under an active policy response three-fourths of the decline in consumption is explained by the direct real rate effect and therefore directly related to monetary policy.

Third, low-wealth households are generally affected the most by an energy price increase. Absent any policy response the decline in consumption is three times larger for low- relative to high-wealth households. An active policy response amplifies the consumption decline for all households. Although the relative decline is larger for wealthier households, the underlying drivers differ starkly. Low-wealth households have to reduce consumption because of the further decline in labor income due to falling economic activity. In contrast, high-wealth households choose to reduce their consumption because a higher real rate incentivizes them to save more.

1 Introduction

Energy prices have reached historical heights, starting their rise in mid-2021 after most economies reopened from COVID-19 lockdowns 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, the terms of trade deteriorated with negative implications for domestic purchasing power. Despite the Euro Area being an energy importer facing an exogenous shock, monetary policy reacted to the energy price surge by raising rates at unprecedented speed. The rise in energy prices and subsequent policy response naturally have heterogeneous effects on households, with less wealthy households likely being affected the most. First, these households are more exposed to energy prices through their consumption basket as they spend a larger fraction of their income on energy-related goods (middle panel). Second, their limited savings makes it difficult for them to smooth their consumption in response to temporary price increases (right panel).[1] Third, low-wealth households almost solely rely on labor income and do not benefit from higher returns on savings.

Figure 1: Energy prices, terms of trade, households' consumption exposures and savings across the income distribution



Note: The "real energy price" indicates the ratio between the energy component of the HICP and the overall HICP index. The terms of trade are proxied by the ratio between the GDP deflator and the private consumption deflator. Charts in the middle and right are based on distributional statistics from the "Household budget survey" and the experimental "Income, consumption, and wealth" datasets provided by Eurostat.

Based on the observed heterogeneity in household consumption and wealth, we build a small

[1] For more details on smaller adjustment margins for low-income households given their consumption basket and savings positions, see also Hobijn and Lagakos (2005), Bobasu et al. (2023) and Bils and Aguiar (2010).

open economy heterogeneous agent New Keynesian (HANK) model to analyse the aggregate and distributional effects of energy price increases and how these effects are shaped by monetary policy. We show first, that an energy price shock is always recessionary in an open economy that imports all energy because it constitutes a wealth transfer from the domestic to the foreign economy. Second, the initial adverse aggregate effects are smaller when monetary policy remains "passive", i.e. keeps the real rate constant. "Active" monetary policy reacting to inflation by raising the real rate exacerbates the initial negative effects, yet implies a faster recovery. By decomposing the aggregate consumption response we show that under a passive policy the negative effects of energy price shocks mainly arise through negative real income effects. In contrast, under an active policy consumption declines predominantly due to a rising real rate instead of the shock itself. Third, low-wealth households are affected the most by an energy price shock. Active policy exacerbates negative effects for low-wealth households through a further decline in labor income, but benefits high-wealth households through higher returns on savings.

In our small open economy 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 that they can only imperfectly insure against due to an occasionally binding borrowing constraint. Firms produce domestic goods utilizing labor and energy as inputs, with limited substitutability between them. While prices are flexible we introduce sticky wages through labor unions. 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 aggregate prices, core inflation, defined as the change in domestic goods prices, and energy price inflation. We contrast these rules with a baseline policy that remains passive 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. We take particular care in matching the heterogeneity observed in household consumption baskets. In particular we use Eurostat's "Household budget survey (HBS)" and "Income, wealth and consumption statistics" (ICWS) to match an average household 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 in our model. On the firm side, we calibrate the degree of complementarity between factor inputs to recent estimates in Bachmann et al. (2022) and additionally take into account information based on input-output tables indicating that the energy use in production is nearly double that of consumption.

We start by illustrating the importance of non-homothetic preferences and input complementarities for the aggregate and individual consumption and income response to an energy price shock under our baseline passive policy. Non-homotheticity imposes a constraint on low-wealth households, while elasticities of substitution in consumption and production govern the ability of households and firms to respond to the shock in relative prices. We show that less wealthy households suffer a larger consumption expenditure shock compared to wealthy households, thereby further raising 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 cheaper domestic goods. Similarly, a high elasticity of substitution in the production function allows firms to decrease their demand for energy and therefore mitigates the decline in labor demand, predominantly benefiting low-wealth households.

Turning to the aggregate effects of an energy price shock we show the strong dependence on the monetary policy response. We contrast a baseline in which monetary policy keeps the real rate constant, i.e. is fully passive, to policy rules which react either to contemporaneous or forecast measures of inflation. In our open economy model, where all energy is imported, an energy price shock is always recessionary regardless of the policy response, as the benefits from higher energy prices solely accrue to the foreign economy. In contrast to the passive baseline, a policy responding to either contemporaneous headline or core inflation raises real interest rates. Higher real rates in turn induce a strong decline in consumption and output that is four times bigger than under the baseline. Rules responding to either forecast measures of headline or core inflation instead effectively "look through" the initial energy price increase. Real rates rise very little under these "passive" responses, thereby alleviating most of the negative effects on aggregate demand. In turn, the decline in both consumption and labor income is less pronounced compared to the baseline rule with otherwise very similar implications. Responding to energy inflation has remarkably different implications. Under such a policy, the increase in the real rate is the highest with an initial complete suppression of energy and therefore headline inflation. However, this comes at the cost of a strong recession that is initially significantly larger than under a headline rule. Additionally, completely containing inflation in the short term comes at the cost of higher inflation in the medium-term, when a speedy recovery of domestic goods demand together with rising foreign demand ultimately raises core and headline inflation.

By analyzing the drivers of the aggregate consumption response we show that the negative effects of an energy price shock stem from indirect negative real income effects but are strongly exacerbated under an active policy response through direct real rate effects. 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 the energy price shock, causing higher expenditures on subsistence consumption thereby leaving a smaller share of income for consumption beyond the subsistence level. Under a fixed real rate, four-fifths and therefore the majority of the consumption decline is due to indirect income effects whereas one fourth is driven by the relative price effect. Since monetary policy is passive, there are no direct real rate effects. This implies that the adverse effects of an energy price shock work predominantly through a reduction in real income with an additional margin for rising costs of the consumption basket. In stark contrast, under an active policy response, three-fourths of the decline in consumption is accounted for by the direct effect and therefore directly related to the rise in the real rate. Forecast rules that are sufficiently passive trigger only a small increase in real rates which positively contributes to aggregate consumption by providing higher returns on savings without adverse effects on aggregate demand and therefore labor income.

Finally, we show that low-wealth households are generally affected the most by an energy price shock. Absent any policy response the decline in their consumption is three times larger relative to high-wealth households. An active policy response amplifies the consumption decline for all households. Although this decline is larger for wealthier households, the driver of the underlying consumption starkly differ between low- and high-wealth households. Low-wealth households *have to* reduce consumption because of the strong decline in labor income. In contrast, wealthy households optimally *choose* to reduce their consumption because higher real rates incentivize them to save more. For these households price effects are immaterial and labor income effects are a lot smaller than for low-wealth households. A passive policy response instead does not induce a (strong) response of real rates and thereby does not cause a strong consumption decline for wealthy households as the energy shock itself does not substantially affect them. However, low-wealth households substantially benefit from a passive policy response because of the strongly mitigated adverse effects on labor income associated with such a policy.

Related literature We relate to three main strands of the literature investigating the aggregate and distributional effects of 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, by 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. More recently, Gagliardone and Gertler (2023) have estimated a New Keynesian model incorporating oil and showing that studying oil price shocks and monetary policy combined provides a good description of the recent aggregate data. While all these papers focus on aggregate outcomes, Del Canto et al. (2023) notably develop an empirical framework to analyze the impact of inflationary shocks throughout the distribution, separately studying energy and monetary policy shocks. Our paper can be understood as a structural counterpart to their empirical approach, with a focus on how the effects of energy shocks are shaped by monetary policy. Despite the differences in approaches, we similarly conclude that energy price shocks are generally regressive and that the monetary policy response can have a substantial impact in shaping these effects.

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) introduces 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 complementarity in a two-agent New Keynesian model. They show that a higher complementarity 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. As we show, energy price shocks have considerably different aggregate and distributional implications compared to other supply shocks. Additionally, their focus on tractable heterogeneity precludes them to fully study distributional effects as we do in our model. Audzei and Sutóris (2023) similarly use a tractable heterogeneous agent model, albeit studying the incentives to invest in energy abatement capital in response to an energy price shock. Perhaps the closest papers to ours are Auclert et al. (2023) and Pieroni (2023). Pieroni (2023) 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 and distributional outcomes, also studying the drivers of individual consumption responses and how they differ across the wealth 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 monetary policy specified as an exogenous rate path 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 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. The section also examines the aggregate and distributional effects under both a baseline keeping the real rate fixed and various active policy rules. Finally, section 5 concludes.

2 Model

In this section we introduce a small open economy New Keynesian model with heterogeneous households. 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 less wealthy 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 $\xi(s_{t+1}|s_t)$. 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

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

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

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. We use a time subscript for the value function to indicate the dependence on a vector of aggregate states $\mathbf{X}_t$ to be specified below and $\Omega_t = \Omega_t(a, s)$, 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

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

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 less wealthy 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_h measures the share of energy consumption in the overall consumption basket. The consumer price index for these preferences is given by

$$P_t \equiv \left[(1-\alpha_h)P_{h,t}^{1-\eta} + \alpha_h P_{e,t}^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{3}$$

where $P_{h,t}$ is the price of domestically produced non-energy goods and $P_{e,t}$ 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

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

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

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

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

2.2 Labor union

We introduce sticky wages following Erceg et al. (2000). 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[2]

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

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 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] Appendix A contains further details on the derivation of the New Keynesian wage Philips Curve.

2.3 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.[3] 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 in the amount of

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

2.4 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

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

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

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

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

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

where Q_t is the real exchange rate, defined below.

2.5 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 $P_{e,t}^*$ 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,

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

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

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

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.

2.6 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

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

This specification nests several special cases. In our baseline, monetary policy keeps the real rate constant, $\phi_{\pi_b} = 1$. In alternative scenarios policy can also react to headline, core or energy price inflation, defined as $\pi_{cpi,t} = P_t/P_{t-1}$, $\pi_{h,t} = P_{h,t}/P_{h,t-1}$ and $\pi_{e,t} = P_{e,t}/P_{e,t-1}$ respectively. We also study forecast rules and allow for policy to react to the inflation forecast, $\mathbb{E}_t\pi_{k,t+1}$, instead of contemporaneous measures of inflation. In the following we will label a policy rule "active" if it induces a strong real rate response and as "passive" if the real rate response is muted.

2.7 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 choose some parameters relying on standard values in the literature and match others to target empirical moments from Euro Area data. Household and firm exposure to imported energy, the heterogeneous consumption exposure of households across the income distribution, and aggregate marginal propensities to consume, are 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 1, 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 like Auclert et al. (2021c) and assume an AR(1) process with persistence of 0.92 and cross-sectional standard deviation of 0.6. We set the borrowing constraint $\underline{a} = 0$.[4] We assume

[4] We choose a zero borrowing constraint to be in line with the vast majority of the HANK literature. However, having a negative borrowing constraint matching the level of savings in the lowest wealth quintile does not

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). We show sensitivity to the choice of these parameters in Section 4.1.

Table 1: Calibration

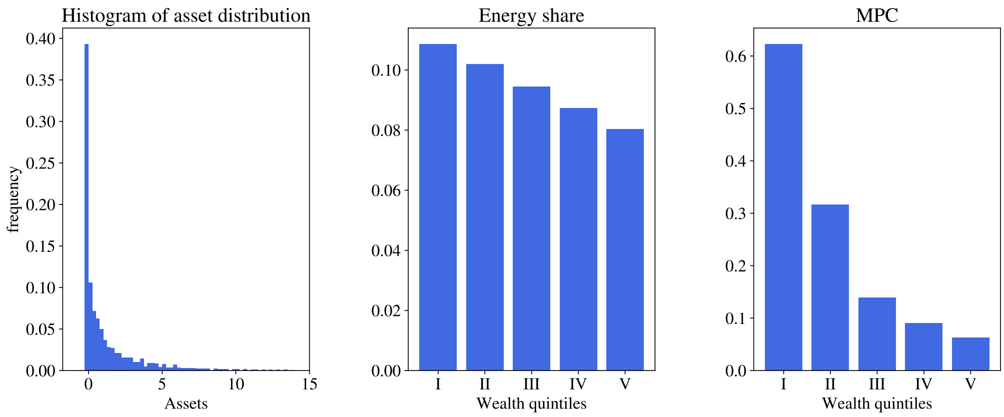
Parameter	Definition	Value	Source/Target
Households			
β	Household discount factor	0.968	Annual nominal rate 2%
σ	Household risk aversion	1	Literature
α_h	Energy share in consumption	0.051	Eurostat $c_e/c = 0.09$
$\underline{c}$	Subsistence level energy consumption	0.037	Eurostat $c_e^{Q1}/c^{Q1} = 0.13$
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	1.01	Carroll et al. (2017) MPC =0.32
World Trade			
C^*	Foreign demand level	0.181	$NX = 0$
λ	Foreign demand elasticity	1/3	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 of 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_h and production α_f,

materially affect any of our results.

the subsistence level of energy consumption $\underline{c}$ and the size of firm markups $\mathcal{M}$. 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 wealth 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 2. 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 in the consumption of households with little wealth is substantially higher than that of high-wealth households. For example, the low-wealth households spend roughly 3 percentage points more on energy than the high-wealth households. The substantial wealth heterogeneity and hence unequal ability to self-insure against shocks is also reflected in a wide dispersion of MPCs. Low-wealth households, defined as those in the bottom quintile of the wealth distribution, spend on average 60 percent of an additional euro on consumption. Wealthy households, defined as the top quintile of the wealth 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.

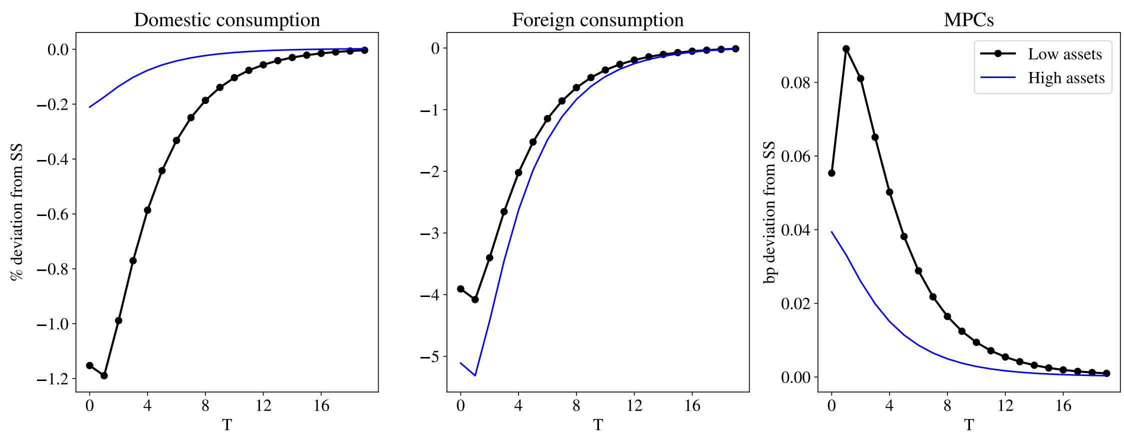
4 Energy price shocks and monetary policy

In this section we study the aggregate and distributional effects of an energy price shock and how monetary policy shapes these effects. Our main exercise of interest simulates an energy price shock comparable to the one that hit the Euro Area in the beginning of 2022. In particular, we consider a 30 percent increase in the foreign price of energy with a persistence of 0.8 matching the magnitude of the rise in energy prices when compared to their average over the past 20 years as shown in Figure 1. We start by illustrating the role of substitution elasticities in consumption and production before turning to the discussion of aggregate and distributional effects of an energy price shock. Throughout, we contrast active rules raising real interest rates with a baseline under which the real rate is constant.

4.1 Elasticities of substitution in consumption and production

We start by illustrating how non-homotheticity in consumption and input complementarity in production affect the consumption response across households. 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*) consumption expenditure and *ii*) general equilibrium income effects. Although both are important drivers of aggregate effects, in this section we focus on the former.

Figure 3: Transmission channel of non-homothetic preferences



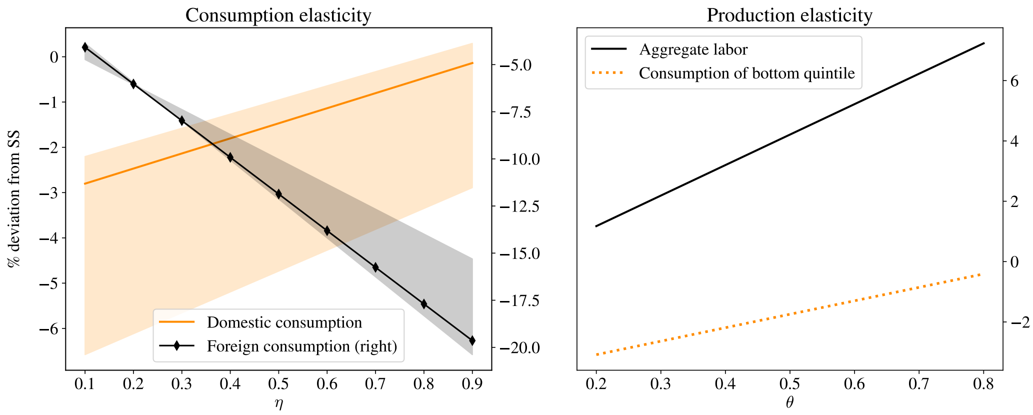
Note: The plots show equilibrium "price" effects, capturing only relative price changes as described in Appendix B. The shock is a 30% increase in foreign energy prices. Monetary policy implements a fixed interest rate rule. The circled line corresponds to the average consumption response of the lowest wealth quintile, while the solid line corresponds to the average consumption response of the second highest wealth quintile.

Figure 3 plots the effect of a rising energy price on the optimal expenditure shares between energy and non-energy goods in the consumption basket as well as MPCs by wealth. As energy becomes more expensive, households want to substitute away from it but are constrained by the subsistence level of energy consumption. In fact, low-wealth households are not able to decrease their energy consumption as much as wealthy households, as illustrated in the middle panel. In turn, this implies that households with little wealth suffer a 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-wealth households thus increase by relatively more. 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 Appendix C for more details).

The magnitude of the consumption expenditure effect is governed by the elasticity of substitution across energy and non-energy goods. On the left panel, Figure 4 plots the initial consumption response to the energy 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 ($\eta = 0.1$) to both goods having a very high degree of substitutability ($\eta = 0.9$) an therefore 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 in foreign consumption are exacerbated because less wealthy households are constrained by the subsistence level of energy consumption.

In the right panel of Figure 4, the solid line 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. As shown by the dotted line, it also benefits low-wealth households which predominantly rely on labor income.[5]

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 fixed interest rate rule. The shaded areas correspond to the difference from the lowest to second highest wealth 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 how they depend on monetary policy, we contrast a policy rule that keeps the real interest rate fixed (baseline) with policy rules reacting either to contemporaneous or forecast measures of inflation. We characterize a policy response as active if the real rate rises substantially and as passive if the real rate response is muted or nil. In the following we show that, a shock to imported energy has adverse consequences regardless of policy as it constitutes a wealth transfer from the domestic to the foreign economy. Active policies like contemporaneous policy rules exacerbate the negative aggregate effects in contrast to passive policies like most forecasting rules.

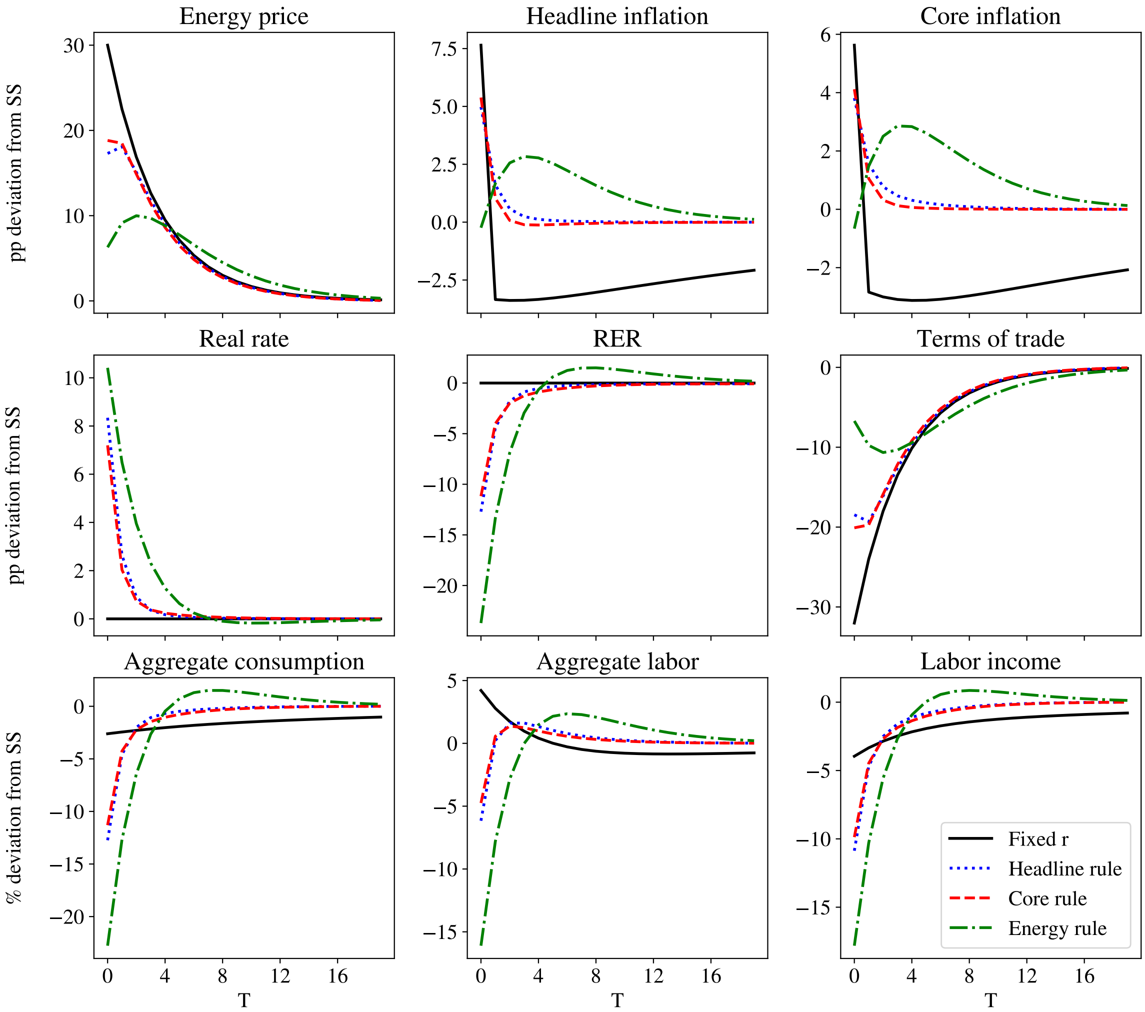
Figure 5 shows impulse responses for selected aggregate variables contrasting the baseline with rules reacting to contemporaneous inflation. Under the baseline rule, an energy price shock leads to a sharp initial rise in inflation that quickly reverts and turns negative after a few quarters. To keep the real rate constant, the Fisher equation implies that the nominal rate has to be set as the sum of the real rate and *future* inflation. The nominal rate therefore mirrors the path for inflation with an initial large increase and a subsequent quick decline. Despite the surge in inflation and an initial strong increase in the nominal rate the baseline rule results in the smallest

[5]We analyze the distributional effects of the energy price shock in more details in Section 4.4.

decrease in aggregate consumption and output. This is due to two channels. First, household consumption-savings decisions are based on the *real* interest rate. In the baseline the real rate does not change, remaining substantially below real rates associates with active policy rules, and hence does not incentivize households to save more and consume less. Second, domestic aggregate demand is also supported through the open economy channel. Because the domestic real rate does not change, it does not differ from the foreign real rate implying a constant real exchange rate via the uncovered interest parity condition. The resulting high pass-through of foreign energy prices to domestic energy inflation causes two effects. First, it prompts a stronger substitution of domestic demand towards domestic goods and therefore leads to a pronounced fall in the terms of trade which boosts foreign demand for domestic goods. Second, high inflation rates combined with flexible prices cause 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.[6]

[6] In Appendix D we show that the initial recession is indeed stronger and associated with a decline in aggregate labor, if the open economy demand channel is absent. Nevertheless, aggregate outcomes would still be far less contractionary under a fixed real rate compared to active policy rules.

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.

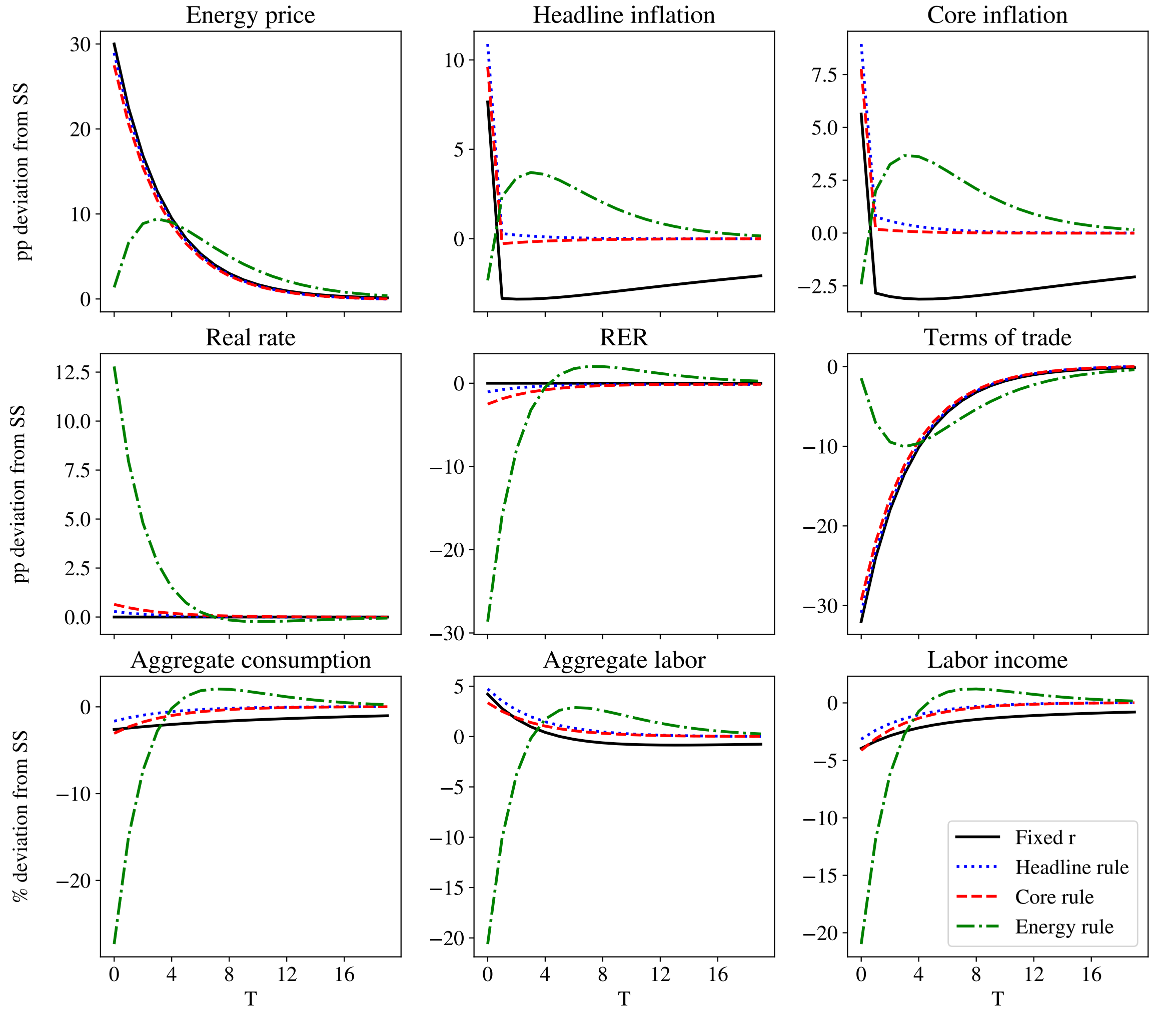
All policy rules reacting to contemporaneous measures of inflation would actively respond to an energy price shock by raising the real rate. A headline rule raises the real rate around 1.5 percentage points higher than a rule reacting to core inflation (around 8 percentage points). The differences between a headline and a core inflation rule in terms of real rates and inflation outcomes are hardly noticeable though a rule targeting core inflation implies slightly higher inflation rates. Given substantially higher real rates, the decline in consumption and output is about fourfold compared to the baseline. As households consume less domestic goods the decrease in demand for domestic goods amplifies negative effects on labor hours. Additionally, a higher real rate causes a real exchange rate appreciation that mitigates the pass-through of foreign energy price. This prevents the terms of trade from falling as strongly and therefore weakens the foreign demand channel.

A policy rule directly responding to energy inflation induces a severe contraction thereby successfully containing inflation in the short run though at the expense of higher medium-term inflation. Real interest rates are highest under an energy price rule rising to around 12 percent and therefore exert a substantial negative effect on domestic goods demand initially turning core inflation even negative. However, in subsequent periods core inflation rises strongly and remains elevated for 3-4 times as long as other policy rules. This medium-term effect arises from two channels. First, containing domestic energy inflation requires a severe contraction in domestic demand which subsequently needs to revert triggering a strong recovery in labor demand and associated labor income. Second, the strong increase in real rates leads to a strong real exchange rate appreciation as foreign interest rates do not move. This implies a complete lack of pass-through of foreign to domestic energy prices effectively containing the energy price shock in the short-term. Since inflation is initially zero the real exchange rate appreciation directly translates into a nominal exchange rate appreciation that subsequently unwinds through depreciations which continuously raise foreign demand for domestic goods adding to the domestic recovery.

It is noteworthy that reacting to different *measures* of inflation is not equivalent to varying the *strength* of the reaction, e.g. through a higher inflation coefficient in the Taylor rule. Figure 5 shows that the differences between targeting headline or core inflation are rather small and that the headline rule can be interpreted as a stricter version of the core rule. Unsurprisingly, the large share of domestic goods in the overall consumption basket implies that the headline inflation rate associated with the entire consumption basket is heavily influenced by its core component mimicking the core inflation profile although being somewhat higher due to high inflation of the energy component. In stark contrast, targeting energy inflation implies an entirely different inflation profile, mitigating inflation in the short-term at the cost of higher inflation in the medium-term for the reasons described above.

Policy rules reacting to forecast measures of inflation can strongly mitigate the negative amplification of contemporaneous rules, but only if they are sufficiently passive, i.e. come with a significantly muted real rate response. In Figure 6 we plot impulse responses of aggregate variables for forecast rules. Anticipating that an energy price spike will subsequently revert, one could think that a forecast rule would effectively "look through", i.e. remain passive to an energy price price shock. This is indeed true for forecast rules reacting to either headline or core inflation, which show a strongly muted real rate response thereby mitigating the negative effects on aggregate demand. For both rules the decline in consumption as well as labor income is even slightly 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.

However, a forecast rule responding to energy inflation is instead very active raising real rates even higher than its contemporaneous counterpart thereby further amplifying adverse aggregate effects. Despite rising *foreign* energy prices, *domestic* energy inflation initially falls before strongly increasing after a couple of quarters. The causes are the same as for the contemporaneous energy rule. The large increase in the real rate induces a severe recession while the real exchange rate substantially appreciates which implies an even larger appreciation of nominal exchange rates due to the falling price level. The initially elevated exchange rate prevents a pass-through of rising energy prices to the domestic economy and even leads to initially lower energy prices. However, this price effect comes at the cost of substantial negative adjustments in quantities on the real side. Moreover, as energy prices in subsequent periods are passing through to the domestic economy and with aggregate demand strongly recovering, inflation rates in the medium term are even higher than under a policy rule responding to contemporaneous energy inflation.

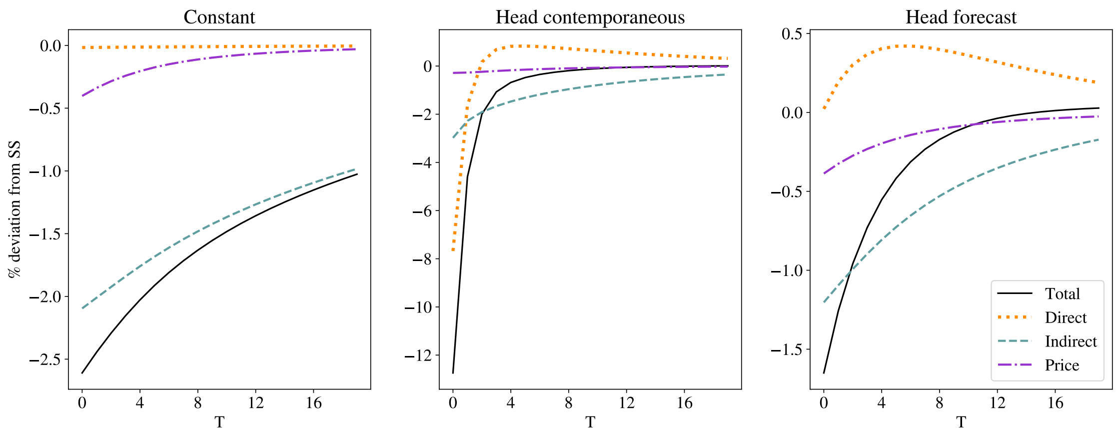
While we treat energy price developments in the past two years as a one-time unanticipated shock that quickly recedes, they can also be viewed as an initial unexpected price spike followed by further anticipated price increases before eventually subsiding. In Appendix E we analyze such a hump-shaped energy shock modelled as an AR(2) process. With a fixed real rate the aggregate responses are initially smaller with output, consumption and labor exhibiting a similar hump-shaped profile peaking a couple of quarters after the shock occurs. In the receding phase of the shock, aggregate outcomes are qualitatively and quantitatively comparable to the effects of an AR(1) shock. Forecast rules perform overall better than rules reacting to contemporaneous inflation but the differences are not as pronounced as under a purely unexpected shock, given that they are a lot more active responding to the shock with significant real rate increases, albeit smaller than contemporaneous rules.

In Appendix F we additionally argue that energy price shocks have different aggregate implications than other supply shocks and are therefore crucial to be studied on their own. A recessionary TFP shock for example decreases labor productivity and therefore implies an increase in labor demand similar to an energy shock. However, there is additional substitution of factor demand towards the energy input to compensate for the decline in labor productivity, implying a *higher* demand for energy as an input whereas an energy price shock leads to substitution away from energy. A price markup shock implies a reduction of both factor inputs as firm owners react to higher desired markups by both raising prices and reducing production. However, a markup shock leads to a redistribution from high MPC to low MPC households in the *domestic* economy, but does not constitute a wealth loss to the foreign economy implying substantially muted effects on real outcomes like output.

4.3 Decomposition of aggregate consumption response

The key drivers of the aggregate consumption response differ starkly across monetary policy rules as we show in the following through a decomposition of aggregate consumption. Figure 7 shows the key drivers of the total consumption response for the baseline (left panel) contrasting it to a policy rule reacting to headline inflation either contemporaneously (middle) or its forecast (right).[7] We decompose the aggregate consumption response into three effects, 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, that causes higher expenditures on subsistence consumption thereby leaving a smaller share of income for consumption expenditures beyond the subsistence level. Any increase in the price of the *overall* consumption basket absent changes in the relative price of goods instead reduces real income and therefore constitutes an indirect effect in our decomposition.

Figure 7: Aggregate consumption decomposition for contemporaneous and 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.

The negative consumption response to an energy price shock is mostly driven by indirect real income effects with the relative price effect playing an additional role (left panel). In the baseline, the energy price shock makes energy goods relatively more expensive and thereby raises the cost of subsistence consumption. This price effect accounts for one fifth of the total consumption decline. However, the majority of the consumption decline (four fifth) arises from indirect general equilibrium effects through falling labor income. In contrast, and in line with the absence of any real rate response, direct (partial equilibrium) effects are zero.

Despite initial inflation rates being substantially higher under a passive policy, the consumption decline is substantially smaller compared to active policy rules. In itself, higher inflation

[7] Results for targeting core or energy inflation as wells as further technical details on the consumption decomposition can be found in Appendix B.

erodes real incomes more strongly, but the fixed real rate is sufficiently stimulative to overturn this real income effect through higher labor demand and therefore higher labor income. Overall, the negative indirect effect on consumption through labor income is even 25 percent smaller compared to active rules. The major difference comes from avoiding any negative consumption effects through rising real rates. Overall, the decline in consumption is almost an order of magnitude smaller compared to an active policy rule.

Policy rules reacting to contemporaneous inflation strongly amplify the negative consumption response through rising real rates. Whereas direct effects are completely absent in the baseline, they account for over three-fourths of the consumption decline under an active rule. Despite the increase in real rates, there is no noticeable reduction in the price effect. However, the restrictive policy is further amplifying negative indirect effects. Despite containing inflation more strongly than a passive policy, the decline in labor demand caused by a reduction in aggregate demand leads to a substantial decrease in labor income which adds to the overall consumption decline. Nevertheless, since an active policy ultimately fosters a faster recovery the contribution of the direct effect turns positive after a couple of quarters as higher real rates help households that hold a sufficient amount of assets rebuild their wealth faster over time.

Forecast rules reacting to headline or core inflation, which show a very muted real rate response, can even mitigate the consumption decline through positive real rate effects as well as less severe indirect effects. Compared to an active policy response, the fall in total consumption is an order of magnitude smaller. The small rise in real rates can even exert a positive impact on consumption as it is insufficient to substantially lower aggregate demand but instead helps most households rebuild wealth through higher returns on savings. Additionally, given the lack of negative demand effects the decline in aggregate labor income is strongly mitigated, as displayed by an indirect effect that is almost half the size compared to a fixed real rate rule

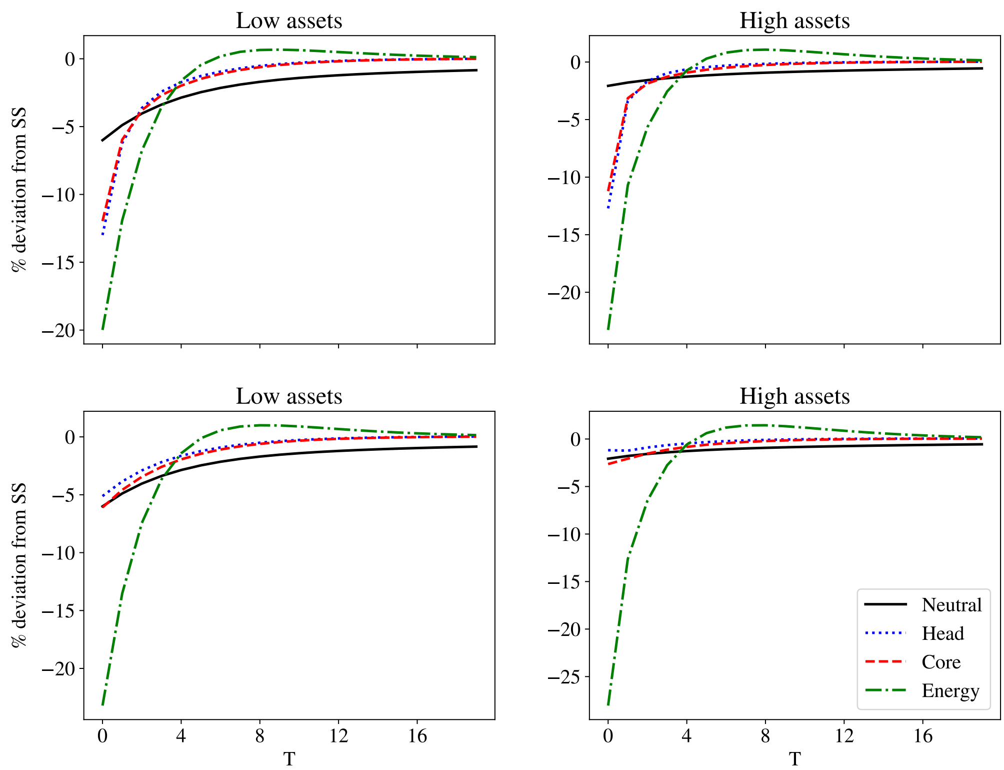
Further decompositions for the core and energy rule as shown in Appendix B are quantitatively different but feature the same underlying forces driving the decline in consumption for the headline rule as discussed in this section. The exception is a forecast rule targeting energy inflation, which triggers a strong decline in consumption through a substantial rise in real rates akin to contemporaneous policy rules albeit with larger magnitude.

4.4 Distributional effects

An energy price shock does not only have adverse aggregate consequences but as we show in this section also affects households with little wealth disproportionately more. Especially active policy rules are strongly amplifying the consumption response through high real rates that reduce aggregate demand and therefore labor income but also benefits wealthy households through higher returns on savings.

To compare the distributional effects across different monetary policy rules, we separately plot the consumption response of low-wealth and high-wealth households for various policy rules in Figure 8. We define low-wealth households as those in the lowest wealth quintile and wealthy households as those in the second highest wealth quintile. In our calibration, low-wealth households are also borrowing constrained without any savings to rely on.

Figure 8: Consumption response of low- and high-wealth households under contemporaneous and forecast monetary policy rules



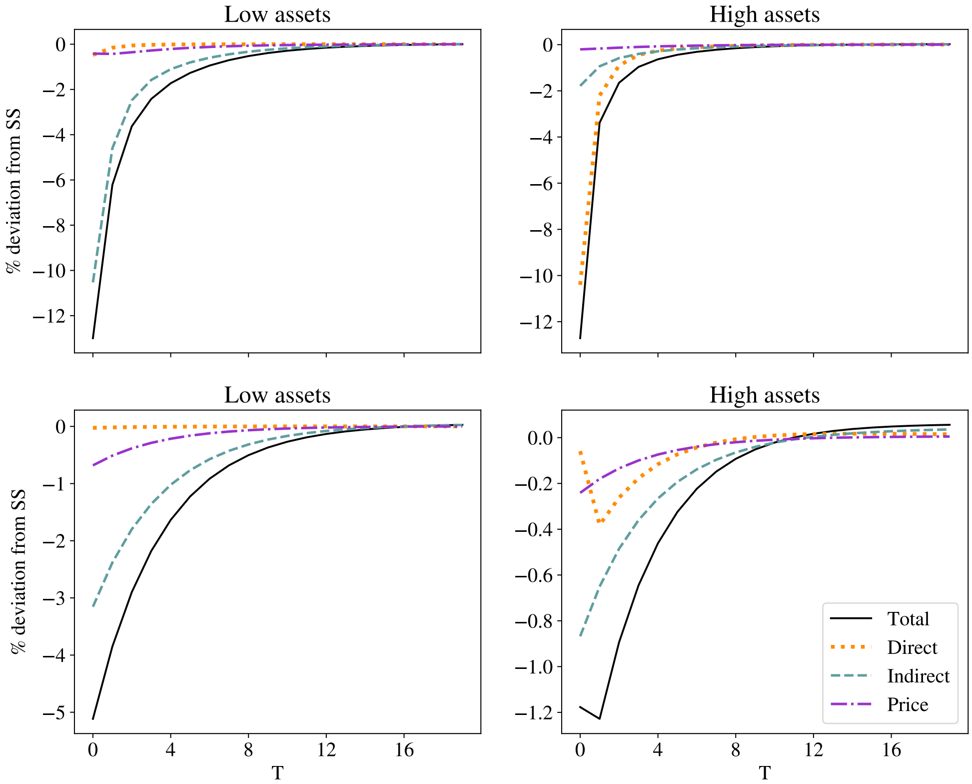
Note: On the top, we plot a comparison of the consumption response of low-wealth and high-wealth households under monetary policy rules reacting to contemporaneous measures of inflation. On the bottom panel, monetary policy reacts to forecast measures of inflation. Low-wealth refer to households in the lowest wealth quintile whereas high-wealth refer to households in the second highest wealth quintile.

Under a fixed real rate, the decline in consumption is larger for low-wealth households as compared to high-wealth households, while active rules mitigate the difference in consumption responses across low and high- wealth households (top panel). In the baseline, the consumption decline for low- and high-wealth households is around 6 and 2 percent, respectively. Active rules amplify the consumption response of low-wealth households twofold for headline and core targeting rules and more than threefold in case of energy inflation targeting, as compared to consumption response in the baseline rule. The consumption response of the high-wealth households instead increases at least five-fold for active policy rules and can even be an order of magnitude larger in case of an energy rule.

While both low-wealth and high-wealth households see a decline in consumption, the reasons for the decline are very different, as shown in Figure 9. Households with little wealth are reducing their consumption due to energy goods becoming more expensive and due to a fall in real income. High-wealth households instead reduce their consumption because higher real rates raise the return on assets thereby strongly incentivizing them to save more. A consumption decomposition across wealth quintiles shows that more than 80 percent of the consumption decline for the lowest wealth quintile is due the indirect effect of a declining labor income. Direct real rate effects and price effects instead play a similar and muted role. In contrast, the consumption decline of the highest wealth quintile is overwhelmingly driven by the direct real rate effect. A small fraction is also related to the indirect effect but is much smaller than for low-wealth households, whereas relative price effects are absent for wealthy households. Indeed, appendix Figure A8 shows that while the savings response of households with little wealth is almost nil, high-wealth households strongly increase their savings under active rules.

As forecast rules exhibit a very mitigated real rate response, their implications are similar to the baseline. In particular, they are beneficial to all households as they mitigate the decline in consumption. However, the negative consumption response of low-wealth households is still larger than that of high-wealth households (bottom panels of Figure 8). For both types of households the response is mostly driven by indirect effects, which however are smaller than under active rules. For low-wealth households, price effects also matter whereas for the wealthy is the direct effect that plays an additional role (bottom panels of Figure 9).

Figure 9: Consumption decomposition for low- and high-wealth households



Note: On the top, we plot a comparison of the consumption response of low- and high-wealth households under monetary policy rules reacting to contemporaneous measures of inflation. On the bottom panel, monetary policy reacts to forecast measures of inflation. Low-wealth refers to households in the lowest wealth quintile whereas high-wealth refers to households the second highest wealth quintile.

5 Conclusions

The surge in energy prices that began in mid-2021 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 the aggregate and distributional effects of the an energy-induced inflation surge. We particularly focus on studying these implications in passive and active monetary policy frameworks under various rules specifications.

In what regards the aggregate effects, given significantly higher real rates, we find that with policy rules reacting to contemporaneous inflation, the decline in consumption and output is around four times greater compared to the baseline rule where real interest rate is constant. We also find that policy rule reacting to energy prices has a substantial bigger 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 initial 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 are 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-wealth households are disproportionately affected by an energy price shock, regardless of the monetary policy response. Contemporaneous monetary policies, whether headline or core rule based, exacerbate this consumption decline for low-wealth households. The higher real rates in the active policy response result in favourable returns on savings, benefiting wealthy households. This is also evident when investigating the consumption decomposition. The decline in consumption is observed across both low-wealth and wealthy households, yet the driving factors differ markedly. For households with little wealth, the reduction in consumption is attributable to the increased costs of energy goods and a decline in real income. Conversely, wealthier households curtail their consumption due to higher real rates, which enhance returns on assets, providing a strong incentive for increased savings. A decomposition of consumption across wealth quintiles reveals that more than 80 percent of the consumption decline in the lowest quintile results from the indirect impact of diminishing labor income. Direct effects via real rates and price changes play comparable roles. In contrast, the consumption decline in the highest wealth quintile is predominantly driven by the direct impact of real rates. Instead, passive policy responses that do not induce a large increase in the real rate also do not impose a larger drop in any households' consumption compared to the fixed interest rate rule.

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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:

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

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

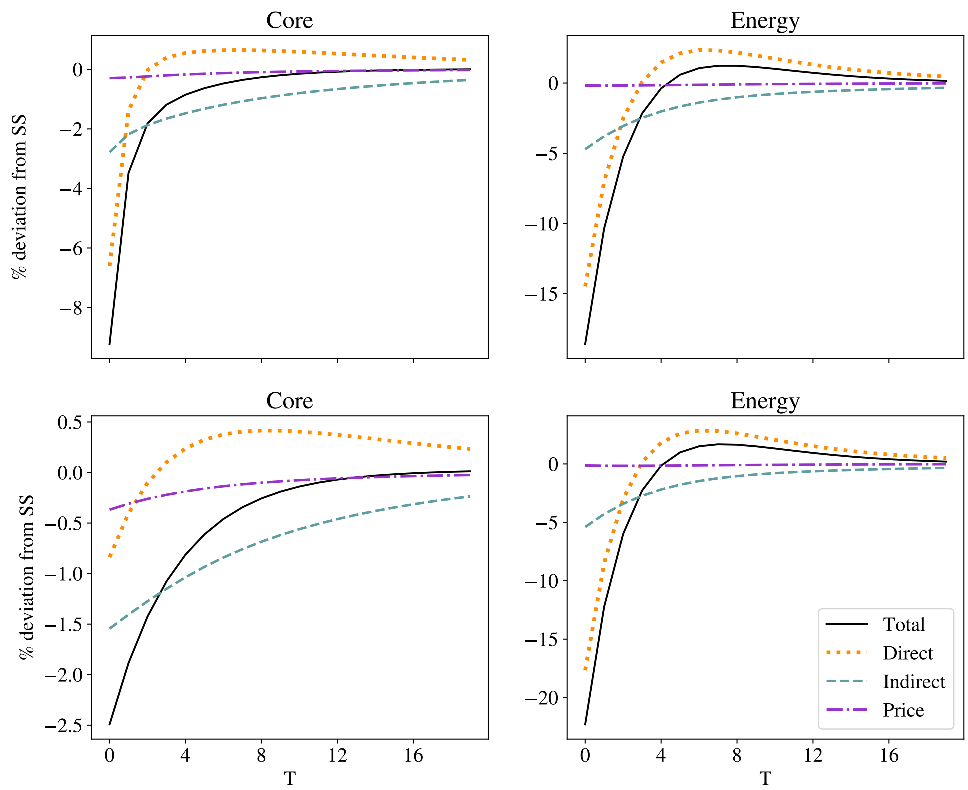
$$d\mathcal{C}_t \left(\{ r_t, w_t, N_t, p_{et} \} \right) = \underbrace{\sum_{s=0}^{\infty} \frac{\partial \mathcal{C}_{t+s}}{\partial r_{t+s}} dr_{t+s}}_{\text{direct effect}} + \underbrace{\sum_{s=0}^{\infty} \frac{\partial \mathcal{C}_{t+s}}{\partial w_{t+s}} dw_{t+s} + \frac{\partial \mathcal{C}_{t+s}}{\partial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

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.

The top panels of 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 A1: Consumption decomposition for core and energy rules



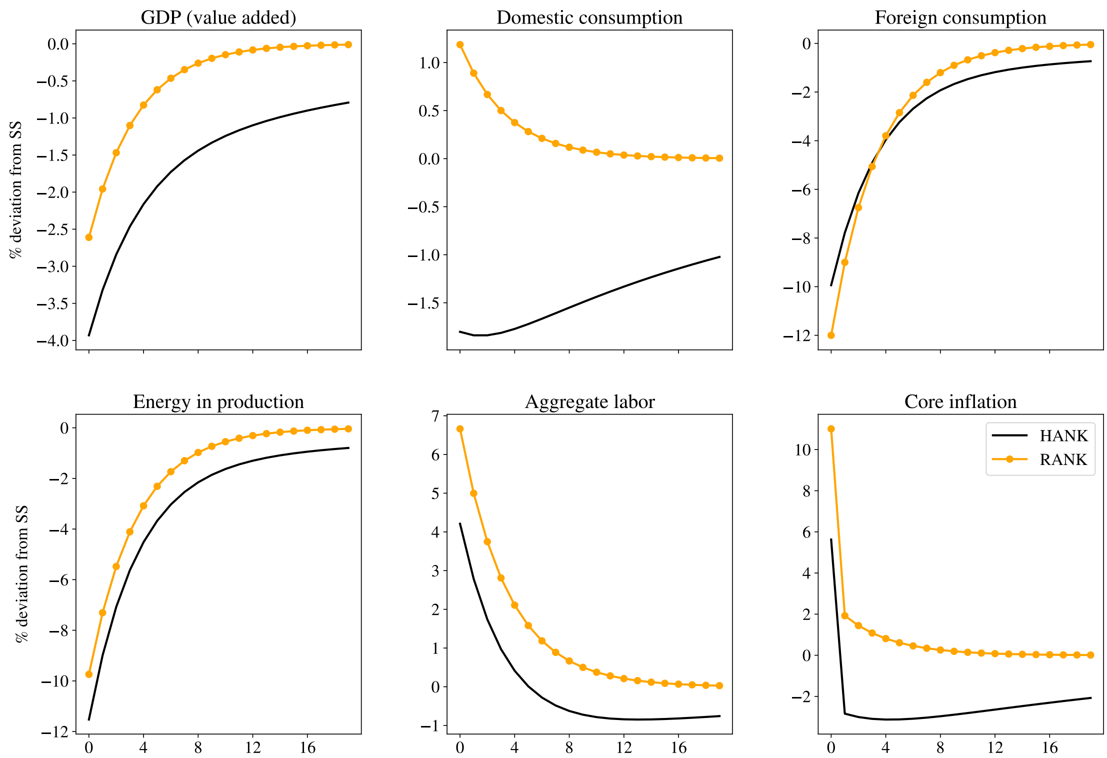
Note: On the top, we plot a comparison of the aggregate consumption decomposition under monetary policy rules reacting to two contemporaneous measures of inflation (respectively core and energy). On the bottom panel, monetary policy reacts to forecast measures of inflation. The "direct" effect captures the contribution from a change in the real interest rate, the "indirect" effect captures income effects and the "price" effect captures relative price changes.

The bottom panels of 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 rule for monetary policy.[8] We then simulate the response of these two economies following the same energy price shock as in Section 4.2. The impulse response functions (IRFs) are displayed in Figure A2.

Figure A2: 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 low-wealth households. On top of having a larger increase in expenditure, these households are unable to insure because they hold zero or little assets. The aggregate effect of these households is large, as we can infer from the top middle and right panel. The general equilibrium effects are stronger in the HANK model,

[8]The only difference between the two models is the discount factor β, which we adjust to be consistent with the steady state real interest rate.

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.

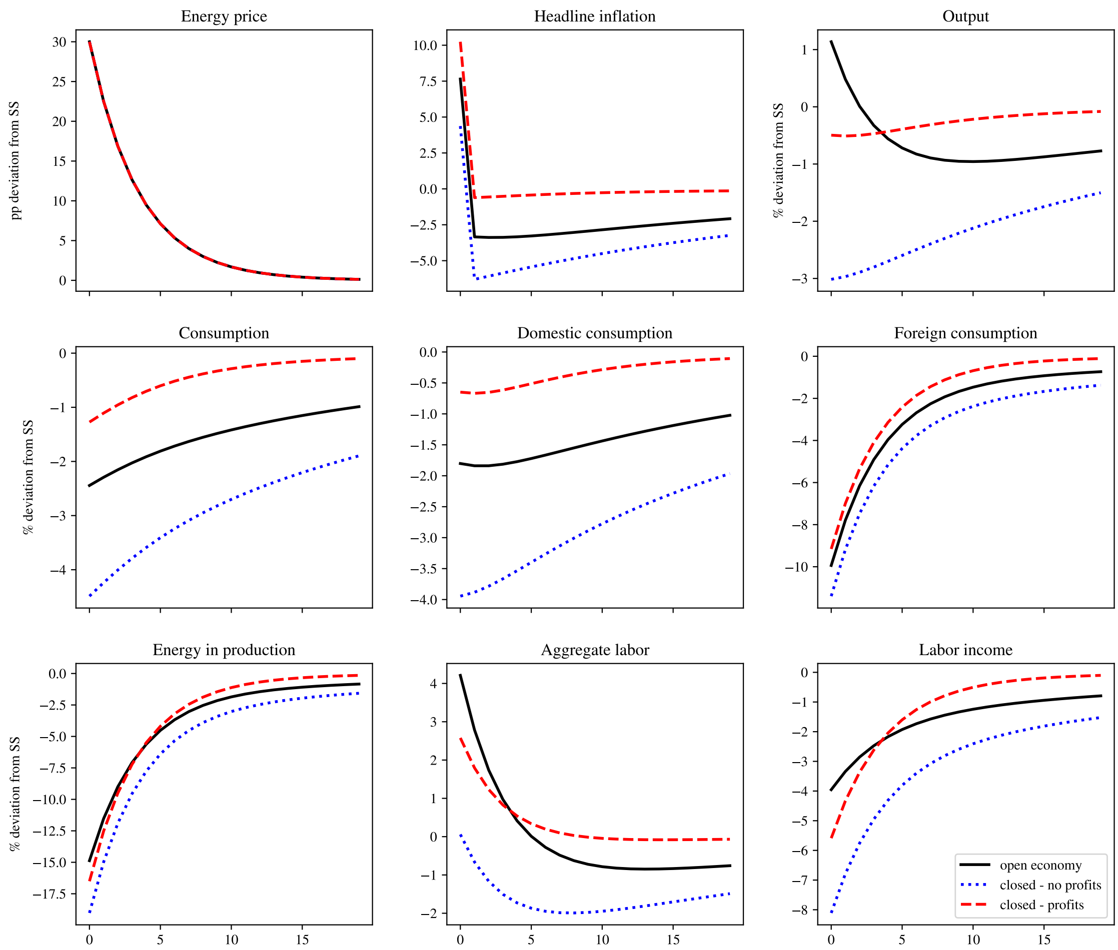
D A closed economy setup

In this section we compare our small open economy setup to a closed economy version. To this end we shut down the terms of trade channel by setting the foreign demand elasticity to zero, enforcing a constant real exchange rate and requiring the mutual fund to only invest in the domestic economy. We then proceed with the same simulation as in the main text, a 30 percent increase in the price of energy goods.[9] We will entertain two assumptions related to the price of energy. First, we assume that the price increase is a deadweight loss to society, e.g. because the extraction of resources has become more costly. Second, we assume that the energy price increase raises profits of a domestic energy producer, who is owned by the mutual fund.

Figure A3 shows the differences between the open and the closed economy setup under constant real rates. In the closed economy the effects of an energy price shock are generally aggravated, when no profits arise from higher energy prices. As opposed to the open economy, there is no foreign demand for domestic goods that can increase in response to a deterioration of the terms of trade thereby mitigating negative effects. The negative consumption response is roughly twice the size and output and labor demand are negative in the closed economy, whereas they are positive initially in the open economy. Firms substitute labor for energy as an input as seen by the smaller decline in aggregate labor.

[9] Note, that in this setting the shock to energy prices is an exogenous change to relative prices that is *independent* of policy. To see this, recall that the price of domestic goods according to equation 16 can be written as a function of the now constant real exchange rate and the exogenous energy price increase.

Figure A3: Open versus closed economy



Note: The energy shock is a 30% increase in foreign energy prices, with persistence of 0.8. Monetary policy implements in all cases a fixed interest rate rule. The solid line is our baseline model; the dotted line corresponds to a closed economy model in which the energy price shock induces a dead weight loss to the domestic economy; and the dashed line is a model in which a local energy producer benefits from the increase in price.

The effects of an energy price shock are generally mitigated in the closed economy, if profits accrue to domestic owners of energy. Aggregate consumption falls less than in an open economy despite the absence of a mitigating foreign demand channel. As energy prices rise, the mutual receives higher profits from energy production raising the return on assets which benefits all households with positive savings. Thus, there is no wealth transfer from the domestic to the foreign economy. Nevertheless, rising energy prices constitutes a transfer from non-savers with high marginal propensities to consume to savers with lower marginal propensities to consume in this economy. The energy price shock therefore is still recessionary, as consumption and output are falling.

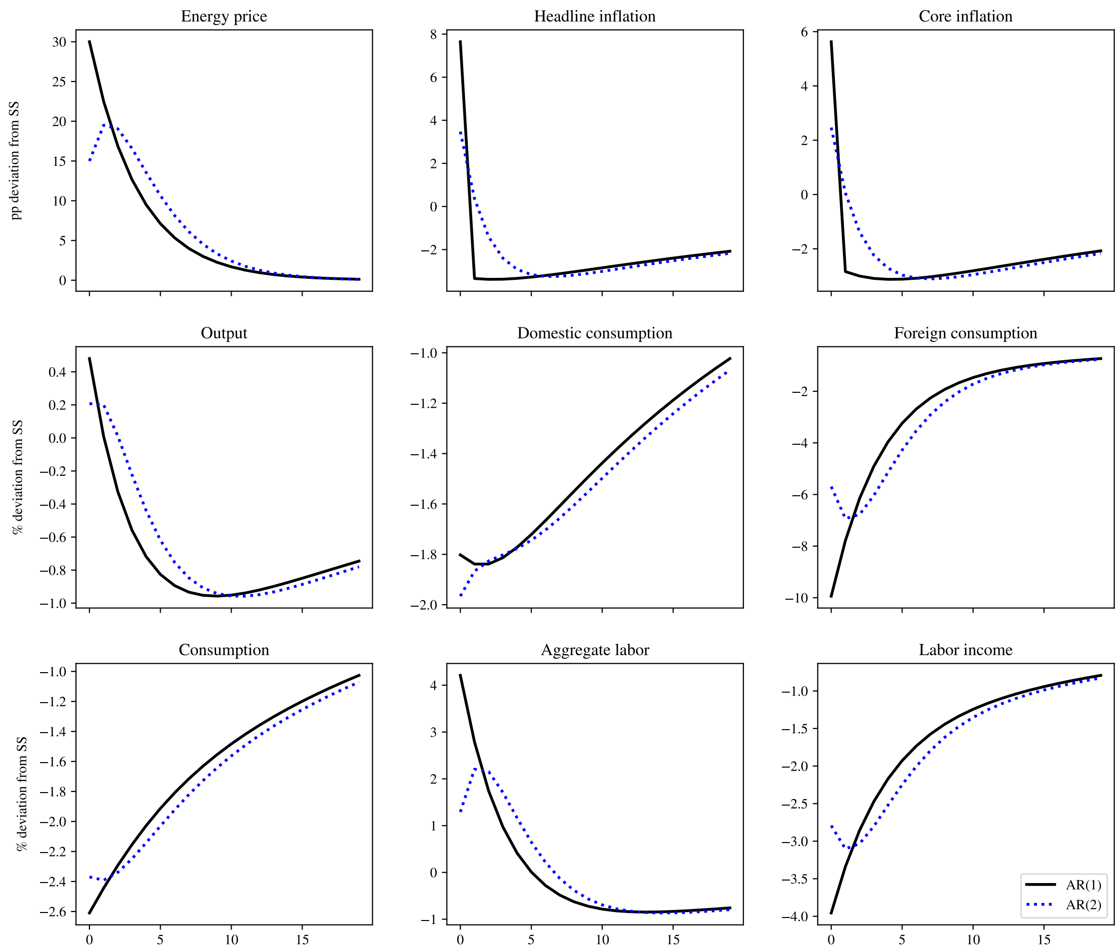
E Hump-shaped energy price shock

In this section, we study the effects of a hump-shaped energy price shock modelled as an AR(2) process. As Figure 1 shows, the energy price developments in the past two years can also be understood as an initial unexpected price increase with the anticipation of further price increases before energy prices eventually settled down.

In Figure A4 we contrast the baseline energy price shock to a hump-shaped shock. The top-left corner contrasts the two different processes. The hump-shaped shock has a lower initial magnitude, then increases until it levels off somewhat later but comparably to the AR(1) process. While the integral of both shocks is comparable, the reaction of aggregate variables is not. Especially the initial response is typically smaller and some variables like output, consumption and labor exhibit a similar hump-shaped profile peaking only a couple of quarters after the shock occurs. Once in the receding phase of the shock, aggregate variables exhibit similar patterns both qualitatively and quantitatively.

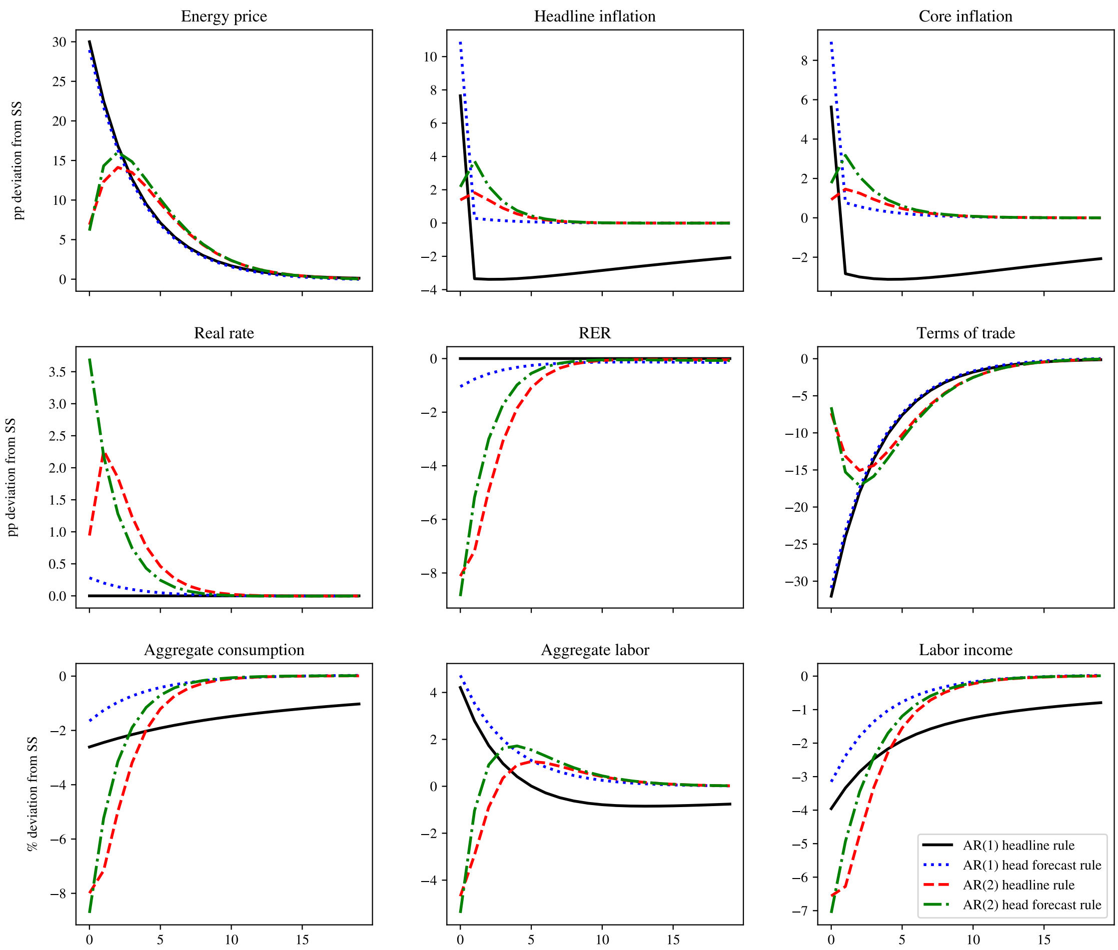
Given different shock profiles the natural question arises whether forecast rules are as advantageous in the case of energy price increases that can be expected to continue for some time. Figure A5 contrasts active monetary policy rules reacting to headline inflation for both profiles of an energy shock. Results for other active monetary policy rules are equivalent. Two main messages arise. First, forecast rules still perform better than rules reacting to contemporaneous inflation. While forecast rules lead to overall higher inflation rates, they stabilize aggregate real outcomes like consumption and labor better by partially looking through the energy price shock. Second however, these differences are by far not as pronounced as in the case of an immediately receding energy shock. Especially in the initial period headline rules yield comparable outcomes. Only in subsequent quarters does the headline rule imply slightly more adverse outcomes for real variables while at the same time leading to lower inflation.

Figure A4: Comparison of energy price shocks with different time profile



Note: The solid line plots a shock of 30% increase in foreign energy prices with persistence of 0.8. The dotted line plots a hump-shaped shock, chosen to have roughly similar overall impact on foreign energy prices. Monetary policy implements in all cases a fixed interest rate rule.

Figure A5: Comparison of policy rules for energy price shocks with different time profile



Note: The solid and dotted lines plot a shock of 30% increase in foreign energy prices with persistence of 0.8. The dashed and dot-dashed lines plot a hump-shaped shock, chosen to have roughly similar overall impact on foreign energy prices.

F Comparison across different supply shocks

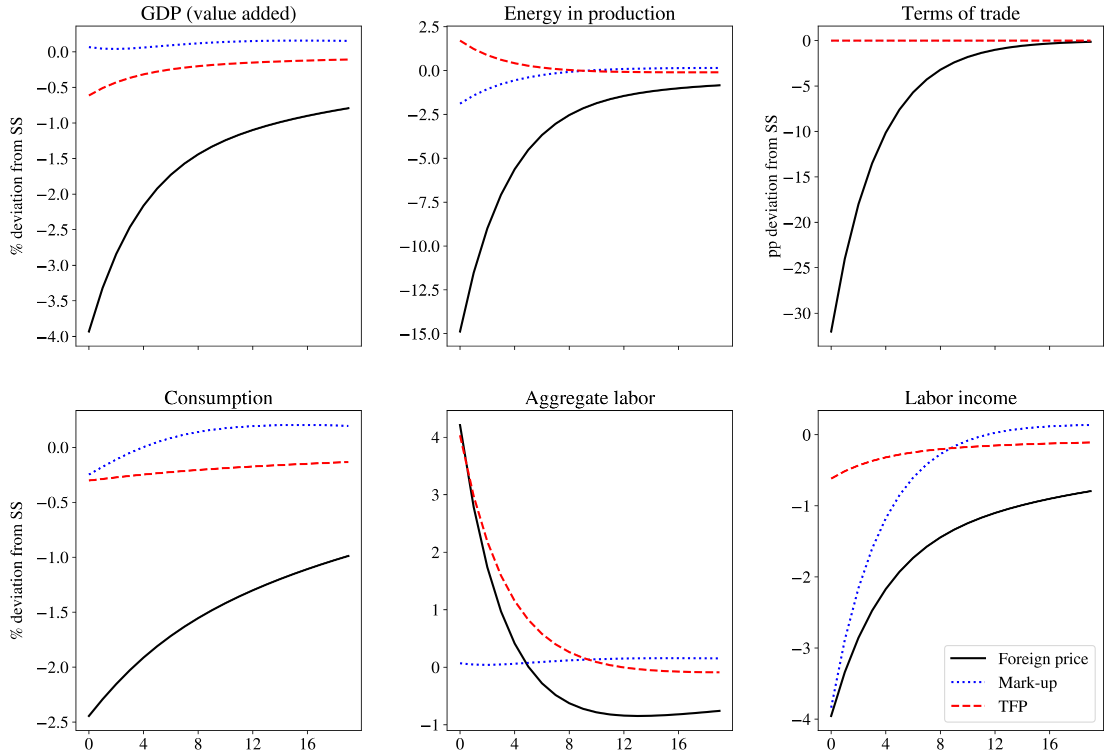
This section aims to underline that modeling an energy price shock is significantly different from modeling standard productivity or cost-push shocks. While all constrain supply, these shocks transmit into the economy through different channels and therefore have different aggregate and distributional effects. In Figure A6, we compare the aggregate effects of our foreign energy price increase with those of an adverse TFP and mark-up shocks. We target the magnitude of the shocks to reach similar magnitudes of the core inflation response in period 0, while we leave the persistence equal. We compare the effects of these shocks under our baseline policy rule.

First, the TFP shock decreases the productivity of labor. Firms thus need to hire more labor to produce the same output and labor demand increases. Instead, the energy price shock increases labor demand due to a substitution effect away from the imported energy good. The latter effect is more persistent, leading to a more persistently depressed labor income. Moreover, the TFP shock increases demand for the energy good, while the foreign price shock has the opposite effect – though both happen because of substitution effects. Furthermore, the TFP shock leads to a smaller decline in the terms of trade, implying a weaker foreign demand channel. The increase in energy demand of firms due to declining labor productivity implies far lower energy price increases as our energy price shock which together with a similar-sized initial response of domestic goods prices implies a smaller deterioration in the terms of trade.

Second, the mark-up shock generates a decrease in real wages and an increase in profits. The decrease in income leads to lower aggregate demand, translating into lower demand for factors of production, which further depresses labor income. The shock induces a redistribution from labor income towards asset income. In fact, low-wealth households witness a relatively higher drop in consumption, while all households with positive savings benefit from rising profits through the returns on the mutual fund. The shock is redistributive within the domestic economy, but all savers benefit from this.

Third, the foreign energy price shock overall entails the biggest output losses. It is also the only shock that generates a terms of trade depreciation, which actually dampens the effect of the shock over time. Importantly, the mark-up shock is redistributive within the economy, while the other shocks entail real economic costs, either because of lower productivity requiring more inputs (TFP) or because of a wealth transfer into the foreign economy (energy shock).

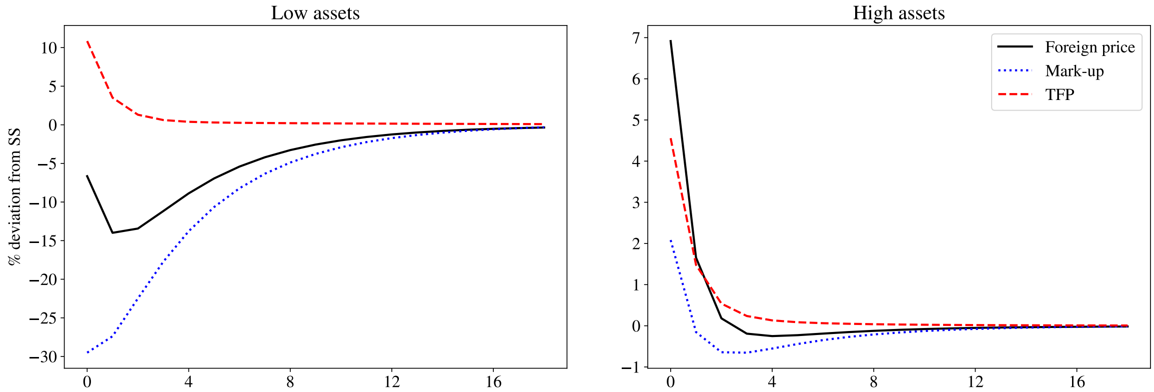
Figure A6: Comparison of the effects of the energy shock with those of a productivity and a price mark-up shock



Note: The energy shock is a 30% increase in foreign energy prices. The productivity shock and the price mark-up shock are calibrated to match the first period response of inflation as induced by the foreign energy price shock. All three shocks assume AR(1) processes with persistence of 0.8. Monetary policy implements in case of all three shocks a fixed interest rate rule.

Not only do the aggregates respond very differently to the three types of shocks, but also the effect on inequality depends on the nature of the shock. For illustration purposes of the heterogeneous effects, Figure A7 plots the savings response of low- and high-wealth households for the different shocks, and under a head monetary policy rule. The energy price shock weights negatively on low-wealth households' savings, while low-wealth households decide to increase savings as a response to the TFP shock. Savings of the low-wealth decrease most after a mark-up shock, consistently with the latter being a transfer from labor to capital earners.

Figure A7: Savings response to an energy, productivity and price mark-up shock

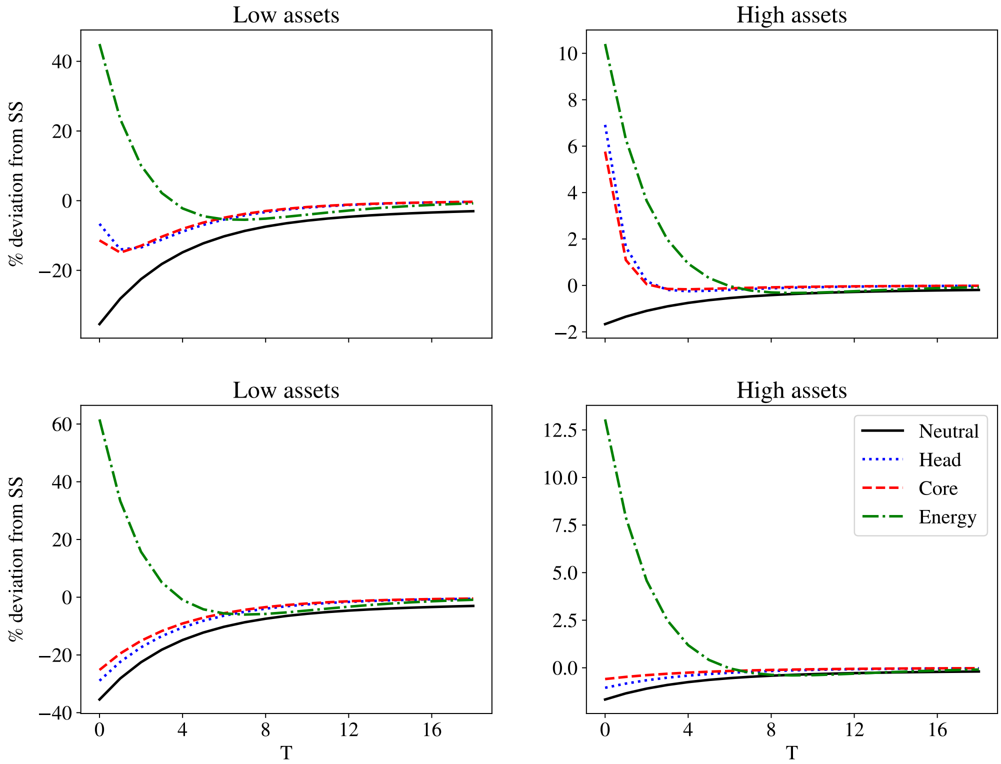


Note: The energy shock is a 30% increase in foreign energy prices. The productivity shock and the price mark-up shock are calibrated to match the first period response of inflation as induced by the foreign energy price shock. All three shocks assume AR(1) processes with persistence of 0.8. Monetary policy implements in case of all three shocks a head rule to contemporaneous inflation. The left panel plots the response of the lowest wealth quintile, while the right panel plots that of the second highest wealth quintile.

G Savings response for low- and high-wealth households

This section shows the savings response for low- and high-wealth households under monetary policy rules reacting either to contemporaneous or forecast measures of inflation. We define low-wealth households as those in the lowest wealth quintile and high-wealth households as those in the second highest wealth quintile. In our calibration, low-wealth households are also borrowing constrained without any savings to rely on.

Figure A8: Savings response under head monetary policy rules



Note: On the top, we plot a comparison of the asset response of low- and high-wealth households under monetary policy rules reacting to contemporaneous measures of inflation. In the bottom panel, monetary policy reacts to forecast measures of inflation. Low-wealth households refer to the lowest wealth quintile whereas high-wealth households refer to the second highest wealth quintile.

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