Energy Shortages and Aggregate Demand: Output Loss and Unequal Burden from HANK

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Abstract

I study the effects of a reduction in energy supply using a quantitative Heterogeneous Agents New Keynesian (HANK) model with energy consumption by households and firms. I find that changes in aggregate demand due to an increase in energy prices and labor market adjustments amplify the macroeconomic effects of the energy shock, but these effects remain manageable. In the model a 10% reduction in the energy supply leads to a Gross National Income (GNI) loss in range between 0.8% and 2%. The economic burden is highly nonlinear across the income distribution: most households face similar and relatively contained costs, while low-income households bear the heaviest burden. I show that monetary and fiscal policy can mitigate the economic costs and the unequal effects of energy shortages.

Keywords: Heterogeneous agents, New Keynesian, energy, fiscal policy, inequality.

JEL Classification: D31, E32, Q43.

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1 Introduction

Estimates based on structural multi-sector models with international trade suggest that a sudden stop in energy imports from Russia can lead to a GNI loss in range between 0.3% and 2.3% for Germany (Bachmann et al. (2022)). In my analysis I take a different approach. I build a quantitative HANK model in which households and firms consume energy to analyze the macroeconomic effects of energy supply shortages on European economies. In particular, I focus on the most exposed countries: Germany and Italy. The model captures business cycle amplification channels that operate through aggregate demand fluctuations due to an increase in the energy bill for households and firms and labor market adjustments.

This paper presents three main findings. First, I provide a range of estimates for the GNI loss due to energy shortages using a general equilibrium framework. I find that the GNI loss can be large but manageable. Second, I show that inequality generates a substantial amplification of the energy shock. I quantitatively illustrate how an energy shortfall affects household income and consumption across the income distribution. The economic burden falls heavily on low-income households increasing the aggregate income loss. Third, I show that monetary and fiscal policies can substantially mitigate the GNI loss and the unequal effects of energy shortages.

I build a quantitative HANK model with energy and solve the full-nonlinear model in general equilibrium to study the dynamics of the economy after a large energy shock. In this paper I focus on the role of energy consumption by firms for production and by households for heating and for transportation. Specifically, I assume that energy inputs enter in a Constant Elasticity of Substitution (CES) production function and in a CES consumption bundle. Since household energy consumption is relatively higher for the poorest households, a change in energy prices can have a direct effect on household consumption at the bottom of the distribution. To capture this effect I introduce a non-homothetic demand for energy by households. Overall, this formulation implies that energy prices directly affect firms' operating costs and households' budgets. Then, following the New Keynesian literature I model sticky wages and sticky prices. This introduces a wage Phillips curve and a price Phillips curve in the model. I assume an exogenous supply of energy. This allows me to keep the model as simple as possible and isolate the role of Marginal Propensities to Consume (MPC) and nominal rigidities in the amplification of the energy shock.

I calibrate several parameters externally following the HANK literature. In the calibration of the remaining parameters I rely on the existing literature based on European micro data (Carroll, Slacalek, and Tokuoka (2014), Slacaleky, Tristani, and Violante (2020)) with both Italy and Germany. The main focus of the paper is on the German economy, however almost all the statistics used in the calibration are similar for Italy. Therefore, the results in the paper can be extended to Italy as well. For the parametrization of the elasticity of substitution I follow the empirical literature measuring the elasticity of energy demand. The assumption of a CES function allows me to map these estimates directly into the energy elasticity of substitution σ. Overall, the model generates a sizable average MPC and fits well the other targeted statistics, such as the average wealth to income ratio, the energy expenditure share from gas, oil and coal over national income, and the average energy expenditure share for heating and for fuel by households. Moreover, the model provides a good fit of other important untargeted statistics. The model generates a realistic share of low-liquidity households, and matches the joint distribution of household income and energy expenditure.

In the main experiment of this paper I simulate a 10% shortfall in the overall national energy consumption after a complete stop of energy imports from Russia. This could be the size of the energy supply shock for the German economy (Bachmann et al. (2022)) and for Italy (Bank of Italy, Economic Bulletin, 2, 2022). Given this shock I solve the fully-nonlinear model and compute the impulse response functions of the main equilibrium variables.[1]. In the baseline model with energy consumption by households and firms, sticky wages and prices, and energy elasticity $\sigma = 0.1$, I find a GNI loss of 1% and the inflation rate is 3.2$\%$ over the first year. Then, I study the cross-sectional predictions of the model to quantify the distributional effects of energy shortages. I find highly nonlinear effects across the income distribution with consumption losses concentrated at the bottom 20% of the distribution. The reason is that these households experience the largest drop in income due to the increase in the energy bill and a substantial reduction in labor earnings. Low-income households are particularly exposed to the energy shock since for these households labor earnings are the main income source and energy accounts for a large share of household expenditures. Since these households do not have enough wealth to smooth the income shock, they need to reduce consumption expenditures. Therefore, I find that the concentration of the economic burden at the bottom of the income distribution significantly amplifies the aggregate cost. To the best of my knowledge this is the first paper to document this unequal response of household consumption to an energy shortfall in the HANK framework and its aggregate implications.

There are several channels through which energy shortages affect aggregate consumption. First of all, there is the direct impact of rising energy prices on household expenditure. However, there are also indirect channels. The scarcity of critical energy inputs for production reduces the demand of labor by firms with negative consequences on wages and employment. These channels generate substantial earning losses for low-income households. The energy supply shock also lowers business profits because the higher energy bill raises production costs and the slowdown in economic activity reduces sales and revenues. Finally, the higher inflation leads the central bank to raise interest rates and the recession increases the demand of saving by households. As a result real interest rates increase, raising interest payments for borrowers, and creating incentives to postpone consumption. All these channels operate in the model. I use the model to disentangle and measure the relative contribution of each channel to the aggregate output loss, which in the model is equivalent to the aggregate consumption loss. I find that the direct effects of energy prices account for 12% of the aggregate consumption loss, and the indirect effects from the labor market explain around 50%. Therefore, the direct effect accounts for a non-trivial fraction of the output loss, but labor income is the most important channel.

[1]To solve the Hamilton-Jacobi-Bellman (HJB) equation and the Kolmogorov Forward (KF) equations I rely on the algorithm of Achdou, Han, Lasry, Lions, and Moll (2022).

Given the uncertainty surrounding aggregate elasticities of substitution I use the model to analyze different scenarios, including several extreme and conservative cases. In particular, I provide a range of estimates using a basic HANK model with flexible wages and energy consumption only for production. These assumptions simplify the model without significantly changing the range of estimates that can obtained from the model. I find that in the model energy shortages leads to a GNI decline in range between 0.8% and 3.4%. Table 1 reports the quantitative results from the basic model for different values of the elasticity of substitution σ. In all the simulations the elasticity of substitution between energy and other inputs is at the lower bound of the empirical estimates. In the more likely outcomes, the energy shortfall leads to a GNI decline between 0.8% and 2%. Throughout these simulations low-income households bear the highest cost.

Table 1: Model simulations

GNI Loss	$\sigma = 0.1$	$\sigma = 0.07$	$\sigma = 0.2$	Fossil gas only
HANK model	1.5%	2%	0.8%	3.4%
CES function	0.6%	0.8%	0.5%	2.3%

Note: The first three columns show the effects of a 10% reduction in the overall energy use. The last column shows the effect of a 30% reduction in the energy inputs from natural gas with $\sigma = 0.16$.

Then, for each parametrization I compute a simple counterfactual output loss in absence of the demand amplification features of the quantitative HANK model. In particular, I obtain these counterfactuals by feeding the energy shock in a simple CES production function calibrated as in the quantitative HANK model. This allows me to quantify the amplification effect in all the different scenarios. Table 1 shows that across all parametrizations the GNI response is substantially lower than in the HANK model. Moreover, the amplification effect increases with the severity of the recession due to the energy supply shock. In the more optimistic case the income loss increases by 0.3 percentage points, in the more pessimistic scenarios the income loss increases by 1.2 percentage points. This implies that household MPCs, labor market adjustments, and price rigidities amplify the effects of the energy shock. However, even in the worst-case scenario in the last column of Table 1 the economic cost remains manageable.

I also consider several extreme and conservative scenarios as well as robustness checks. First, I model the energy input as representing only gas. Therefore, following the calculations in Bachmann et al. (2022) I consider a 30% energy shortage. The result is a GNI loss of 3.4%. In this case the energy shock can cause a very large recession. However, gas is not the only energy input and the assumptions that support this scenario are rather extreme. In the same spirit I consider a counterfactual in which the energy shortage lasts for a long period of time. Moreover, I assume that less than 60% of the energy shortfall can be reversed after 1 year from the shock. This generates a consumption drop of 2.7%, in line with the most pessimistic scenario on the elasticity of substitution considered in the paper ($\sigma = 0.05$). Finally, I also study the sensitivity of the aggregate consumption loss to the size of the MPC. I find that by doubling the average MPC the consumption loss increases by 0.7 percentage points.

In the remaining of the paper I study the macroeconomic effects of monetary and fiscal policies. In particular, I model two distinct policies: interest rate policy and targeted fiscal transfers for low-income households. After an energy supply shock monetary policy faces a trade-off between inflation and economic activity. For example, in the model a more conservative monetary policy stance on inflation by increasing the contraction of output by 0.5 percentage points reduces the increase in inflation by approximately 0.7 percentage points. However, a more precise quantification of this trade-off crucially depends on the definition of monetary policy rules, and on the effect of the energy shortfall on potential output. Since the GNI loss depends on the stance of monetary policy, a more accomodative policy can significantly reduce the output contraction while inflation remains between 3%-4%. Such policy however is problematic if inflation is already high. Then, fiscal policy provides a better alternative. An expansion of social insurance programs that targets the most exposed and vulnerable households can substantially mitigate the recession without causing additional inflation. I model these type of policies as fiscal transfers targeted to low-income households. This policy redistributes resources across households and reduces the concentration of the economic burden at the bottom of the income distribution preventing the amplification effects of the energy shock. It is important to highlight that since this policy targets a very small population group it does not cause additional inflation. Therefore, these computational experiments suggest that social insurance targeted to the most vulnerable households can significantly lower the unequal consequences of the recession, reduce the aggregate demand amplification effects, and mitigate the overall economic cost of energy shortages.

It is important to highlight that this study does not consider other important factors that can further amplify or mitigate the macroeconomic effects of energy supply shocks, such as the effects in the global markets, international trade adjustments and re-organization of supply chains, and different combinations of monetary and fiscal policies. Moreover, there are two important limitations that provide new directions for future research. First, I focus on a positive analysis leaving room for normative analyses. In the model labor supply and different consumption goods enter in the utility function. As a consequence welfare inequality is not equivalent to consumption inequality or income inequality. This can have important implications for optimal policy. Second, in the model I use a standard Taylor rule based on the national inflation rate. However, countries in the Eurozone (EZ) have the same policy rate, this is set by the European Central Bank (ECB) according to EZ harmonised inflation rather than one national inflation rate. Therefore, the model provides a good approximation of the ECB monetary policy only under the assumption that energy shortages have similar effects on inflation across different EZ countries. An interesting extension is to study how potential differences between EZ and national inflation dynamics shape the systematic component of monetary policy.

Literature. This paper is related and contributes to two strands of the economic literature. First, it contributes to the literature studying the importance of MPC heterogeneity using HANK models. Second, it is related to the empirical literature on the elasticity of energy demand and to recent quantitative work studying the macroeconomic effects of an energy supply shortfall.

In the first strand of the literature several papers study the amplification or mitigation of aggregate shocks, including the effects of monetary and fiscal policies, with quantitative HANK models (Alves, Kaplan, Moll, and Violante (2020), Kaplan, Moll, and Violante (2018), Gornemann, Kuester, and Nakajima (2021), Hagedorn, Manovskii, and Mitman (2019), Laibson, Maxted, and Moll (2021), Luetticke (2021), Kaplan and Violante (2021), Auclert, Rognlie, and Straub (2020), Auclert, Rognlie, and Straub (2018), Wolf (2021), Auclert, Rognlie, Souchier, and Straub (2021)). Relative to these papers I introduce energy in the HANK framework to quantify the amplification effect of energy shortages due to fluctuations in aggregate demand through general equilibrium effects. I document the unequal consumption and income effects of these type of shocks. I illustrate quantitatively how these results depend on several dimensions of economic inequality and on the energy elasticity of substitution by households and firms. Finally, this paper provides a new macroeconomic framework to study other topical problems as the transition to clean energy.

In the second strand of the literature I add to the work by Bachmann et al. (2022) on the macroeconomic effects of a sudden stop in energy imports. The authors focus mainly on the macroeconomic implications of trade and supply chains. In this paper I focus on business cycle effects and aggregate demand amplification channels. I see these different methods as complementary and useful to provide a broader view of the macroeconomics of energy shocks. The estimates for the GNI loss in this paper are higher than in Bachmann et al. (2022) reflecting an important role of aggregate demand fluctuations in the amplification of these type of energy shocks. Finally, my analysis is also closely related to the empirical literature on energy demand elasticities (Auffhammer and Rubin (2018), Labandeira, Labeaga, and Lopez-Otero (2017), Steinbuks (2012)). In particular, in their meta-analysis Labandeira, Labeaga, and Lopez-Otero (2017) distinguish carefully between short-run and long-run elasticity estimates, specific energy sources, type of consumers, country or geographical area, type of data and model.

Outline. The remaining of the paper is organized as follows. Section 2 presents the model. Section 3 describes the parametrization and validation of the model. Section 4 contains the main quantitative results on the aggregate and distributional effects of energy shocks. I also analyze more conservative scenarios and the sensitivity of the results to different aspects of the model's calibration. Section 5 shows how monetary and fiscal policies can mitigate the economic cost of energy shortages. Section 6 concludes.

2 The model

This section presents the quantitative model that I use for my analysis. I consider an economy in continuous time with incomplete markets and no aggregate risk. Individuals can trade assets a_t, face borrowing constraints, and idiosyncratic labor income risk z_t. Let $M = (X, \mathcal{X})$ be a measurable space where $(a, z) \in X = A \times Z \subseteq \mathbb{R}^2$, $\mathcal{X} = \mathcal{B}(A) \otimes P(Z)$ is the product σ-algebra generated by the Borel σ-algebra $\mathcal{B}(A)$, and the power set $P(Z)$. Moreover, $\psi_t : M \to [0, 1]$ is the probability distribution over idiosyncratic states and f_t the associated density.

2.1 Households

I model two broad consumption categories, namely consumption of energy inputs c_e and consumption of other goods c_g. The consumption bundle c_t aggregates these two spending categories according to the Stone–Geary CES function

$$c_t = \left(\alpha^{\frac{1}{\sigma}} (c_{e,t} - \underline{c})^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}} c_{g,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}.$$

The elasticity of substitution between goods is given by σ, and α is the distribution parameter. In order to capture the different composition of household expenditure across the income distribution I use non-homothetic preferences. In particular, I introduce a subsistence level of energy consumption $\underline{c}$. The consumption bundle is chosen to be the numeraire so the Consumer Price Index (CPI) is one in real terms, $p_t = 1$ and $p_t c_t := p_{g,t} c_{g,t} + p_{e,t} c_{e,t}$ where $p_{g,t}, p_{e,t}$ are the real prices of the consumption goods. Households decide the total consumption level solving the following program

$$\max_{c_t} \quad \mathbb{E}_0 \int_0^\infty e^{-\rho t} \left(\frac{c_t^{1-\gamma}}{1-\gamma} - \frac{n_t^{1+\nu}}{1+\nu} \right) dt,$$

$$\text{s.t. } da_t = (w_t n_t z_t + r_t a_t + d_t - c_t) dt,$$

$$a_t \geq -\phi,$$

where $\gamma > 0$ is the inverse elasticity of intertemporal substitution, $\nu > 0$ is the inverse Frisch elasticity of labor supply. The lump-sum transfers d_t include dividends distributed to households proportionally to $z_t / \int_X z_t d\psi_t$. Idiosyncratic labor income risk z_t follows a lognormal process

$$d \ln z_t = -\nu_e \ln z_t dt + \sigma_e d\hat{w}_{z,t},$$

where σ_e is the standard deviation rate of the log-income process, ν_e the mean reversion parameter, and $d\hat{w}_{z,t} \sim N(0, dt)$ is a standard Brownian motion. Following the recent HANK literature (e.g. Hagedorn, Manovskii, and Mitman (2019), Auclert, Rognlie, and Straub (2018)) I introduce sticky wages in the model. Unions set nominal wages by maximizing the average welfare of the households, and employ all households for an equal number of hours $n_t = N_t / \int_X z_t d\psi_t$ where N_t is the aggregate labor supply. In particular, a competitive recruiting firm aggregates a continuum of differentiated labor services indexed by $j \in [0, 1]$ maximizing $W_t N_t - \int_0^1 W_{jt} N_{jt} dj$, where W is the nominal wage and N is labor demand or hours, subject to the following technology

$$N_t = \left(\int_0^1 N_{jt}^{\frac{\theta_w - 1}{\theta_w}} dj \right)^{\frac{\theta_w}{\theta_w - 1}}.$$

where θ_w is the elasticity of substitution across differentiated labor inputs. This implies a demand for the labor services of type j equal to

$$N_{jt} = \left(\frac{W_{jt}}{W_t} \right)^{-\theta_w} N_t.$$

Households supply a continuum of labor services which are imperfect substitutes and for each labor input j a union sets the nominal wage to maximize the average welfare of the union members, taking their marginal utility of consumption $u'(c) = c^{-\gamma}$ and the labor disutility $\upsilon(n) := n^{1+\nu}/(1+\nu)$ as given. Wage adjustment is subject to a quadratic utility cost. Let C_t be aggregate consumption and P_t the consumer price index, the union solve the problem

$$\max_{\dot{W}_{jt}} \int_0^\infty \left[\exp\left(- \int_0^t r_s ds \right) \left(\int_0^1 \frac{W_{jt}}{P_t} N_{jt} - \frac{\upsilon(N_{jt})}{u'(C_t)} - \frac{\Psi_w}{2} \left(\frac{\dot{W}_{jt}}{W_{jt}} \right)^2 N_t dj \right) \right] dt$$

$$\text{s.t. } N_{jt} = \left(\frac{W_{jt}}{W_t} \right)^{-\theta_w} N_t.$$

Let $\mu_w := \theta_w/(\theta_w - 1)$ and $\pi_{w,t} := \dot{W}_t / W_t$, in a symmetric equilibrium with $W_{jt} = W_t$ and $N_{jt} = N_t$ we obtain a New Keynesian Phillips Curve for nominal wages given by

$$\pi_{w,t} \left(r_t - \frac{\dot{N}_t}{N_t} \right) = \dot{\pi}_{w,t} + \frac{\theta_w}{\Psi_w} \left(\frac{\upsilon'(N_t)}{u'(C_t)} - w_t \mu_w^{-1} \right).$$

See Appendix A.1 for further details. Finally, the household intratemporal maximization of the the Stone–Geary CES preferences over $c_{g,t}, c_{e,t}$ given the optimal net-of-subsistence expenditure $\hat{c}_t := p_{g,t} c_{g,t} + p_{e,t}(c_{e,t} - \underline{c})$ yields the following CES demand system

$$c_{e,t} = \underline{c} + \alpha \left(\frac{p_{e,t}}{p_t} \right)^{-\sigma} \hat{c}_t,$$

$$c_{g,t} = (1 - \alpha) \left(\frac{p_{g,t}}{p_t} \right)^{-\sigma} \hat{c}_t,$$

$$p_t = \left(\alpha p_{e,t}^{1-\sigma} + (1 - \alpha) p_{g,t}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}.$$

2.2 Firms

A representative firm produces one final composite good which will be the consumption bundle using a continuum of intermediate inputs, indexed by $i \in [0,1]$. This firm chooses intermediate goods Y_{it} to maximize nominal profits $P_t Y_t - \int_0^1 P_{it} Y_{it} di$ subject to a CES production function

$$Y_t = \left(\int_0^1 Y_{it}^{\frac{\theta_p - 1}{\theta_p}} di \right)^{\frac{\theta_p}{\theta_p - 1}}.$$

The final good producer operates in a competitive market, and profit maximization with respect to intermediate good i yields the following demand

$$Y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\theta_p} Y_t.$$

Intermediate good producers demand labor N_{it} and energy E_{it} to minimize production costs $w_t N_{it} + p_{e,t} E_{it}$ where $p_{e,t}$ is the real energy price. These firms use a CES production function

$$Y_{it} = \left(\alpha^{\frac{1}{\sigma}} E_{it}^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}} N_{it}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

where σ is the elasticity of substitution between production factors and α is the distribution parameter that weights each input. These parameters are critical to capture the supply effects of an energy shock even in richer multi-sector models with input-output linkages and international trade like the Baqaee-Farhi framework (Baqaee and Farhi (2021)). These models typically feature a nested CES structure. Therefore, the elasticities of substitution across production inputs are key parameters that shape the supply-chain effects in the model.

The optimal demand of labor and energy obtained from the cost minimization problem are given by the following set of equations

$$N_{it} = (1-\alpha) \left(\frac{w_t}{mc_{it}} \right)^{-\sigma} Y_{it},$$

$$E_{it} = \alpha \left(\frac{p_{e,t}}{mc_{it}} \right)^{-\sigma} Y_{it}.$$

This demand system implies that the real marginal cost mc_t only depends on real wages, energy prices, and structural parameters. Therefore, real marginal costs are the same across all firms, see Appendix A.3 for further details. Note that the distribution parameter α and the elasticity of substitution σ are the same for households and firms. This assumption may appear too restrictive. However, it reduces the number of parameters to be calibrated, while at the same time it does not prevent the model from matching key statistics on energy consumption. I discuss in details the quantitative implications of this assumption as well as the evidence on the elasticity of energy demand by residential and industrial consumers in Section 3.

Let m_{it} denote nominal marginal costs so that $mc_{it} = m_{it}/P_t$. Intermediate producers set prices to maximize profits under price adjustment cost and solve the following problem

$$\max_{\dot{P}_{it}} \int_0^\infty \left[\exp\left(-\int_0^t i_s ds\right)\left((P_{it} - m_{it})Y_{it} - \frac{\Psi_p}{2}(\pi_{it})^2 P_t Y_t\right)\right] dt$$

$$\text{s.t. } Y_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\theta_p} Y_t.$$

Let $\mu_p = \theta_p/(\theta_p - 1)$, the optimization problem in a symmetric equilibrium, i.e. $P_{it} = P_t$, yields a New Keynesian Phillips Curve (NKPC) given by

$$\pi_t\left(r_t - \frac{\dot{Y}_t}{Y_t}\right) = \dot{\pi}_t + \frac{\theta_p}{\Psi_p}\left(mc_t - \mu_p^{-1}\right).$$

The real profits of the firms are given by $D_t = (1 - \mu_p^{-1})Y_t$. To avoid price adjustment costs becoming a non-trivial fraction of output, I model these costs as being virtual (Hagedorn, Manovskii, and Mitman (2019)). These costs affect optimal choices but do not cause a waste of real resources. The same assumption is needed for the marginal cost component. The profits are distributed to hoouseholds as dividends, $d_t = (z_t/\int z_t d\psi_t)D_t$ so that high-income households receive a larger share of profits moving the model towards the data.

2.3 Monetary Policy

Following the NK literature I assume that the central bank sets nominal interest rates following a simple CPI-based Taylor rule

$$i_t = r + \phi_\pi \pi_t + \epsilon_t,$$

where ϵ_t is a monetary policy shock. There are several assumptions that is important to highlight and discuss. First, I assume that the central bank responds to CPI inflation. In practice, monetary policy tend to react more to core inflation that excludes the most volatile components such as food and energy. However, in the model using core inflation is also equivalent to use the CPI Taylor rule with a lower ϕ_π. In Section 5.1 I explore the sensitivity of the results to this parameter. Second, countries in the Euro Area (EA) do not have independent monetary policy. Therefore, the interpretation of the Taylor rule requires more care given that π is a national inflation rate while the nominal interest rate i depends on the EA harmonised inflation. Therefore, I assume that the energy shock studied here generates similar inflation dynamics across EA members and leave a more careful characterization of systematic monetary policy in the EA for future research. Third, I assume that the central bank responds only to inflation however monetary authorities also take into account changes in economic activity and output. Relaxing this assumption mitigates the contractionary effect of an energy shock. Therefore, in order to focus on pessimistic scenarios I keep this simple formulation as the baseline. In Section 5.1 I also explore the sensitivity of the results to this third assumption.

2.4 Equilibrium

I assume that energy supply $\{E_t\}$ is exogenous while the energy price is given by the demand of energy from firms $E_{f,t}$ and households $C_{e,t} := \int_X c_{e,t} d\psi_t$. I use the short hand notation m_a to denote the drift of household flow budget constraint and m_z to denote the drift of the stochastic process for $\ln z_t$. I formulate the household problem recursively by means of the Hamilton-Jacobi-Bellman (HJB) equation. The law of motion of the density function f_t is given by the Kolmogorov Forward (KF) equation, reflecting households' optimal choices and the stochastic process for income risk. The HJB and KF equations are two partial differential equations respectively given by

$$\rho v(x_t) = \max_{c_t} \left\{ u(c_t, n_t) + v_a(x_t) m_a + v_z(x_t) m_z + \frac{1}{2} v_{zz}(x_t) s_z^2 \right\},$$

$$\frac{\partial f_t}{\partial t} = -\frac{\partial}{\partial a}(f_t(x_t) m_a) - \frac{\partial}{\partial z}(f_t(x_t) m_z) + \frac{1}{2}\frac{\partial^2}{\partial z^2}(f_t(x_t) s_z^2).$$

The equilibrium in the model is given by household decisions $\{c_t, a_t\}$, aggregate variables $\{C_t, Y_t, N_t, E_t, E_{f,t}, C_{e,t}, C_{g,t}, D_t\}$, and prices $\{r_t, w_t, p_{e,t}, p_{g,t}, \pi_t, \pi_{w,t}, i_t\}$ such that: (i) the HJB and the KF equations hold, (ii) markets clear

$$B = \int_X a_t d\psi_t,$$

$$N_t = \int_X z_t n_t d\psi_t,$$

$$E_{f,t} + \int_X c_{e,t} d\psi_t = E_t,$$

where $C_t := \int_X c_t(x_t) d\psi_t$. (iii) the price NKPC, the wage NKPC, and the Taylor rule hold. Finally, in the model the following accounting relationships hold $r_t = i_t - \pi_t$ and $\dot{w}_t / w_t = \pi_{w,t} - \pi_t$. The resource constraint in this economy is given by $C_t = Y_t - p_{e,t} E_{f,t} + Q_t$. Since I abstract from energy production for industrial use and model energy inputs for industrial use $E_{f,t}$ as an exogenous resource the income $p_{e,t} E_{f,t}$ should be subtracted from aggregate output to measure value added. The last term Q_t is an endowment component of income that captures exogenous payments of financial assets $r_t B$. Note that despite the fact that I introduce in the model exogenous endowments, this formulation still gives a fully-fledged general equilibrium model that endogenously generates interactions and equilibrium feedback between labor markets, financial markets, and energy markets. The prices $w_t, r_t, p_{e,t}$ are endogenous and simultaneously determined by market clearing conditions. Throughout this paper I focus on aggregate consumption to measure the economic losses since it has a welfare interpretation. Moreover, since there is no investment in the model, aggregate consumption is equivalent to GNI, so the consumption losses in this paper can also be interpreted as GNI losses.

3 Calibration

In this section I briefly discuss the calibration of the model. The model is calibrated at quarterly time frequency. Given the purpose of this study I calibrate the model with two broad objectives. First, the model should deliver an empirically realistic average MPC and be consistent with the size of household wealth relative to income. Second, the model should match statistics on consumption of energy inputs from gas, oil and coal by households and firms. To achieve this I calibrate most of the parameters externally using standard values in the literature. Then, I calibrate the remaining parameters $E, B, \rho, \underline{c}$ to match statistics on household wealth and income, MPC, and energy expenditure shares.

I set the preference parameters γ, ν, the borrowing limit ϕ, and the Taylor coefficient ϕ_π to values common in the literature. The value for ϕ implies that the wealth distribution has a point mass of households close to zero as we observe in the data. Following the New Keynesian literature I set the intermediate goods elasticity θ_p to match a steady state profit share of income $1/\theta_p$ equal to 10%, and the price adjustment cost parameter Ψ_p to match a slope of the Phillips curve θ_p/Ψ_p of 0.1. Following the literature I set the parameters of the wage Phillips curve θ_w, Ψ_w so that the wage and price curves have same slope. Since the main focus of this study is on the aggregate implications of an energy shocks I choose standard values for ν_e, σ_e as well. In particular, the calibration procedure implies an annual autocorrelation for $\ln z_t$ equal to 0.9 and a standard deviation rate of innovations equal to 0.2.

The CES parameters σ, α are taken from the empirical literature on the price elasticities for energy demand. I set the distribution parameter $\alpha = 0.04$. This choice is motivated by the fact that in this way my results are directly comparable with those in Bachmann et al. (2022). In particular, in the comparison between a quantitative model and a simple CES production function we use the same CES calibration. In the baseline calibration I set $\sigma = 0.1$. Since the absolute value of the price elasticity of a CES demand function is the elasticity of substitution, the CES function allows to easily map empirical estimates of the price elasticity of energy demand to the elasticity of substitution. It is important to highlight that in the spirit of being as conservative as possible this value is below the lower bound of empirical estimates. In their meta-analysis of existing elasticity estimates for energy demand Labandeira, Labeaga, and Lopez-Otero (2017) find an average short-run elasticity for natural gas of 0.18 and of 0.22 for energy in general (oil, coal, and gas). In their study the authors also provide estimates of the energy demand elasticities for residential consumption, industrial consumers, and commercial use from the service sector. They find an average short-run elasticity for households around 0.21, the elasticity for industry is 0.16, and the commercial elasticity is 0.23. Since all these estimates are well above the value that I use in the baseline calibration I keep the same elasticity for households and firms. This implies that the baseline calibration is very conservative on the household sector. Moreover, given the uncertainty surrounding the elasticities of substitution I analyze different scenarios in the more optimistic $\sigma = 0.2$, and in a more pessimistic case the elasticity $\sigma = 0.07$.

I jointly calibrate $E, B, \rho, \underline{c}$ to match the quarterly average liquid wealth to income ratio of 4.2, an average quarterly MPC out of small transfers (500 Euros) between 15%-25%, the annual energy expenditure share from gas, oil and coal over national income of 4%, and the average energy expenditure share for heating and for fuel by households between 6% and 12% of total household consumption. The energy shares targets are taken from Bachmann et al. (2022). In particular, the household share is obtained from the German Income and Consumption Survey. The value of the average wealth to income ratio is taken from Carroll, Slacalek, and Tokuoka (2014). Finally, the empirical benchmark for the average MPC is taken from the existing literature and the model based estimates of Carroll, Slacalek, and Tokuoka (2014). I calibrate these statistics on the German economy. However, the values of these targets are also comparable to those of the Italian economy computed in those studies. Table 2 shows the calibrated parameters in the baseline case.

Table 2: Model parameters

Parameter	Description	Value	Source
Households			
γ	CRRA/Inverse IES	1	External
ν	Frisch elasticity of labor supply	1	External
ϕ	Borrowing limit	1	External
B	Net asset supply	5.8	Internal
ρ	Discount rate (p.a.)	8%	Internal
$\underline{c}$	Minimum consumption	0.0015	Internal
ν_e	Mean reversion coeff.	0.0263	External
σ_e	S. d. of innovations	0.2	External
Firms and policy			
σ	Elasticity of substitution	0.1	External
α	Distribution parameter	0.04	External
E	Energy supply	0.067	Internal
Ψ_p	Price adjustment cost	100	PC slope of 0.1
Ψ_w	Wage adjustment cost	100	External
θ_p	Intermediate goods elasticity	10	Profit share of 0.1
θ_w	Labor inputs elasticity	10	External
ϕ_π	Taylor coeff.	1.25	External

Overall, the model fits the targeted statistics quite well. The average wealth-income ratio is equal to 4.4, the energy share is 4%, the average quarterly MPC is 10% and 43% annually, and the fraction of liquidity constrained households is 14%. Jointly matching the dispersion in wealth and average MPC is a well known challenge for heterogeneous agents models. See Carroll, Slacalek, and Tokuoka (2017) for a detailed discussion of this point. The baseline calibration provides a good balance between the wealth target and the MPC target. In particular, it is important to highlight that the model generates sizable MPCs and a realistic share of low-liquidity households. Slacaleky, Tristani, and Violante (2020) using household micro data estimate a share of low-liquidity households of 22% between 2013 and 2015 for both Germany and Italy. Since the average MPC is at the lower end of the estimates provided by the literature, in the Appendix B.2 I also consider a low-wealth calibration that yields and average quarterly MPC of about 20%. Finally, the average energy expenditure share by households is around 9% in the model as in the data. Bachmann et al. (2022) estimate an average expenditure share of about 10% from the German Income and Consumption Survey.

To validate the model I also consider untargeted statistics that are important for my analysis. The model generates a realistic income distribution for Germany and Italy and substantial heterogeneity in the energy expenditure share across income groups. Figure 1 shows the income distribution (left panel) and the composition of household expenditure across the income distribution in the model (right panel). Income is given by the sum of earnings $w_t z_t n_t$, financial income $r_t a_t$, and dividends d_t. The left panel also reports the distribution of after-tax income in Italy and Germany. In the model the Gini coefficient is 0.48 while in the data is around 0.35. The model slightly overstates the concentration of household income at the top. However, it provides a good fit at the bottom 20% of the income distribution.

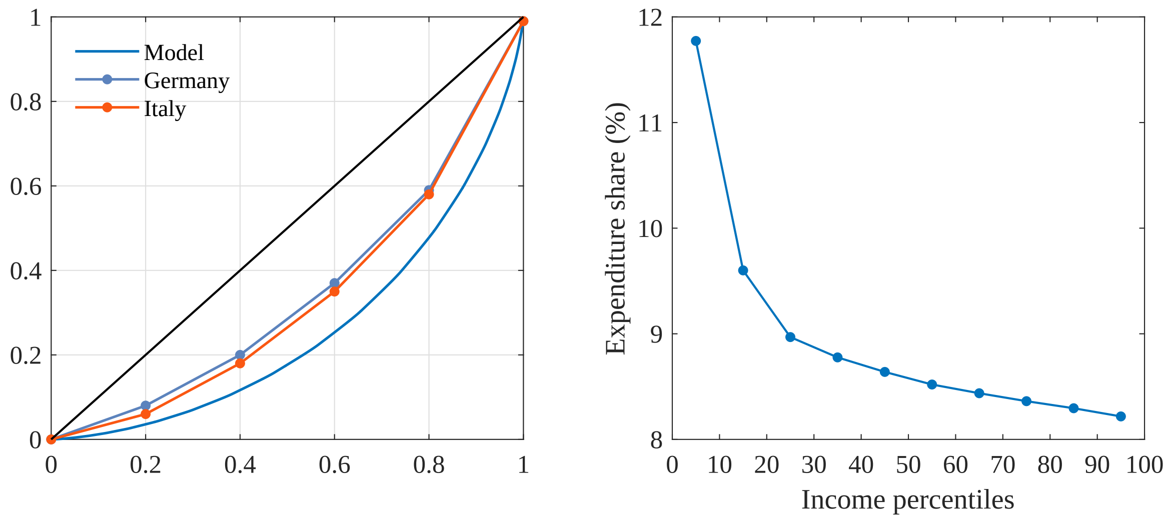

Figure 1: Income distribution and energy consumption.

Note: The left panel shows the Lorenz curves of the income distribution in the model, in Germany, and in Italy (World Bank data). The right panel shows the average energy expenditure share across income groups.

The right panel in Figure 1 shows the share of household energy expenditure relative to the total household consumption expenditures. For most of the income distribution the expenditure share is close to the population average of 9%. On the other hand, poor households at the bottom 10% of the income distribution have low levels of consumption and as a result their energy bill becomes a substantial fraction of household expenditures.

Figure 2 shows the energy expenditure shares by quintiles of the income distribution and the MPCs across the income distribution. In the left panel I contrast the households' energy expenditure share in the model (light blue bars) with its empirical counterpart in Germany (orange dots). I compute the energy expenditure shares in Germany using the evidence on household energy consumption from Bachmann et al. (2022). In particular, the authors report the household expenditure for heating across quintiles of the income distribution. I also use this distribution to impute household expenditure shares on fuel and obtain a the total energy expenditure share over income quintiles. Starting from the first quintile, the bottom 20%, we observe a decline in the energy consumption. Overall, the model with non-homothetic demand generates a realistic joint distribution of household energy consumption and income. In the right panel, I show the MPCs across the income distribution. The model generates large MPCs in line with microeconometric evidence. Households at the bottom 20% are either liquidity constrained or have a substantial precautionary saving motive given that they hold little wealth and are close to a borrowing limit. This makes low-income households the most vulnerable to income losses.

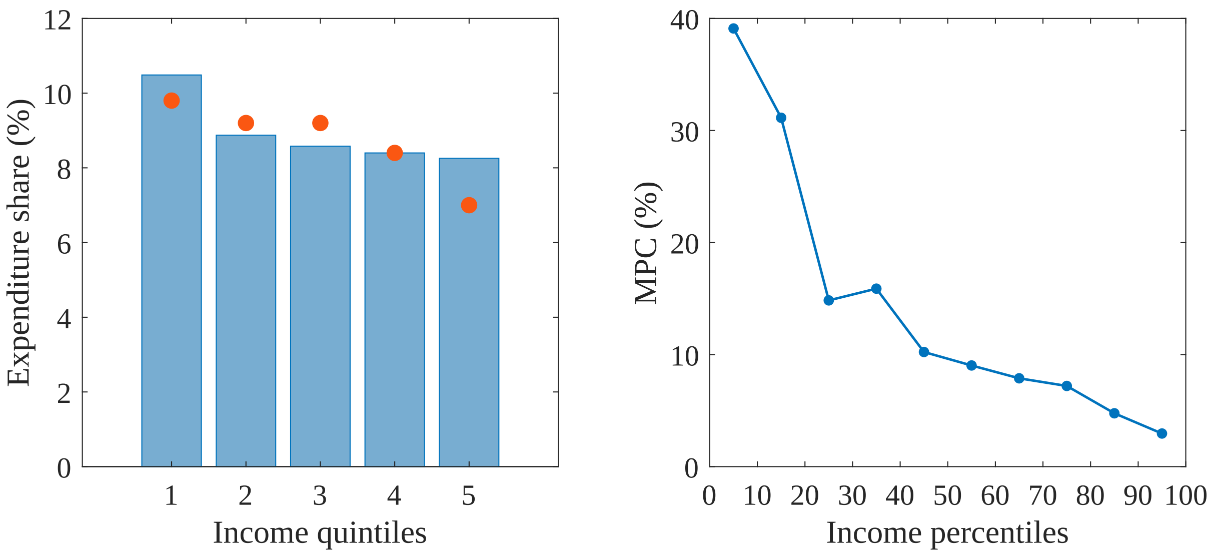

Figure 2: Energy expenditure and MPCs across the income distribution.

Note: The left panel shows energy expenditure shares in the model (light blue bars) and in Germany (orange dots). The right panel the average MPC across income groups. Data: own computations based on evidence from the German Income and Consumption Survey (Einkommens-und Verbrauchsstichprobe, EVS).

Household heterogeneity in demand composition and consumption behavior is important for the quantification of the unequal effects of an increase in energy prices. Additionally to this direct effect of an energy supply shock another indirect channel can shape aggregate and distributional dynamics. In the model more than 80% of household disposable income comes from labor earnings $w_t z_t n_t$, and this share is quite stable across the income distribution. This implies that also labor market adjustments due to energy shortages can have a first-order impact on households' income and consumption.

4 Energy supply shock

In this section I present the main quantitative experiments of this paper. Having calibrated the model, I solve the dynamics of the fully nonlinear economy after an unexpected reduction in the energy supply. Following Bachmann et al. (2022) I assume a 10% reduction in the supply of energy. First, I show the response of the economy in the baseline calibration. Second, since energy shortages affect household consumption through various channels, I explore the transmission mechanisms of the energy shock to aggregate consumption and leverage the model to quantify the relative importance of each channel. Third, I study how much the aggregate responses depend on the energy elasticity of substitution and the size of the shock.

4.1 Quantitative results

Figure 3 shows the reduction in energy supply. I calibrate the persistence of the shock so that the energy supply is fully back at the steady state level after 3 years. The half-life of the shock is in the third quarter and more than 70% of the shock is absorbed after 1 year. In the model household and firms split energy inputs almost equally. In practice some form of energy rationing that affects both households and firms will be needed, but given the uncertainty on the particular rationing scheme I leave these dimensions of the model unrestricted.

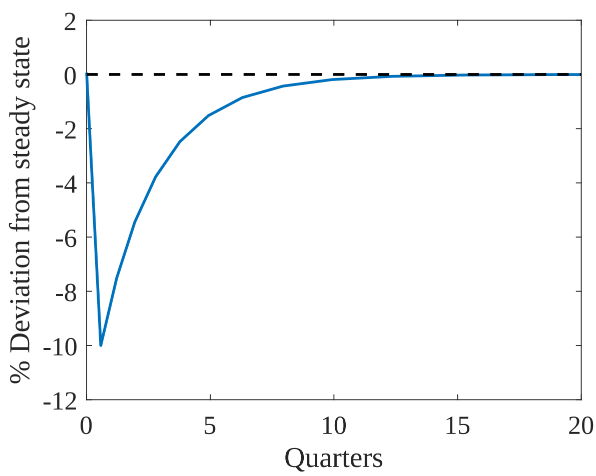

Figure 3: Energy supply shock.

Figure 4 shows the impulse responses of consumption, employment, and prices to the energy shock. A reduction in the energy supply leads to lower consumption and employment, higher real energy prices, and to an increase in the inflation rate. In the baseline case household expenditure falls by 1% at the peak of the response. This is a consequence of lower earnings, higher real interest rates, lower profits, and higher energy bills. In Section 4.2 I evaluate the importance of each channel.

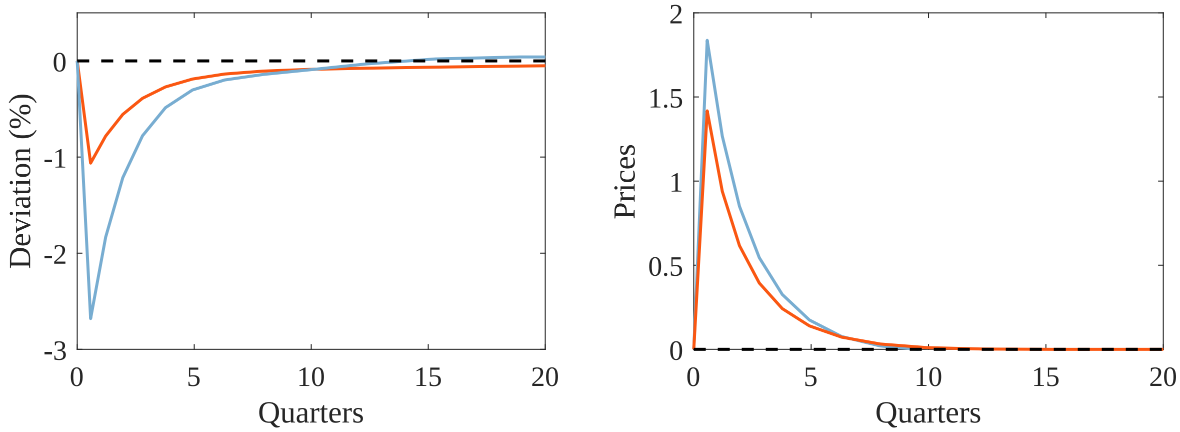

Figure 4: Impulse response functions to the energy shock.

Note: The figures show the response of consumption (orange line left panel), labor supply (light blue line left panel), and inflation (light blue line right panel) in percentage deviations from steady state. Increase of the real energy price over its steady state value (orange line right panel) in decimals.

The fall in earnings is an indirect general equilibrium effect that reflects a lower labor demand due to the complementarity between labor and energy inputs in production. A lower labor demand leads to lower wages and hours worked. Importantly, the presence of nominal wage rigidities shifts the adjustment from wages towards hours. This fact has two main implications. On one hand, since hours worked do not decline as much as real wages would decline in a flexible wage economy this mitigates the overall fall in earnings and its negative effect on aggregate consumption. In Section 4.3 I consider a version of the model with flexible wages and show that the recession can be substantially more severe under flexible wages. On the other hand, the reduction in employment is larger in the model with sticky wages. Real wages falls by 1.3%, and labor supply by 2.7% on impact. The energy price increases by a factor of 2.4, and the inflation rate is 3.2% over the first year. There are several aspects regarding the response of prices that are important to discuss and clarify. First, since energy prices enter in the CPI they directly increase inflation. Energy prices also affect the production costs of consumption goods, through this channel the energy price indirectly contributes to inflation. Second, from Figure 4 we can see that the real price of energy increases. This reflects an adjustment in relative prices. In particular, the energy shortfall generates an excess demand of energy that is absorbed through higher energy prices. Since for firms is costly to fully transfer the increase in the energy price on the price of final goods, the relative price of energy increases. This is an important signal to households and firms to reduce energy consumption. Finally, the annualized real interest rate increases by 1.8 percentage points. Two forces contribute to this outcome. The central bank increases the nominal interest rates above the inflation rate. On the other hand, the increase in the real interest rate also reflects an higher demand of saving from households, and given a fixed net supply of assets the market adjustment falls moslty on asset returns.

The costs of energy supply shortages are not borne equally across across households. In this section I study the responses of consumption and income across the income distribution. In particular, households are allocated to different groups according to the deciles of the stationary distribution of income, before the energy supply shock materializes. I define total income or disposable income as the sum of earnings $w_t z_t n_t$ and financial income $r_t a_t$, and profits d_t. As for the aggregate variables I focus on the impact response at the peak of the energy supply shortage. Figure 5 shows the cross-sectional effects of the energy supply shock.

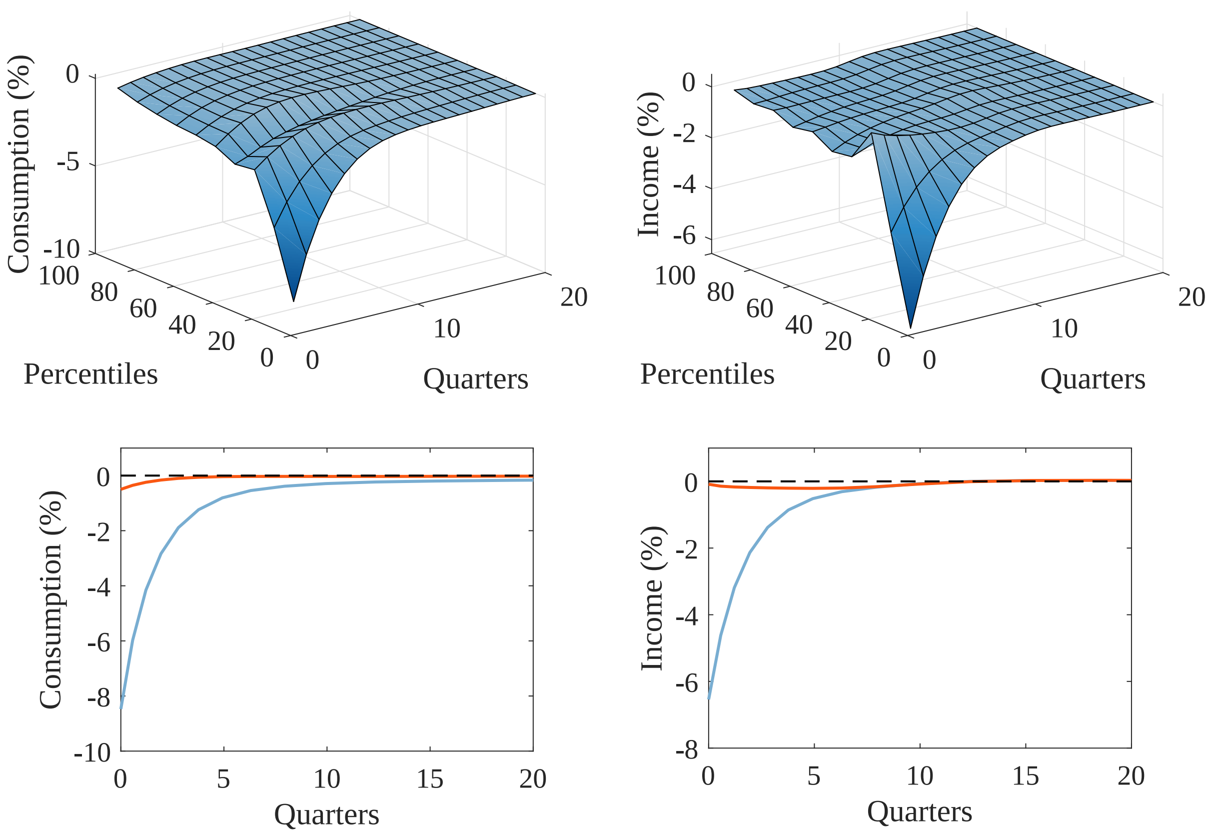

Figure 5: Consumption and income responses across the income distribution.

Note: The bottom panels show the average consumption and income responses of the top 10% (orange line) and of the bottom 10% (light blue line). Percentage deviations from steady state shown.

Figure 5 reports the average consumption and income losses for each group in percentage deviation from the steady state. In the model, the economic cost of an energy shortfall is highly nonlinear across the income distribution. Low-income households face the largest cost. The consumption decline for households at the bottom 20% of the distribution is between 4% and 8%, this is an order of magnitude higher than the decline faced by households in the other income groups, which is between 0.4% and 2%. Households at the bottom of the income distribution also experience a larger fall in their income, with a peak response of around 6%.[2] This effect is driven by earnings and reflects the decline in labor demand and salaries following an energy shortage. Households at the bottom 20% have a larger direct and indirect exposure to the energy shock. For these households the energy bill represent a large share of their total consumption. This implies an higher direct exposure to changes in energy prices. Moreover, low-income households rely mostly on labor earnings as income source. Therefore, they are indirectly exposed to the energy shock through labor market adjustments, i.e. the lower wages and employment levels. Income changes feed into consumption mostly for the bottom 20%. The reason is that these households do not have a buffer stock of wealth that can help them coping with the income decline and must reduce their expenditures. On the other hand, the income and consumption of the top 10% of the income distribution remains almost unchanged. Some of these households experience income gains driven by higher real interest rates and financial flows. The income and consumption dynamics at the household level are similar to those observed at the aggregate level across all income groups. After an initial peak on impact the income and consumption losses are all back to zero after two or three years.

Table 3: The effects on inequality

	Consumption	Income	Wealth
Δ Gini coefficient	0.5	0.6	0.2

Table 3 shows the predictions of the model on the dynamics of inequality. In particular, this table shows the maximum percentage point increase in the Gini coefficient of consumption, income, and wealth. The energy shortage leads to a large increase in income inequality driven by the earning losses at the bottom of the distribution. This also generates a substantial increase in consumption inequality, although to a lesser extent. Also wealth inequality increases, as more households hit the borrowing limit.

[2] It is important to keep in mind that the starting levels of consumption and income for these households are very low, so large percentage changes still corresponds to small absolute amounts.

4.2 Transmission mechanisms

In this section, I quantify the relative importance of different income channels for aggregate consumption dynamics. In the model there is one direct effect via energy prices and three indirect effects that operate through interest rates and financial income $r_t a_t$, profits d_t, and labor market conditions, i.e. real wages w_t and hours worked N_t.

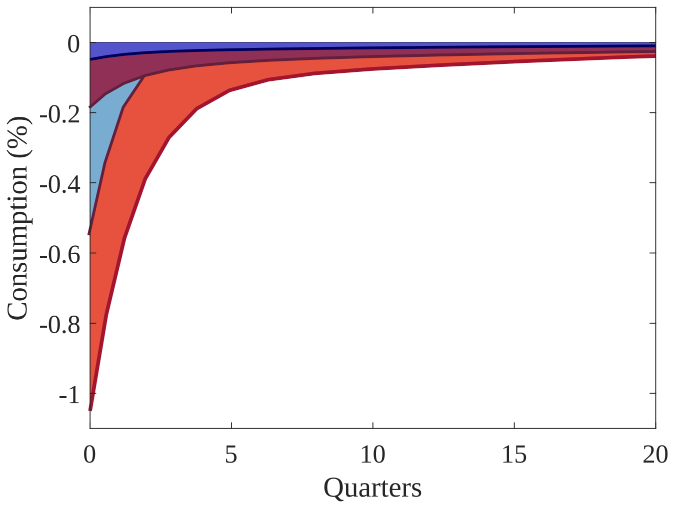

Figure 6: Consumption decomposition.

Note: Labor market conditions (red area), interest rate (light blue), energy prices (purple), and profits (blue). Percentage deviations from steady state shown.

Figure 6 shows the decomposition of the aggregate consumption response.[3] Notably, labor market adjustments are the most important determinant of the aggregate consumption loss. On impact, energy prices explain 12% of the aggregate consumption loss. Among the general equilibrium channels wages and hours account for around 50% of the consumption loss, interest rates for about 33%, profits for only 4%. The increase in the energy price particularly affects low-income families given their higher energy expenditure share. The increase in the energy bill forces these households to reduce energy consumption and other household expenditures. The substitution of energy consumption dampens this negative income effect. As explained in Section 4.1, the importance of labor market outcomes crucially depends on the income composition, amount of wealth, and consumption behavior of the bottom 20% of the income distribution. The high labor income share at the bottom of the distribution implies that these households are highly exposed to variations in wages and employment. The sizable MPCs of low-income households amplify the impact of the income loss on consumption. Real wages explain around one third of the consumption loss due to labor market adjustments, hours worked account for the remaining two thirds. Wealthy households are less exposed to the shock and have a lower precautionary saving motive. This explains the limited role of financial income and profits.

[3]The Appendix A.4 contains further details on this decomposition.

4.3 The role of the elasticity of substitution

In this section, I explore the role of the energy elasticity of substitution in production. The main objective of these computations is to provide a broad range of estimates for the output loss depending on the parametrization of the energy elasticity. In order to explore the more pessimistic scenarios I use a version of the model without sticky wages. The quantitative results of the baseline model show that general equilibrium effects via labor income are the key drivers of the consumption dynamics and sticky wages dampen this channel. Moreover, I also remove energy consumption by households. This allows me to keep the model as simple and transparent as possible. At the same time, since the direct effect of energy prices represents a small fraction of the aggregate consumption loss this simplification does not produce a substantial impact on the range of estimates that one can obtain from the model. Therefore, in this section of the paper I focus on the role of energy as a production input.

I calibrate the basic model as the baseline model with sticky wages and energy consumption by households. Across the simulations of this section the calibrated parameters are similar to those presented in Table 2. Also, the targeted statistics from the basic model are almost unchanged with respect to the baseline model. In the basic model the fraction of liquidity constrained households is 17% and the average MPC is 9% quarterly and 36% annually. In the baseline case I set $\sigma = 0.1$, in a more pessimistic scenario $\sigma = 0.07$, and in the more optimistic case $\sigma = 0.2$. As discussed in Section 3 all these values are at the lower bound of empirical estimates. Figure 7 and Figure 8 show the impulse responses of consumption, labor supply, and prices to the energy shock across calibrations. In the baseline case household expenditure falls by 1.5% at the peak of the response. This is a consequence of lower wages and higher interest rates. In the baseline case household expenditure falls by 1.5% at the peak of the response. This estimate varies substantially with the production elasticity. In the worst case consumption falls by 2%, while an elasticity of 0.2 leads to a contraction of 0.8%. The energy price increases by a factor of 2 in the baseline case and by a factor of 2.5 in the worst-case scenario. The fall in the price of labor is approximately in range between 3% to 8%, the annualized inflation rate varies from 1% to 4%. Under the parametrization with $\sigma = 0.07$ real wages fall significantly. There are two reasons driving this result. First of all, there is a macroeconomic context in which inflation rises and labor demand declines. Specifically, a reduction in the energy supply leads to high energy prices that increase firms' production costs. In turn, firms increase their prices, reduce production, and labor demand. As a result inflation rises, and real wages decline. The central bank increases real interest rates as inflation rises. As a consequence of lower wages and higher interest rates, households reduce consumption and labor supply. These demand effects further amplify the recessions. Moreover, there is a very high degree of complementarity between labor and energy in the production function. This increases the impact of an energy shortfall on labor demand. Related to this, also the assumption that labor is the main factor of production besides energy implies that firms adjust only over the labor dimension. Finally, in this basic model wages are fully flexible.

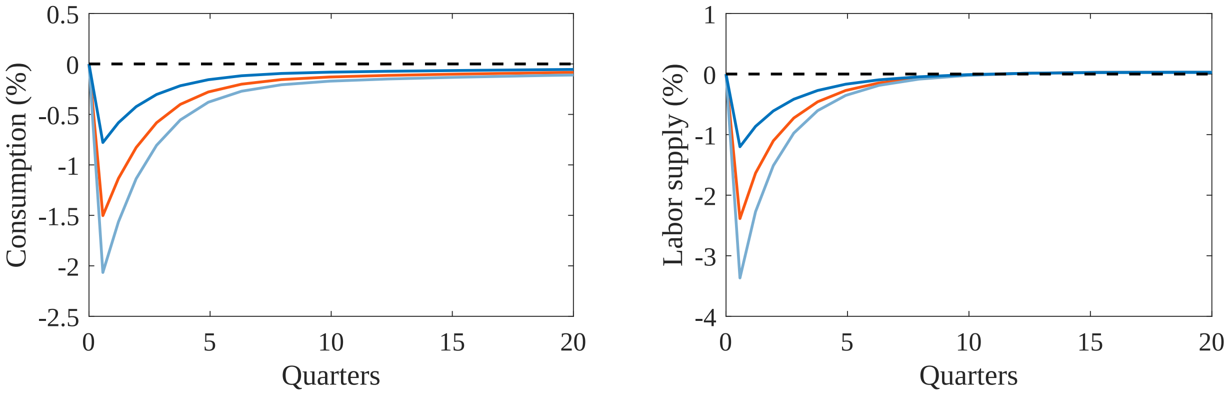

Figure 7: Impulse response of quantities to energy supply shock.

Note: The figures show percentage deviations from steady state. $\sigma = 0.1$ (orange line), $\sigma = 0.07$ (light blue line), $\sigma = 0.2$ (blue line).

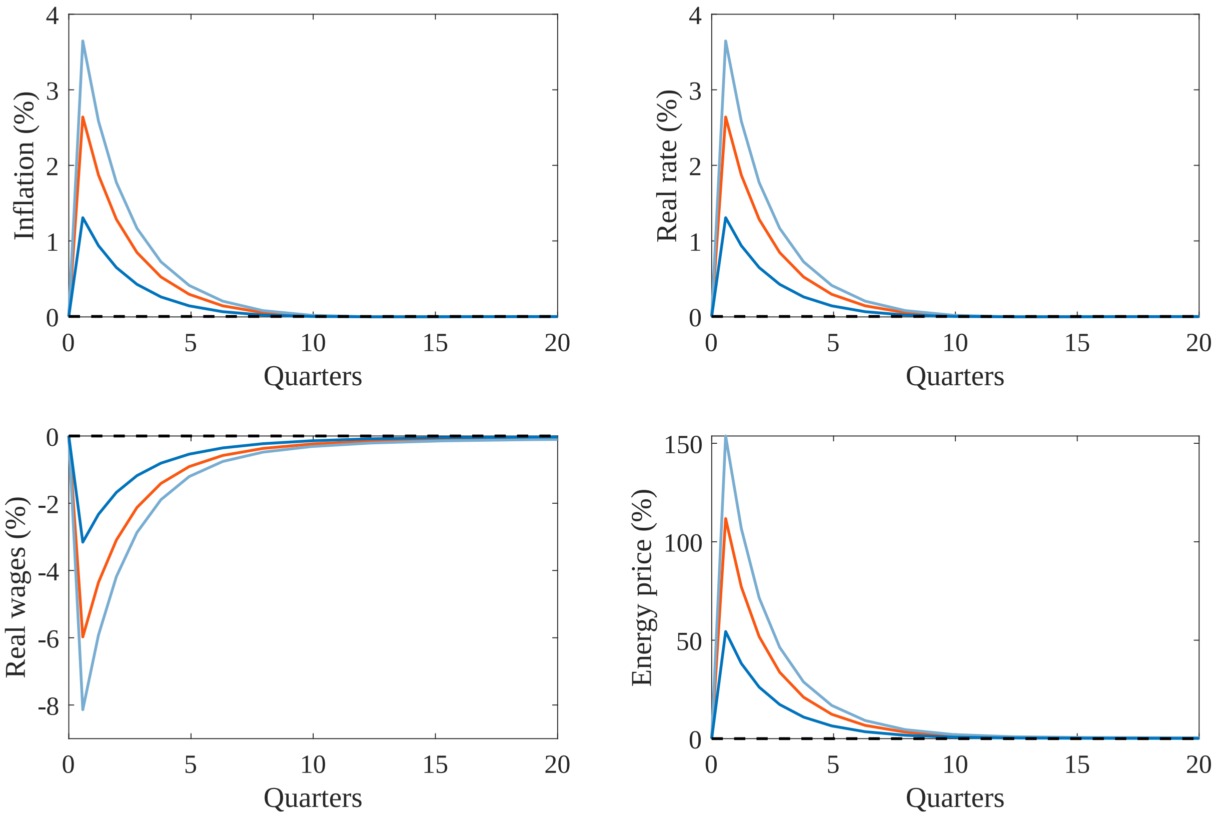

Figure 8: Impulse response of prices to energy supply shock.

Note: The figures show percentage deviations from steady state. $\sigma = 0.1$ (orange line), $\sigma = 0.07$ (light blue line), $\sigma = 0.2$ (blue line).

It is important to emphasize that in the worst-case scenario with $\sigma = 0.07$, the elasticity of substitution is half of the median estimate of the short-run energy elasticity from Labandeira, Labeaga, and Lopez-Otero (2017). However, for completeness I further investigate the predictions of the model when the aggregate elasticity of substitution is close to zero. For example, with $\sigma = 0.05$ the GNI loss is 2.7%, energy prices increase by a factor of 3, and inflation by 5%. These responses are somewhat close to those obtained with $\sigma = 0.07$. Overall, the results are robust to the choice of the worst-case scenario. The main conclusion from these simulations is that despite all the uncertainty regarding aggregate elasticities the economic costs of an energy shortage remain bounded and manageable even in worst-case scenarios.

To conclude this section I also consider an alternative scenario in which I focus only on gas and model the energy input E as that specific energy source. Following the calculations in Bachmann et al. (2022) I consider a 30$\%$ reduction in the energy supply. This would be the shortfall of energy inputs from natural gas consumption. The persistence of the shock is the same as before. For this exercise I use an elasticity of substitution $\sigma = 0.16$ at the lower bound of empirical estimates (Steinbuks (2012)). The distribution parameters $\alpha = 0.024$. I calibrate this parameter so that the CES production function generates a GNI reduction of 2.3$\%$ as in Bachmann et al. (2022). Figure 9 shows the impulse response functions. Agrgegate consumption falls by 3.4$\%$. This more than doubles the economic loss measured by national expenditure of the baseline case with $\sigma = 0.1$. The energy price increases by a factor of about 5, inflation rises by more than 6$\%$. I should emphasize that since gas is not the only energy input this is not a likely outcome. Rather than providing a realistic prediction on the effects of energy shortages the main purpose of this computational exercise is to quantify the amplification effect in an extreme scenario.

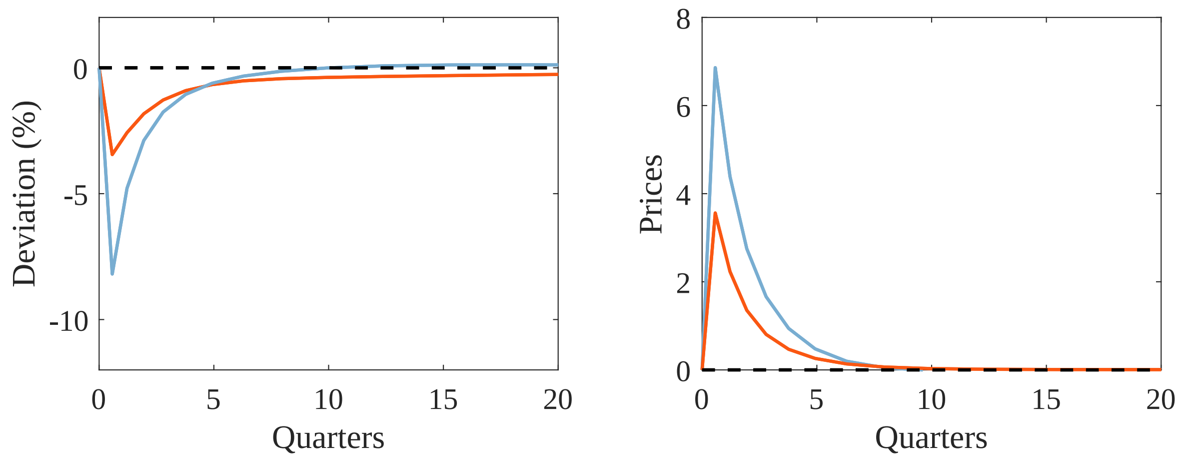

Figure 9: Impulse responses to a -30% energy shock.

Note: The figures show the response of consumption (orange line left panel), labor supply (light blue line left panel), and annualized inflation (light blue line right panel) in percentage deviations from steady state. Increase of the real energy price over its steady state value (orange line right panel) in decimals. $\sigma = 0.16$.

5 Policy analysis

In this section I analyze how monetary policy and fiscal policy can mitigate the economic cost of energy shortages. To this end I study the response of the economy to two distinct policies: interest rate policy and social insurance mechanisms. In practice is very likely that a combination of these policies would be needed. However, these policies shape the economic loss from an energy shortfall in very different ways. The main objective of these experiments is to isolate and quantitatively assess these different effects.

5.1 Monetary policy and Taylor rules

The response of the economy to macroeconomic shocks depends on the stance of monetary policy. The energy shock generates a trade-off between prices and economic activity. Therefore, the relative importance that the central bank attach to inflation and economic activity is important to assess the macroeconomic outcomes of energy shortages. Parallel to that, the stance of monetary policy might change with the state of the economy. The model that I consider embeds a feedback rule in which the policy instrument is a fixed function of endogenous variables. Therefore, a first concern is to what extent the results depend on a given parametrization of the Taylor rule. In this section I quantitatively explore the impact on aggregate dynamics of several monetary policy rules that attach different weights to inflation and output.

To analyze the role of the monetary policy stance during an energy supply shortfall, I first compare the results of the baseline model and those of two alternative policies. Note that the baseline formulation is a special case of the more general feedback rule

$$i_t = r + \phi_\pi \pi_t + \phi_y y_t + \epsilon_t,$$

where $\phi_\pi > 1, \phi_y > 0$ and $y_t := Y_t - Y$ is the output gap since in this economy steady state output coincides with flexible price output. In the baseline case studied in Section 4.1 we have $\phi_\pi = 1.25$ and $\phi_y = 0$. I start with two alternative policies. Specifically, I consider a first case in which $\phi_\pi = 1.5, \phi_y = 0$ and a second case in which $\phi_\pi = 1.25, \phi_y = 0.125$. The first monetary policy rule captures a more conservative approach on inflation relative to the baseline, the second policy captures a more accomodative monetary policy stance relative to the baseline where the central bank also respond to changes in the economic activity.

Figure 10 shows the response of aggregate consumption, employment, real interest rates, and inflation to the energy supply shock across Taylor rules. Under the more accomodative policy the real interest rate rises by 1.1% instead of 1.8% in the baseline, consumption falls by 0.7% instead of 1%, and in one year inflation increases by 3.8% instead of 3.2%. Under the more strict rule the real rate rises by 2.8%, consumption falls by 1.5%, and inflation is 2.5%. As expected, under more accommodative monetary policy rule the severity of the recession caused by the energy supply shock is mitigated relative to the baseline, but prices increase more.

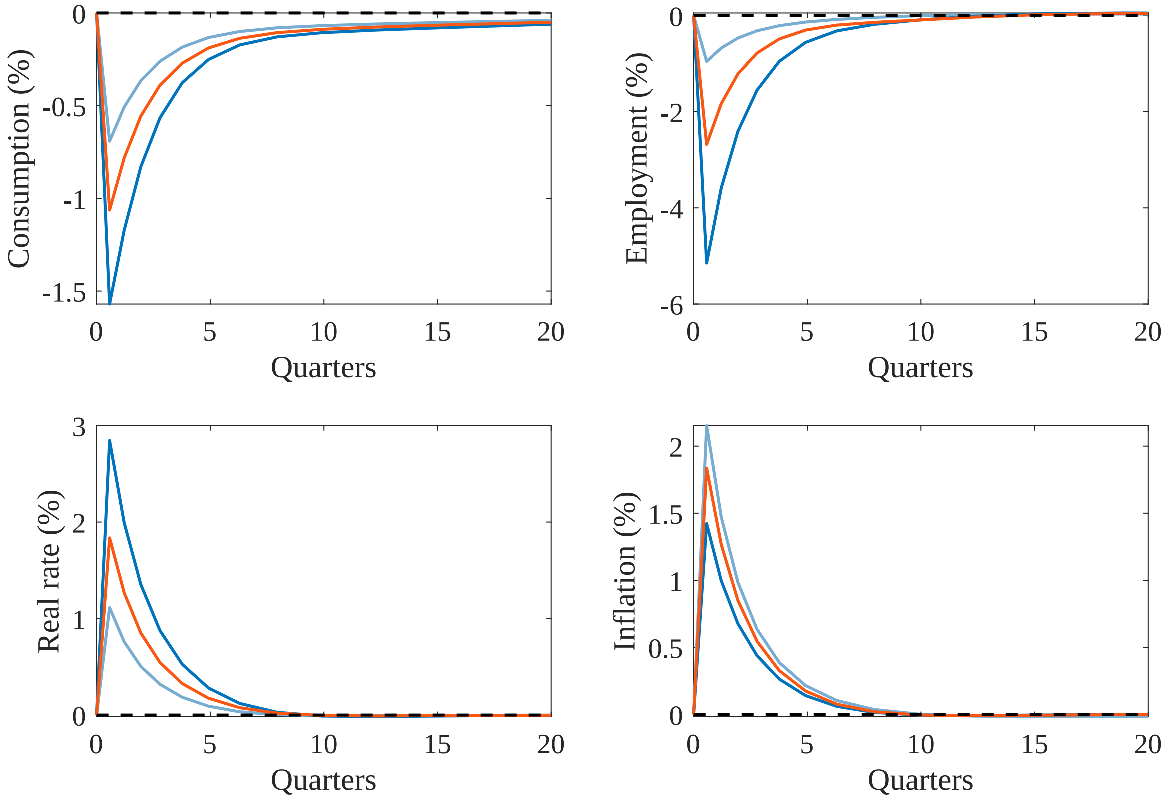

Figure 10: Monetary policy and energy shortages.

Note: The figures show percentage deviations from steady state with $\sigma = 0.1$ across different policy rules. $\phi_\pi = 1.5, \phi_y = 0$ (blue) and $\phi_\pi = 1.25, \phi_y = 0$ (orange) and $\phi_\pi = 1.25, \phi_y = 0.125$ (light blue).

Finally, for completeness I consider a combination of the two alternative cases with $\phi_\pi = 1.5, \phi_y = 0.5$. Note that in this case the increase in the output coefficient is two times the increase in the inflation coefficient leading to a more accomodative policy relative to the baseline. Consumption decreases by 0.6% and inflation is 3.9% after one year. Together these experiments show that increasing the response of output by 0.5 percentage points reduces the response of inflation by approximately 0.7 percentage points. However, a more precise quantification of this trade-off would require to carefully estimate and model the impact of the energy supply shortfall on potential output.

Overall, these computations show that a more accomodative monetary policy stance can mitigate the business cycle amplification channels that operate through labor market adjustments. This substantially reduce the severity of the recession after an energy supply stop. Importantly, reducing the output loss by 40% leads to a one-fifth increase in the inflation rate. Therefore, in the model the cost in terms of higher inflation is moderate with respect to the output gains. However, this policy becomes problematic when the inflation rate in the economy is already high. As a more accomodative policy stance on inflation can result in a de-anchoring of inflation expectations. In the next section I study how fiscal policy can mitigate the negative consequences of the energy suppply shortfall.

5.2 Social insurance

Fiscal transfers and the expansion of social insurance programs can be used to contain amplification effects stemming from more indirect channels such as labor market adjustments and aggregate demand fluctuations. In Section 4.2 I show that exaclty these type of indirect effects are the prominent determinants of the aggregate consumption loss and the highly unequal burden of the energy shortfall. In this section, I analyze the predictions of the model regarding the macroeconomic outcomes of these policies.

I model an expansion of social insurance programs as a fiscal transfer targeted to low-income households to mitigate the drop in total income and consumption of the recipients. In particular, the ammount of the transfer is b_t if $z_t \leq \bar{z}$ and $a_t \leq \bar{a}$, and zero otherwise. The dynamics of the transfers are given by $b_t = e^{-\eta t} b_0$ where b_0 is the value of the transfer on impact ($t = 0$) at its maximum peak. I set $\eta = 0.5$ so that almost all the payments are made during the first year. Then, I calibrate $\bar{a}$ and $\bar{z}$ so that only households at the bottom 20% of the income distribution receive the social insurance benefit b_t. This is consistent with a policy design that targets low-income househlds that are relatively more exposed and vulnerable to the recession. Specifically, Figure 5 shows that with this parametrization the policy exactly includes those households that would face the largest income and consumption loss after an energy supply shock. Finally, I calibrate the value of b_t at its peak. I choose a value of b_0 around 5% of the average income. Note that despite being a small fraction of the average income this is a relatively generous program since this amount corresponds to 50% of the average income at the bottom 10% of the distribution and 25% of the average income of the next decile.

The cumulative cost of the policy is around 0.7% percent of annualized steady state income. Therefore, the policy requires a substantial fiscal adjustment. In practice European governments would have to adjust their budgets to finance this policy either through taxes and transfers or via government debt. To keep the model as simple as possible, I do not model all the possible fiscal adjustments. In particular, I focus on the aggregate effects of the policy rather than on the question of how these effects can change with the choice of the fiscal instrument used to finance them. However, as a robustness check I also introduce in my computational experiment lump-sum taxes T_t to finance the policy. These taxes are distributed across all households proportionally to $z_t / \int_X z_t d\psi_t$ so that high-income households bear most of the fiscal adjustment. The government budget constraint is

$$T_t = \int_X b_t(x_t) f_t(x_t; \{T_t\}) dx_t.$$

I impose a balanced budget with total tax revenues T_t equal to the total cost of the social insurance policy. Since now the joint density of idiosyncratic states $f_t(x_t; \{T_t\})$ depends also on the tax revenue through household saving decisions, this is the additional equilibrium condition that I need to pin down equilibrium taxes $\{T_t\}$ given the policy $\{b_t\}$. I find quantitatively similar responses of consumption and inflation as in my main analysis without taxes.

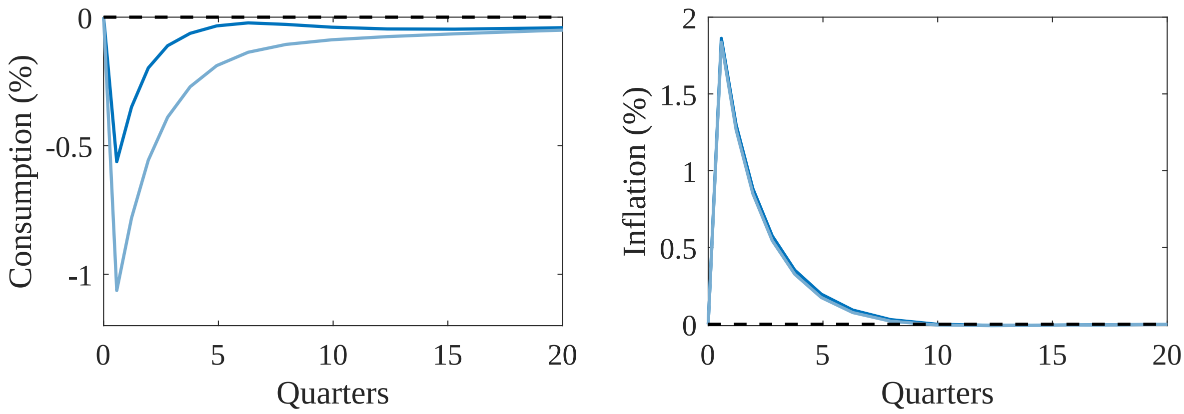

Figure 11: Fiscal policy and energy shortages.

Note: The figures show percentage deviations of consumption and inflation from steady state in the baseline case without policy (light blue line) and with fiscal policy (blue line).

Figure 11 shows the response of consumption and inflation to the social insurance policy. Fiscal transfers targeted to the most vulnerable households can reduce the aggregate consumption loss by almost 0.5 percentage points or 50 percent. The figure also shows that since this policy targets a small population group it does not generate additional inflation. On the other hand, the social insurance payments disincentivize labor supply at the bottom of the distribution. The reduction in the aggregate labor supply is about 0.7 percentage points higher than in the baseline. This policy can undo all the demand amplification effect leading to an output loss of 0.55 percent in the HANK model, an income loss even below the output contraction of 0.6 percent given by the simple aggregate production function as parametrized in the quantitative model. This policy also has a large effect on consumption inequality. The Gini coefficient of consumption decreases by 0.2 percentage points with the policy reducing the unequal burden of the energy shortfall. Finally, it is important to highlight that this policy does not change the dynamics of relative prices. The path of the real energy price is the same as in the baseline case without fiscal policy. As a result, with this policy households still reduce energy consumption from fossil fuels as they would in the baseline case. This is a key difference relative to other policies such as price controls or energy subsidies for residential and industrial energy consumption that reduce the incentives to substitute fossil fuels. Adding equilibrium taxes to the analysis leads to a consumption loss of 0.6% a value close to the one that I obtain without taxes.

To summarize, the computational experiments suggest that targeted fiscal transfers can substantially reduce the size of the recession and the aggregate consumption loss. Since this policy targets a small population group it does not generate high inflation. Importantly, this policy reduces the unequal burden of the energy supply shock without lowering the incentives of firms and households to substitute energy consumption from coal, oil, and gas. Overall, I find that an expansion of social insurance programs targeted to the most exposed and vulnerable households can address the business cycle amplification effects and mitigate the cost of energy shortages.

6 Conclusion

This paper builds an Heterogeneous Agents New-Keynesian (HANK) model with energy consumption by households and firms and studies how much a recession caused by energy shortages can be amplified through aggregate demand channels, such as an increase in the energy bill and labor market adjustments that disproportionately affect low-income households. A series of numerical simulations highlights a substantial business cycle amplification. However, even in the more conservative scenarios, in which energy inputs have an extremely low aggregate elasticity of substitution, I find manageable income losses. It is important to emphasize that the costs of an energy supply shortfall are not borne equally within the society. Households with low income face an economic loss which is an order of magnitude higher than the cost faced by all other households. The unequal effects substantially contributes to the amplification of the energy shock and to its aggregate cost. In the paper I also investigate the role of monetary and fiscal policy. Monetary policy faces a trade-off between inflation and economic activity. However, social insurance programs can significantly mitigate the aggregate income loss by reducing the unequal effects of the energy shock.

Going forward there are several questions that can be investigated in future research. Let me list four of them. First, the model provides a novel framework to analyze other topical problems related to energy consumption, e.g. the relationship between climate change, within countries inequality, and the transition to clean energy. Second, as first step in this paper I analyze monetary and fiscal policy separately. The model provides a quantitative framework to evaluate different combinations of monetary and fiscal policies, study their interaction and how these economic policies can mitigate the negative effects of energy shortages. Third, I use a standard Taylor rule. However, differences in inflation dynamics across EZ countries can shape the ECB response and the effects of the energy shock at the national level. This observation calls for a more careful analysis of systematic monetary policy in the EZ. Fourth, the model can be extended to include energy production and different energy markets. This framework will be particularly useful to analyze other policies already implemented or under discussion at the European level such as energy subsidies or a price cap on energy.

References

Achdou, Yves, Jiequn Han, Jean-Michel Lasry, Pierre-Louis Lions, and Benjamin Moll (2022). "Income and Wealth Distribution in Macroeconomics: A Continuous-Time Approach". In: *Review of Economic Studies* 89, pp. 45–86.

Alves, Felipe, Greg Kaplan, Benjamin Moll, and Gianluca Violante (2020). "A Further Look at the Propagation of Monetary Policy Shocks in HANK". In: *Journal of Money Credit and Banking* 52 (2), pp. 521–559.

Auclert, Adrien, Matthew Rognlie, Martin Souchier, and Ludwig Straub (2021). "Exchange Rates and Monetary Policy with Heterogeneous Agents: Sizing up the Real Income Channel". Working Paper.

Auclert, Adrien, Matthew Rognlie, and Ludwig Straub (2018). "The Intertemporal Keynesian Cross". Working paper.

— (2020). "Micro Jumps, Macro Humps: Monetary Policy and Business Cycles in an Estimated HANK Model". Working Paper.

Auffhammer, Maximilian and Edward Rubin (2018). "Natural gas price elasticities and optimal cost recovery under consumer heterogeneity: Evidence from 300 million natural gas bills". Technical Report, National Bureau of Economic Research.

Bachmann, Rudiger, David Baqaee, Christian Bayer, Moritz Kuhn, Andreas Löschel, Benjamin Moll, Andreas Peichl, Karen Pittel, and Moritz Schularick (2022). "What if? The economic effects for Germany of a stop of energy imports from Russia". Working Paper.

Baqaee, David and Emmanuel Farhi (2021). "Networks, Barriers, and Trade". Working Paper.

Blundell, Richard, Luigi Pistaferri, and Itay Saporta-Eksten (2016). "Consumption Inequality and Family Labor Supply". In: *American Economic Review* 106 (2), pp. 387–435.

Carroll, Christopher, Jiri Slacalek, and Kiichi Tokuoka (2014). "The Distribution of Wealth and the MPC: Implications of New European Data". In: *American Economic Review* 104 (5), pp. 107–11.

— (2017). "The Distribution of Wealth and the Marginal Propensity to Consume". In: *Quantitative Economics* 8 (3), pp. 977–1020.

Chetty, Raj, Adam Guren, Day Manoli, and Andrea Weber (2011). "Are Micro and Macro Labor Supply Elasticities Consistent? A Review of Evidence on the Intensive and Extensive Margins". In: *American Economic Review* 101 (3), pp. 471–475.

Gornemann, Nils, Keith Kuester, and Makoto Nakajima (2021). "Doves for the Rich, Hawks for the Poor? Distributional Consequences of Systematic Monetary Policy". Working Paper.

Hagedorn, Marcus, Iourii Manovskii, and Kurt Mitman (2019). "The Fiscal Multiplier". Working Paper.

Kaplan, Greg, Benjamin Moll, and Gianluca Violante (2018). "Monetary Policy According to HANK". In: *American Economic Review* 108 (5), pp. 697–743.

Kaplan, Greg and Gianluca Violante (2021). "The Marginal Propensity to Consume in Heterogeneous Agent Models". Working Paper.

Labandeira, Xavier, Jose Labeaga, and Xiral Lopez-Otero (2017). "A meta-analysis on the price elasticity of energy demand". In: *Energy Policy* 102, pp. 549–568.

Laibson, David, Peter Maxted, and Benjamin Moll (2021). "Present Bias Amplifies the Household Balance-Sheet Channels of Macroeconomic Policy". Working Paper.

Luetticke, Ralph (2021). "Transmission of Monetary Policy with Heterogeneity in Household Portfolios". In: *American Economic Journal: Macroeconomics* 13 (2), pp. 1–25.

Slacaleky, Jiri, Oreste Tristani, and Gianluca Violante (2020). "Household Balance Sheet Channels of Monetary Policy: A Back of the Envelope Calculation for the Euro Area". In: *Journal of Economic Dynamics and Control* 115.

Steinbuks, Jevgenijs (2012). "Interfuel substitution and energy use in the UK manufacturing sector". In: *The Energy Journal* 33 (1).

Wolf, Christian (2021). "Interest Rate Cuts vs. Stimulus Payments: An Equivalence Result". Working Paper.

Appendix

A Further details on the model

A.1 Deriving the wage NKPC

In this section I derive the wage Phillips curve of the model. The Hamiltonian associated to the wage setting problem with control $\dot{W}_{jt}$, state W_{jt}, and costate μ_t taking W_t, N_t, r_t as given is

$$H_t(\dot{W}_{jt}, W_{jt}, \mu_t) = \exp\left(-\int_0^t r_s ds\right)\left(\int_0^1 \frac{W_{jt}}{P_t}N_{jt} - \frac{\upsilon(N_{jt})}{u'(C_t)} - \frac{\Psi_w}{2}\left(\frac{\dot{W}_{jt}}{W_{jt}}\right)^2 N_t dj + \mu_t \dot{W}_{jt}\right).$$

The first order conditions are

$$H_{\dot{W}_{jt}} = -\Psi_w\left(\frac{\dot{W}_{jt}}{W_{jt}}\right)\frac{N_t}{W_{jt}} + \mu_t = 0,$$

$$H_{W_{jt}} = \left(\frac{1-\theta_w}{P_t} + \theta_w \frac{\upsilon'(N_{jt})}{u'(C_t)W_{jt}}\right)\left(\frac{W_{jt}}{W_t}\right)^{-\theta_w} N_t + \Psi_w\left(\frac{\dot{W}_{jt}}{W_{jt}}\right)^2 \frac{N_t}{W_{jt}} = r_t\mu_t - \dot{\mu}_t.$$

Imposing a symmetric equilibrium with $W_{jt} = W_t$ and $N_{jt} = N_t$, using $\dot{\mu}_t = \Psi_w(\dot{\pi}_{w,t}(N_t/W_t) + \pi_{w,t}\dot{(N_t/W_t)})$ in the second equation above, after simplifying and rearraging terms, yields the following wage Phillips curve

$$\pi_{w,t}\left(r_t - \frac{\dot{N}_t}{N_t}\right) = \dot{\pi}_{w,t} + \frac{\theta_w}{\Psi_w}\left(\frac{\upsilon'(N_t)}{u'(C_t)} - w_t\mu_w^{-1}\right),$$

where $\mu_w := \theta_w/(\theta_w - 1)$. The Phillips curve connects the real side of the economy, namely w_t, r_t to wage inflation and other nominal variables. The New Keynesian price Phillips curve is isomorphic to the wage Phillips curve and its derivation follows the exact same steps.

A.2 Non-homothetic demand

This section briefly discuss the implementation of the household problem with non-homothetic preferences following the approach of Auclert, Rognlie, Souchier, and Straub (2021). In particular, rewriting the budget constraint as $da_t = (w_t z_t n_t + r_t a_t + d_t - \hat{c}_t - p_{e,t}\underline{c})dt$, we can solve the household problem for the net-of-subsistence expenditure $\hat{c}_t$. Then, the CES demand system presented in Section 2, specifies the composition of household expenditure.[4] The derivation of the CES demand system is standard and extremely similar to the derivation of the energy demand by firms presented in detail below in this appendix.

[4] I find that since subsistence expenditure $p_{e,t}\underline{c}$ is a small fraction of C_t, the results are quantitatively identical if I use $\hat{C}_t$ instead of C_t to compute the marginal rate of substitution between labor and consumption.

A.3 Energy demand and marginal cost

In this section I derive the demand for the production factors, and an analytical expression for the marginal costs of the firms. In the model intermediate firms solve the following problem

$$\min_{E_{it},N_{it}} w_t N_{it} + p_{e,t} E_{it},$$

$$\text{s.t.} \quad Y_{it} = \left(\alpha^{\frac{1}{\sigma}} E_{it}^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}} N_{it}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}.$$

The first order conditions $w_t = mc_{it}(1-\alpha)^{\frac{1}{\sigma}} Y_{it}^{\frac{1}{\sigma}} N_{it}^{\frac{-1}{\sigma}}$, $p_{e,t} = mc_{it}\alpha^{\frac{1}{\sigma}} Y_{it}^{\frac{1}{\sigma}} E_{it}^{\frac{-1}{\sigma}}$ yields

$$N_{it} = (1-\alpha)\left(\frac{w_t}{mc_{it}}\right)^{-\sigma} Y_{it},$$

$$E_{it} = \alpha\left(\frac{p_{e,t}}{mc_{it}}\right)^{-\sigma} Y_{it}.$$

Substituting the demand functions in the cost function and taking the derivative with respect to Y_{it} delivers the real marginal cost of each firm, which is the same across firms and given by

$$mc_t = \left((1-\alpha) w_t^{1-\sigma} + \alpha p_{e,t}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}.$$

A.4 Decomposing the aggregate consumption response

In this section I provide further details on the derivation and implementation of the decomposition in Section 4.2, that follows the approach of Kaplan, Moll, and Violante (2018). In particular, totally differentiating aggregate consumption

$$C_t(\{p_{e,t}, r_t, w_t, d_t, N_t\}) = \int_X c_t(x_t; \{p_{e,t}, r_t, w_t, d_t, N_t\}) d\psi_t,$$

delivers a decomposition of the total consumption response given by

$$dC_t = \int_0^\infty \frac{\partial C_t}{\partial p_{e,s}} dp_{e,s} ds + \int_0^\infty \left(\frac{\partial C_t}{\partial w_s} dw_s + \frac{\partial C_t}{\partial N_s} dN_s + \frac{\partial C_t}{\partial r_s} dr_s + \frac{\partial C_t}{\partial d_s} dd_s \right) ds.$$

This expression gives the relative role of direct effect and indirect effects. The direct effect is given by the energy price in the first integral, the indirect effects are given by the changes in the labor market and financial markets in the second integral. Each term includes an interaction between a partial equilibrium response $\partial C_t / \partial x_t$ and general equilibrium changes dx_t. In practice, I compute each integral numerically by feeding the equilibrium path of $p_{e,t}, r_t, w_t, d_t, N_t$ one variable at a time while keeping all other variables fixed at the steady state.

B Additional results

B.1 Long-term energy shortages

In all the simulatons of Section 4.3 the energy shock lasts for 3 years and more than 70% of the energy shortfall is absorbed within 1 year. Here, I consider a more conservative scenario in which the energy supply shortage lasts for 5 years and less than 60% of the energy shortfall is absorbed within 1 year.[5] In this exercise I focus on the basic model with flexible wages, energy consumption only for production, an energy decline of 10%, and $\sigma = 0.1$. I choose this value for the elasticity of substitution over the other cases discussed in Section 4.3 to build-in a dose of caution and at the same time acknowledge that macro elasticities tend to be larger in the long run than the short run. Figure 12 contrasts the consumption response under this new scenario with the consumption response to the energy shock in Figure 3. Now consumption falls by 2.7% and returns to its previous level only after 3 years. This implies that the cumulative loss can be substantial. The difference on impact moslty reflects a larger decline in real wages relative to the baseline. The responses of the other variables are similar in both couterfactuals.

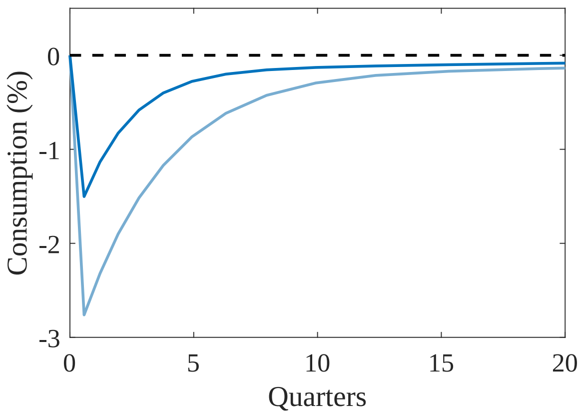

Figure 12: Energy dynamics and aggregate consumption.

Note: The figure shows the percentage deviation from steady state of aggregate consumption in the high-persistence case (light blue line) and in the baseline case (blue line).

This exercise shows that the assumptions on the dynamic path of the supply shock are important for the aggregate outcomes. In the baseline calibration the income loss can increase by a factor of 1.8 under a highly persistent energy shock. On the other hand, the responses of inflation and energy prices are close to their baseline counterparts. However, despite the uncertainty regarding dynamic aspects of the energy shortfall the economic cost remains within the lower bound of the most pessimistic scenario of Section 4.3 with a fixed elasticity of 0.05.

[5]In March of 2022 the European Commission announced a plan to cut out two-thirds of its Russian gas imports by the end of the year, and to make Europe independent from Russian fossil fuels well before 2030.

B.2 A low-wealth calibration

In this section I investigate the sensitivity of the results to the size of the average MPC. In this exercise I use the basic model as in Section 4.3. The model generates large MPCs, yet these MPCs are at the lower bound of empirical estimates, as I discuss in Section 3. The average MPC shapes the demand amplification effect that I study in this paper. Therefore, in the spirit of the "liquid-wealth-only calibration" advocated by Carroll, Slacalek, and Tokuoka (2017), I analyze a low-wealth economy with a substantially higher average MPC. To achieve this I recalibrate the discount rate and the asset size to match a real return on wealth of 1% and an average quarterly MPC of 20%. This generates an economy with a large share of low-liquidity households, around 33% of the population. However, the quarterly MPC in the low-wealth calibration is 17% which is about two times the MPC of the baseline calibration.

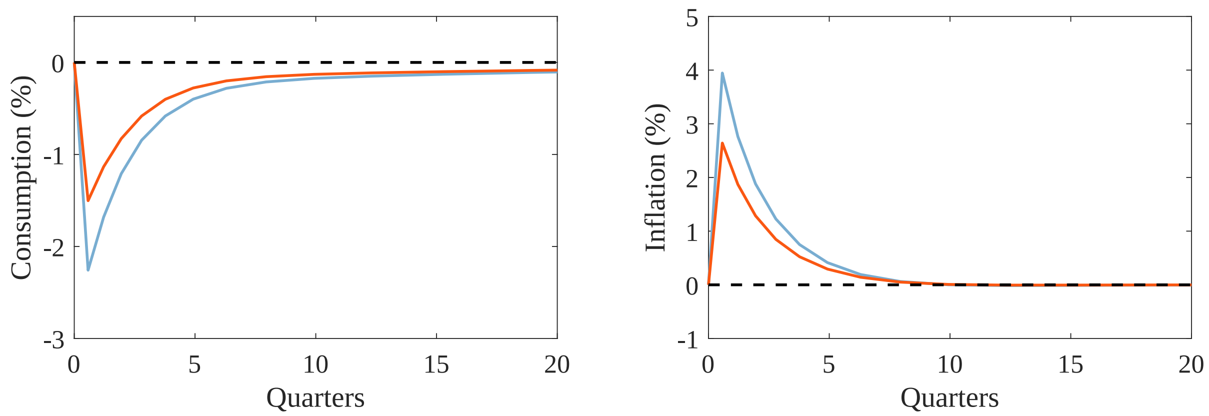

Figure 13: MPC and aggregate consumption.

Note: The figure shows the percentage deviation from steady state in the low-wealth case (light blue line) and in the baseline case (orange line). $\sigma = 0.1$.

Figure 13 shows the response of consumption and inflation to the energy shock across calibrations. At its peak the response of inflation increases from 2.6% to 4.4%. On impact, the response of the real interest rate rises from 2.6% to 4.9%, and the energy price increases by 30 percentage points across calibrations. Consumption falls by 2.2%, this implies that doubling the MPC only increases the consumption response by 0.7 percentage points or by 46 percent. This is somewhat a large change. However, it remains a small effect in comparison with the range of estimates generated by the uncertainty regarding the macro elasticity of substitution across inputs. Therefore, I leave a more complete analysis on the determinants of a large average MPC and the implications for the propagation of energy shocks to future work, instead I only emphasize here that the quantitative results in Section 4.3 are likely to be robust.

B.3 Labor supply elasticity

In this section I present the sensitivity of the results to the Frisch elasticity of labor supply $1/\nu$ in the baseline model. The value for the Frisch elasticity that I use in the baseline calibration is 1 this is in line with the estimates from Blundell, Pistaferri, and Saporta-Eksten (2016). However, since Chetty, Guren, Manoli, and Weber (2011) a value of 0.5 is more consistent with other micro estimates. Therefore, I set $\nu = 2$ without recalibrating the other parameters. Figure 14 reports the responses of consumption, labor supply, inflation and energy price. The peak of the consumption response is 1.3%, while employment falls by 3%. The differences of aggregate consumption and employment from the baseline are within 0.3 percentage points. Real wages fall by 1.7% and the annualized real interest rate increases by 2.2%. Reducing the elasticity of hours to the real wage dampens the partial equilibrium response of employment. However, given a more contained adjustment of hours in general equilibrium this causes a larger fall in real wages even in the presence of sticky wages. Then, the demand amplification channel generates a deeper recession with a larger contraction of consumption and employment.

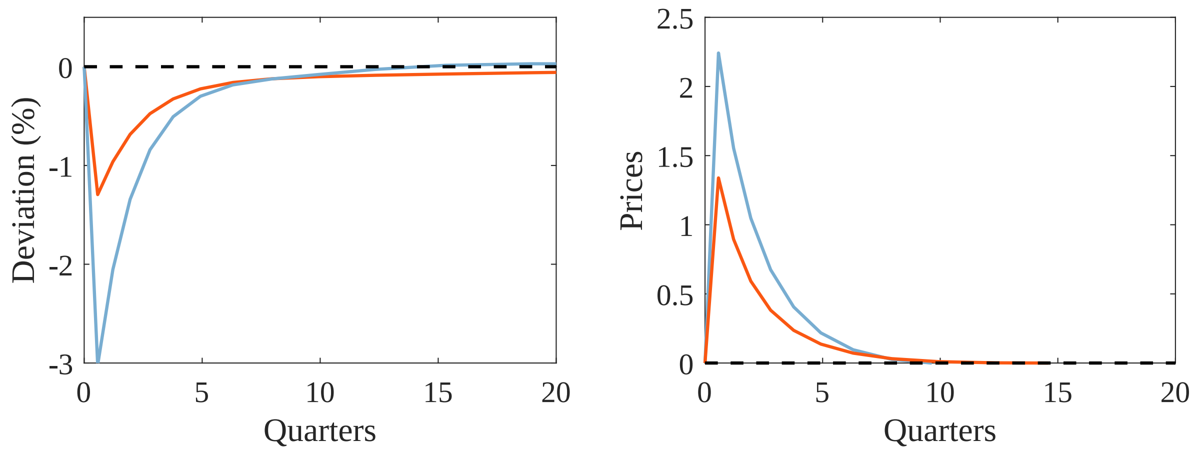

Figure 14: Frisch elasticity and aggregate dynamics.

Note: The figures show the response of consumption (orange line left panel), labor supply (light blue line left panel), and inflation (light blue line right panel) in percentage deviations from steady state. Increase of the real energy price over its steady state value (orange line right panel) in decimals.