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

Valerio Pieroni*

UAB and Barcelona School of Economics

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Preliminary and incomplete.

Abstract

In this paper I build a quantitative Heterogeneous Agents New Keynesian (HANK) model with energy as a critical production factor to study the effects of a reduction in the energy supply. I find that changes in aggregate demand 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 2.7%. The economic burden is highly nonlinear across the wealth distribution: most households face similar and contained costs, while low-wealth households bear the heaviest burden.

JEL Classification: D31, E32, Q43.

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1 Summary

Estimates based on structural trade models suggest that a 10% reduction in the energy supply 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 and leverage a quantitative HANK model in which energy is a key production input to analyze the macroeconomic effects of energy supply shortages on the German economy. The model features a business cycle amplification channel that works through labor market adjustments and changes in the level of aggregate demand.

I show that in the model energy shortages leads to a GNI decline in range between 0.8% and 2.7%. Given the uncertainty surrounding aggregate elasticities of substitution I use the model to analyze different scenarios, including several extreme and conservative cases. In all the simulations the elasticity of substitution between energy and other production inputs is at the lower bound of the empirical estimates. Table 1 reports the main quantitative results from the model for different values of the elasticity of substitution σ. In the more likely outcomes, the energy shortfall leads to a GNI decline between 0.8% and 2.7%. Throughout these simulations low-income households bear the highest cost.

Table 1: Model simulations

GNI Loss	$\sigma = 0.1$	$\sigma = 0.05$	$\sigma = 0.2$	Only gas case
HANK model	1.5%	2.7%	0.8%	3.8%
CES function	0.6%	1.2%	0.5%	2.3%

Note: The last column shows the effect of a 30% reduction in the energy supply (Bachmann et al. (2022)). In the last column I use $\sigma = 0.15$, and the reported value of the CES function is taken from Bachmann et al. (2022), the CES function as parametrized in the HANK model gives a 4% income loss.

To quantify the amplification effect from aggregate demand channels I feed the energy shock in a simple CES production function. Table 1 shows that the GNI response is substantially lower than in the HANK model. This implies that heterogeneity in the household Marginal Propensity to Consume (MPC), labor market adjustments, and price rigidities amplify the effects of the energy shock. However, the economic cost remains manageable.

Finally, 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 endogenous energy production, direct energy consumption by households, the effects in the global markets, and macroeconomic policies.

2 Introduction

Bachmann et al. (2022) show that a 10% reduction in the energy supply can lead to a GNI loss of 0.3-2.3% for Germany. These estimates vary substantially depending on the calibration of production elasticities and distribution parameters. In my analysis I take a different approach and leverage a quantitative HANK model in which energy is a key production input to analyze the macroeconomic effects of energy supply shocks on the German economy. As a first step, I focus on the role of energy consumption by firms and 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 sticky prices in the amplification of energy shocks.

This paper presents three main findings. First, aggregate demand channels generate a substantial amplification of energy shocks. Second, I provide a range of estimates for the GNI loss. In line with previous studies I find that the GNI loss can be large but manageable. Third, I use the model to quantitatively illustrate how an energy shortfall affects household income and consumption across the wealth distribution. The economic burden falls heavily on low-wealth households while other households face similar and relatively more contained costs.

In the calibration of the model I rely on the existing literature based on European micro data. For the parametrization of the elasticity of substitution between inputs and the distribution parameter I follow Bachmann et al. (2022). Overall, the model generates a sizable average MPC and a realistic share of low-liquidity households.

In the main experiment of this paper I simulate an energy supply shock following the argument in Bachmann et al. (2022) regarding the size of the shock for the German economy. The result is a 10% shortfall in the energy consumption in Germany. Given this shock I solve the fully-nonlinear model and compute the impulse response functions of the main equilibrium variables under different parametrizations of the energy elasticity of substitution.[1] The choice of these values is guided by the literature review from Bachmann et al. (2022) on the empirical estimates of energy demand elasticity. The resulting income loss for each case is reported in Table 1. 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 (See Table 1). Finally, I study the cross-sectional predictions of the HANK model to quantify the distributional effects of an energy shortage. I find highly nonlinear effects across the wealth distribution with consumption losses concentrated at the bottom of the distribution. The reason is that these households also experience the largest drop in income, and relative to other households they do not have enough wealth to smooth the income shock. 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.

[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).

In the remaining of the paper I 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 3.8%. In this case the energy shock can cause a very large recession in Germany. 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.

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 within 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)). Relative to these papers I introduce energy in the HANK framework to quantify the amplification effect of energy shortages. I also document the unequal consumption and income effects of these type of shocks within the HANK framework.

In the second strand of the literature I closely follow the work by Bachmann et al. (2022). The authors provide a review of the empirical literature on energy demand elasticities (Auffhammer and Rubin (2018), Labandeira, Labeaga, and Lopez-Otero (2017), Steinbuks (2012)). Bachmann et al. (2022) focus mainly on trade and on the macroeconomic implications of supply chains. In this paper I focus more 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 somewhat higher than in Bachmann et al. (2022). However, this difference does not change the main conclusions of their study.

Outline. The remaining of the paper is organized as follows. Section 3 presents the model. Section 4 describes the parametrization of the model. Section 5 contains the main quantitative results on the aggregate and distributional effects of energy shocks. I also analyze more conservatice scenarios and the sensitivity of the results to the model calibration. Section 6 concludes.

3 The model

This section presents the 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.

3.1 Households

Households solve the following program

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

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

$$a_t \geq -\phi,$$

where $\gamma > 0$ is the inverse elasticity of intertemporal substitution, $\nu > 0$ is the inverse Frisch elasticity of labor supply. The lump-sum transfers τ_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.

$$d \ln z_t = -\nu_e \ln z_t dt + \sigma_e d\hat{w}_{z,t}, \quad d\hat{w}_{z,t} \sim N(0, dt).$$

3.2 Firms

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

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

The final good producer operates in a competitive market, and profit maximization with respect to intermediate good i yields the following demand $Y_{it} = (P_{it}/P_t)^{-\theta} Y_t$. Intermediate good producers demand labor and energy to minimize production costs. 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. As emphasized in Bachmann et al. (2022) these parameters are critical to capture the supply effects of an energy shock even in richer models like the Baqaee-Farhi framework. Let m_{it} denote nominal marginal costs and $mc_{it} := m_{it}/P_t$. Intermediate producers set prices to maximize profits under price adjustment cost and solve the following problem

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

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

The optimization problem in a symmetric equilibrium, i.e. $P_{it} = P_t$, yields a New Keynesian Phillips Curve (NKPC) given by

$$\pi_t\left(r_t - \frac{\dot{Y}_t}{Y_t}\right) = \dot{\pi}_t + \frac{\theta}{\Psi}\left(mc_t - \mu^{-1}\right).$$

3.3 Equilibrium

The consumption good is chosen to be the numeraire so its price is one in real terms, the real energy price is $p_{e,t}$. I assume that energy supply $\{E_t\}$ is exogenous while the energy price is given by the demand of energy by firms. 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 $\ln z_t$. We can formulate the household problem recursively by means of two partial differential equations the Hamilton-Jacobi-Bellman (HJB) equation and the Kolmogorov Forward (KF) equation. Respectively these equations are

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

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

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

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

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

where $C_t := \int_X c_t(x_t)d\psi_t$. (iii) the NKPC and the Taylor rule $i_t = r + \phi_\pi \pi_t + \epsilon_t$ hold.

In the context of this model GNE is equivalent to Gross National Income (GNI) so the numbers in this paper can also be interpreted as GNI losses.

4 Calibration

In this section I briefly discuss the calibration of the model. The model is calibrated to the German economy 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 the share of consumption of gas, oil and coal in German Gross National Expenditure (GNE). To achieve this I calibrate most of the parameters externally using standard values in the literature. Then, I calibrate the remaining parameters E, B, ρ to match three statistics measuring household wealth, MPC, and the aggregate energy expenditure share.

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 to match a steady state profit share of income $1/\theta$ equal to 10%, and the price adjustment cost parameter Ψ to match a slope of the Phillips curve θ/Ψ of 0.1. 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 Bachmann et al. (2022). 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 $\sigma = 0.1$. In their study Bachmann et al. (2022) provide a review of the empirical evidence on price elasticities for energy demand. The CES function allows to map these estimates to the elasticity of substitution between inputs. 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. This lower bound is given by $\sigma = 0.16$. However, given the uncertainty surrounding the aggregate production elasticity I analyze different scenarios with the more optimistic case close to the empirical lower bound.

I jointly calibrate E, B, ρ 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%, and the annual energy expenditure share of 4%. The energy share target is taken from Bachmann et al. (2022). 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) for the German economy. Table 2 shows the calibrated parameters.

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	6.5	Wealth-income ratio
ρ	Discount rate (p.a.)	8%	Average MPC
Income process			
ν_e	Mean reversion coeff.	0.0263	External
σ_e	S. d. of innovations	0.2	External
Firms and policy			
σ	Elasticity in production	0.1	External
α	Distribution parameter	0.04	External
E	Energy supply	0.0318	Energy share of 4%
Ψ	Price adjustment cost	100	PC slope of 0.1
θ	Intermediate goods elasticity	10	Profit share of 0.1
ϕ_π	Taylor coeff.	1.25	External

Overall, the model fits the targeted statistics quite well. The average wealth-income ratio is equal to 4.6, the energy share is 4%, the average quarterly MPC is 9% and 36% annually, and the fraction of liquidity constrained households is 17%. Jointly matching the dispersion in wealth and average MPC is a well known challenge for heterogeneous agents models. The reason is that matching a high wealth-income ratio implies that a substantial fraction of households are well-insured against income risk. 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. For example Slacaleky, Tristani, and Violante (2020) using household micro data estimate a share of low-liquidity households for the German economy of 22% between 2013 and 2015. However, since the average MPC is at the lower end of the estimates provided by the literature, in the next section I also consider a low-wealth calibration that yields and average quarterly MPC of 20%.

5 Energy supply shock

5.1 Main results

In this section I present the main quantitative exercise. 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. Figure 1 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.

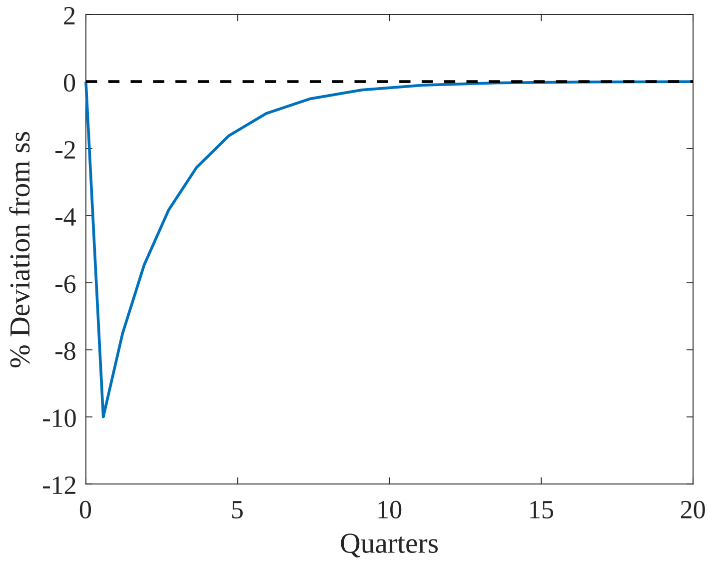

Figure 1: Energy supply shock.

In the baseline calibration I set $\sigma = 0.1$, in a more pessimistic scenario $\sigma = 0.05$, and in the more optimistic case $\sigma = 0.2$. Figure 2 and Figure 3 show the impulse responses of consumption, labor supply, and prices to the energy shock across calibrations. A reduction in the energy supply leads to lower consumption, higher real energy prices, and an increase in the inflation rate. 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. This estimate varies substantially with the production elasticity. In the worst case consumption falls by 2.7%, 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 calibration and by a factor of about 3 in the worst case scenario. The fall in the price of labor is approximately in range between 3% to 11%, the rise in the inflation rate varies from 1% to 5%.

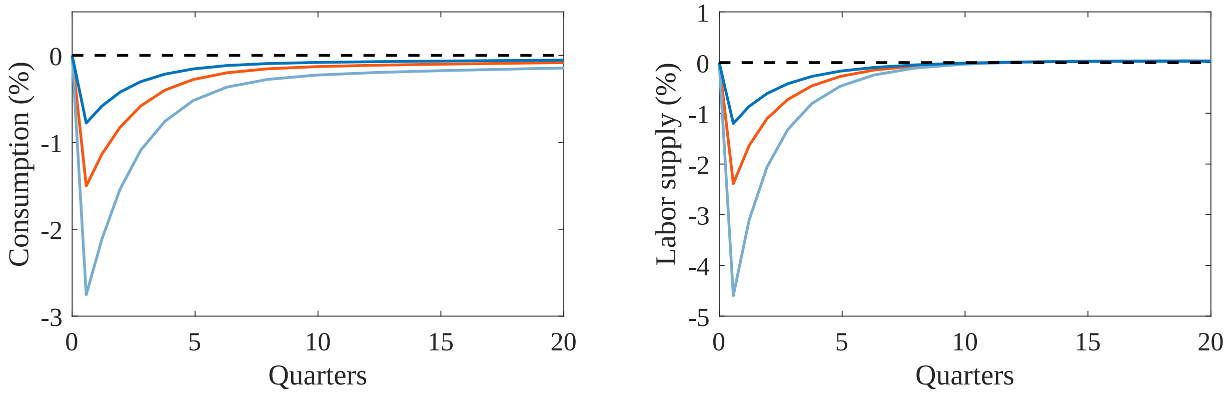

Figure 2: Impulse response of quantities to energy supply shock.

Note: The figures show percentage deviations from steady state. $\sigma = 0.1$ (orange line), $\sigma = 0.05$ (light blue line), $\sigma = 0.2$ (blue line).

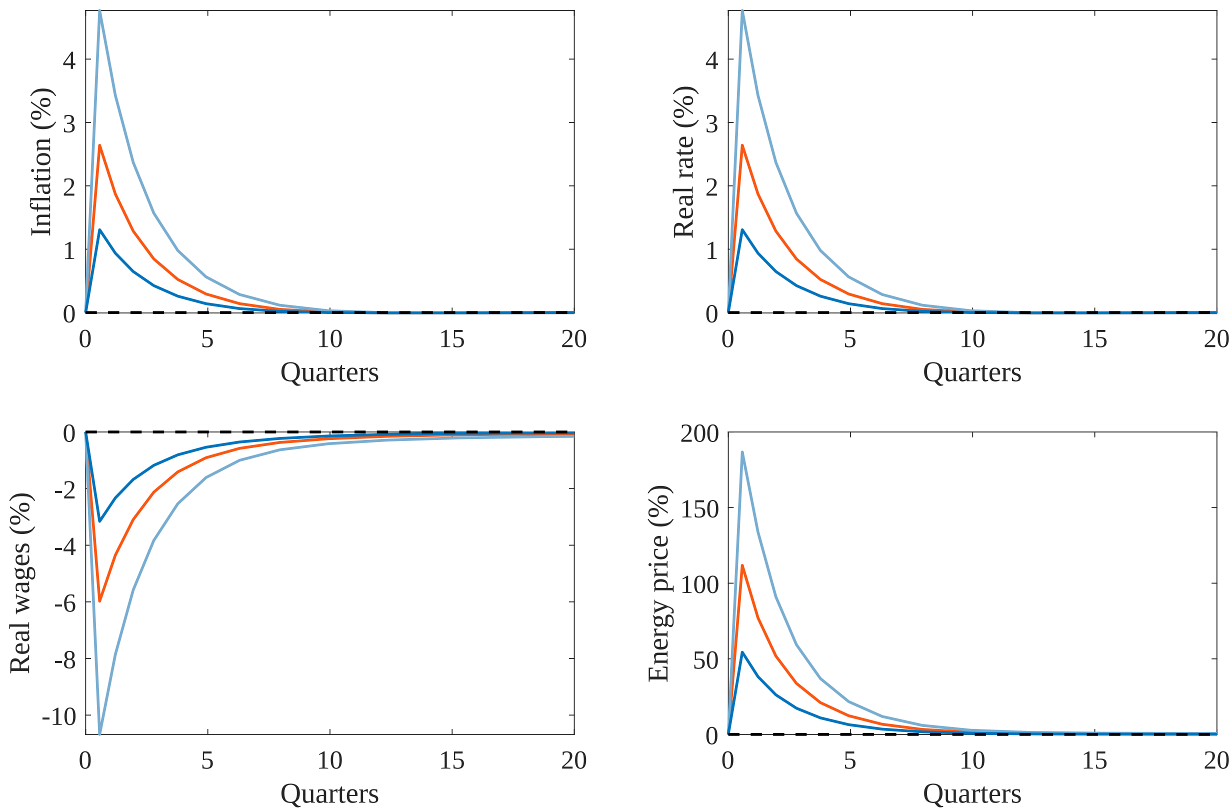

Figure 3: Impulse response of prices to energy supply shock.

Note: The figures show percentage deviations from steady state. $\sigma = 0.1$ (orange line), $\sigma = 0.05$ (light blue line), $\sigma = 0.2$ (blue line).

The costs of energy supply shortages are not borne equally across across households. Following the heterogeneous agent literature I analyze the responses of consumption and income by wealth and income. In particular, households are allocated to different groups according to the quintiles of the stationary distribution of wealth a or income risk z, 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 incomes $r_t a_t$. As for the aggregate variables I focus on the impact response at the peak of the energy supply shortage. The income and consumption losses are all back to zero after three years. Table 3 shows the cross-sectional effects of the energy supply shock in the baseline case when the elasticity of substitution $\sigma = 0.1$. Specifically, this table shows 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 wealth distribution. Low-wealth households face the largest cost. The consumption of the bottom 20% of the distribution declines by almost 7%, this is an order of magnitude higher than the 2.2-0.8% decline faced by households in the other wealth groups. Households at the bottom of the wealth distribution also experience a larger fall in their income, with a peak response of around 10%. This effect is driven by earnings and reflects the decline in labor demand and salaries following an energy shortage. Households in the bottom 40% have a comparable income exposure to the energy shock however 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.

Table 3: Distributional effects

	Wealth		Income risk	
Percentiles	Consumption	Income	Consumption	Income
0-20	6.8	9.3	4.8	4.2
20-40	2.2	9.9	2.4	4.3
40-60	1.5	7.3	1.6	4.2
60-80	1.3	4	1.4	2.8
80-100	0.8	0	1	0.7

Note: The table reports consumption and income losses for each group in percentage deviation from the steady state. Households are ranked according to the stationary wealth and income distribution.

The income of the top 20% of the wealth distribution increases by 3.9 percent. This income gain is driven by higher real interest rates and financial flows. These households respond to higher interest rates by increasing their wealth holdings and by slightly reducing consumption.

The last two columns of Table 3 reports the effects of the energy supply shock across the distribution of the idiosyncratic income component. As in the wealth case there is a stark consumption decline at the bottom 20% of the distribution. The consumption of these households falls by 4.8%, this response is twice as large as that of the next group and three times the response of the group that contains the median household. Specifically, the consumption responses of the other income groups fluctuate between 2.4% and 1%. The income loss is more equally distributed across households. Low-income groups as well as the middle part of the distribution experience an income loss of about 4%. On the other hand, top income groups face an economic burden of 0.7%.

Table 4 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, disposable 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. The shock also generates a substantial increase in consumption inequality, although to a lesser extent than income inequality. This in turn reflects the fact that at the bottom of the distribution income changes feed into consumption generating a large consumption decline. Also wealth inequality increases, this is due to the fact that while low-wealth groups are harshly affected the income of the top 20% of the wealth distribution increases. Over time this income gain contributes to wealth accumulation at the top of the distribution. The effects on wealth inequality are more persistent than the effects on income and consumption inequality.

Table 4: The effects on inequality

	Consumption	Income	Wealth
Gini coefficient	0.5	0.8	0.3

Note: The table reports the percentage point increase in inequality as measured by the Gini coefficient. The table shows the maximum increase in the Gini.

Overall, I find similar effects across the income distribution and the wealth distribution. This is not surprising since the model endogenously generates a strong correlation between household income and wealth. Therefore, the main conclusion from this exercise is that households with low income and wealth face the largest cost while the consumption decline is much less dramatic for all the other households. This stark inequality suggests that to mitigate the negative distributional and aggregate effects of the energy shortfall social insurance and fiscal policies should primarily target low-income households.

5.2 Gas as a separate energy input

Now 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 total gas consumption in Germany. The persistence of the shock is the same as before. For this exercise I use an elasticity of substitution $\sigma = 0.15$ below the lower bound of empirical estimates as explained in Section 4. The main purpose of this exercise is to study the dynamics of the economy in an extreme scenario. Figure 4 shows the impulse response functions. Agrgegate consumption falls by 3.8%. This more than doubles the economic loss measured by national expenditure of the baseline case in the previous section. The energy price increases by a factor of about 4 and inflation rises by 6.7%. Real wages fall by 18% and real interest rates rise by 6%.

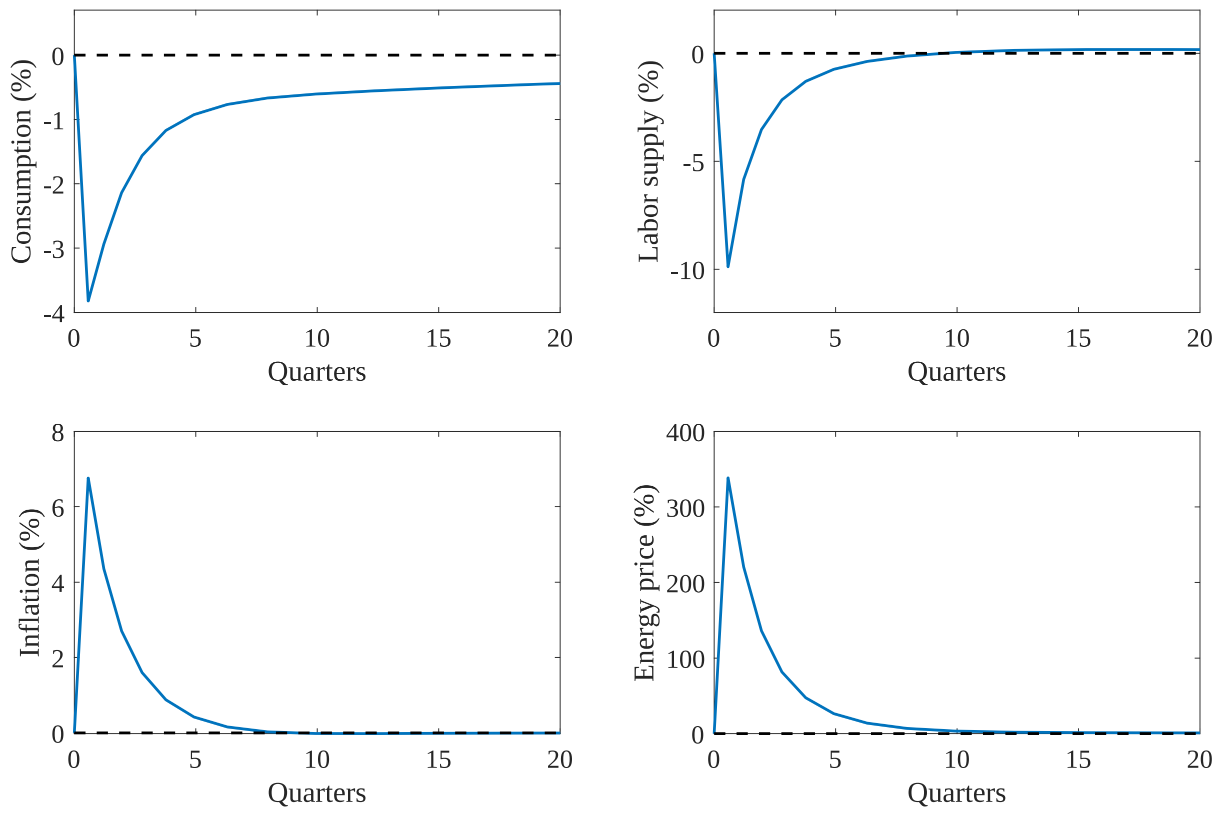

Figure 4: Impulse responses to a -30% energy shock.

Note: The figures show percentage deviations from steady state ($\sigma = 0.15$).

Another feature of the model that we can observe from Figure 4 is that the effect on household consumption from such a large shock becomes much more persistent. Therefore, the cumulative economic loss can be substantial. However, I should emphasize that since gas is not the only energy input this is not the most likely outcome.

5.3 Long-term energy shortages

In all the simulatons of Section 5.1 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 only 60% of the energy shortfall is absorbed within 1 year.[2] In this exercise I focus on the baseline calibration with 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 5.1 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 5 contrasts the consumption response under this new scenario with the consumption response to the energy shock in Figure 1. Now consumption falls by 2.7% and returns to its previous level only after 3 years. 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.

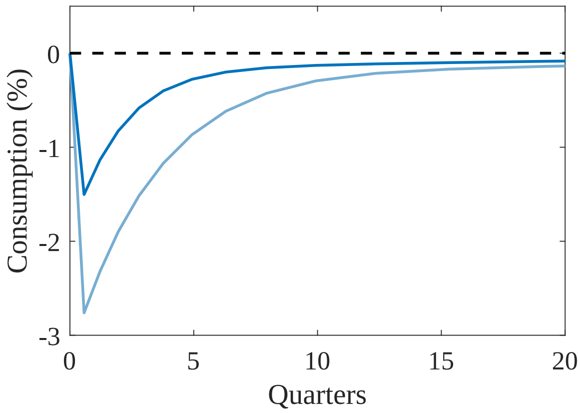

Figure 5: Energy dynamics and aggregate consumption.

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, it is important to highlight that 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 5.1 with a fixed elasticity of substitution of 0.05 throughout the entire transition path.

[2] 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.

5.4 A low-wealth calibration

In this section I investigate the sensitivity of the results to the size of the average MPC. The model generates large MPCs for households with low income and wealth, but the MPCs decrease rapidly in wealth leading to an average MPC at the lower bound of empirical estimates, as I discuss in Section 4. 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 33% share of low-liquidity households, which is too large for the German economy. However, the quarterly MPC in the low-wealth calibration is 17% which is about two times larger than the MPC of the baseline calibration.

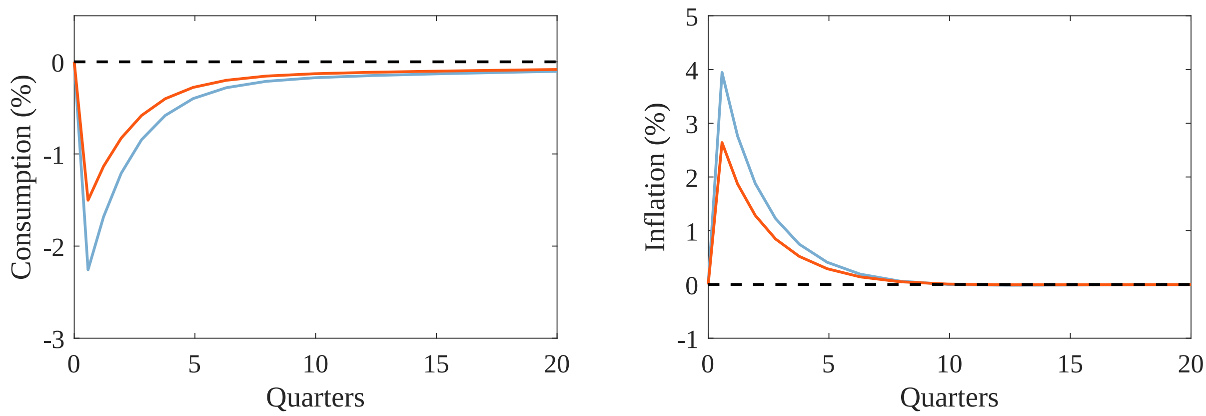

Figure 6: MPC and aggregate consumption.

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 6 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 5.1 are likely to be robust.

6 Conclusion

This paper builds an Heterogeneous Agents New-Keynesian (HANK) model with energy as a critical production factor and studies how much a recession caused by energy shortages can be amplified through aggregate demand channels. A series of numerical simulations highlight a substantial business cycle amplification. However, even in the most conservative scenarios in which energy inputs have an extremely low aggregate elasticity of substitution I find manageable income losses. It is important to highlight that the costs of an energy supply shortfall are not borne equally within the society. Households with low income and wealth face an economic loss which is an order of magnitude higher than the cost faced by all other households.

Going forward there are several questions that can be investigated in future research. First, the analysis should include direct energy consumption by households. This is important to analyze to what extent energy shortages fall on households and firms. Second, the model provides a quantitative framework to evaluate different combinations of monetary and fiscal policies, and study how these economic policies can mitigate the negative effects of energy shortages. Third, differences in the composition of household expenditures further amplify the heterogeneous effects of energy shocks. So, this is also an important factor to quantitatively model.

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