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# Essays on Inequality in Macroeconomics

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# Contents

# Preface

This Thesis is the result of the research conducted during my Ph.D. studies at the Department of Economics of Universitat Autònoma de Barcelona. It consists of three Chapters related to different topics in the field of Macroeconomics.

Chapter 1 studies how wealth concentration shapes the transmission channels and aggregate effects of monetary policy. To this end, I combine micro data on the joint distribution of consumption, income, and wealth in the US with a quantitative Heterogeneous Agents New Keynesian (HANK) model. I find that low-wealth households and wealthy households at the tails of the wealth distribution account for most of the aggregate consumption response to monetary policy shocks. A decomposition of the transmission channels shows that labor market outcomes and capital gains due to changes in stock prices account for the large responses at the tails. More broadly, this result suggests that in a large class of HANK models endogenous changes in the wealth distribution substantially shape aggregate dynamics.

In Chapter 2 I study the propagation and macroeconomic consequences of large energy shocks. In particular, I focus on the effects of a sudden stop in energy imports and evaluate to what extent aggregate demand fluctuations amplify the impact of the energy shock on the economy. To this end, I build a quantitative HANK model with energy consumption by households and firms. I find a substantial amplification due to labor market adjustments as the economic cost is concentrated on low-income households with a high pass-through of income losses to consumption. This amplification channel substantially varies with the elasticity of substitution of energy inputs. Finally, I show that targeted and non-distortionary fiscal policies can provide social insurance and mitigate the output loss without leading to additional inflation.

In Chapter 3 I analyze empirically the heterogeneous effects of monetary policy and the transmission channels. First, I construct a novel time series of monetary policy shocks for the European Central Bank (ECB) identified using the high-frequency approach. Then, I validate these shocks using a proxy Structural VAR to estimate the macroeconomic effects of monetary policy shocks in Italy. Finally, I combine the series of monetary policy shocks with the Survey of Household Income and Wealth (SHIW) from the Bank of Italy to estimate the cross-sectional effects of monetary policy on consumption and income by household net worth.

# Chapter 1

# Wealth Distribution and Monetary Policy

Valerio Pieroni[1]

How does wealth inequality shape the transmission of monetary policy to household consumption? I quantitatively assess the contribution of different wealth groups to the response of aggregate consumption, using the joint distribution of consumption, income, and wealth in the US and a quantitative Heterogeneous Agents New Keynesian (HANK) model. I find that households at the tails of the wealth distribution account for most of the dynamics in aggregate consumption. Wealthy households in the top 10% have an important impact on aggregate consumption. The reason is that relative to other wealth groups, households at the top of the distribution benefit the most from higher equity prices and have sizable consumption shares. The findings in this paper provide new quantitative insights about the role of the wealth distribution for the aggregate effects of macroeconomic shocks.

*Keywords:* Heterogeneous Agents, Wealth Inequality, Consumption, New Keynesian.
*JEL:* D31, E21, E30, E43, E52.

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## 1.1 Introduction

In view of rising inequalities in advanced economies, there is a growing interest in the interactions between wealth inequality and monetary policy. Recent empirical work documents large effects of monetary policy on households at the top of the income and wealth distribution through asset price channels (Amberg, Jansson, Klein, and Rogantini Picco (2022a), Andersen, Johannesen, Jorgensen, and Peydró (2021)). This evidence suggests that wealth concentration amplifies systematic differences in households' exposure to monetary policy across wealth groups. The aim of this paper is to quantitatively study the interactions between the wealth distribution and the aggregate effects of monetary policy shocks.

I combine cross-sectional data on the joint distribution of consumption, income, and wealth in the US with a quantitative HANK model to assess the role of different wealth groups in the transmission mechanism of monetary policy to household consumption. I focus on the effects of monetary policy across the distribution of financial wealth, following the recent literature on heterogeneous agents models that highlights the importance of liquid asset holdings. Using microdata from the Consumption Expenditure Survey (CE) and identified monetary policy shocks, I provide new empirical evidence on the effects of monetary policy on household consumption expenditures across the distribution of liquid wealth. Then, I use the structural HANK framework to rationalize the empirical findings, analyze the transmission mechanisms of monetary policy, and study counterfactuals. My quantitative analysis also exploits cross-sectional data from the Survey of Consumer Finances (SCF) and the Panel Study of Income Dynamics (PSID) with comprehensive information on household income, consumption, and wealth. I calibrate and validate the model to be consistent with key features of the microdata as well as external evidence from other studies on household consumption behavior.

This paper presents two main findings. First, households at the tails of the wealth distribution exhibit the largest consumption responses to monetary policy. I show that in a broad class of HANK models the consumption responses across wealth groups tend to be U-shaped. I show that this prediction is consistent with empirical evidence from the US. Second, I find that in the model the consumption response of top wealth groups depends on the dynamics of the wealth distribution. These dynamics arise endogenously in the model through changes in equity prices after a monetary policy shock. These results are important for several reasons. First, they provide new quantitative insights into how different wealth groups contribute to the aggregate effects of monetary policy. Understanding how different groups within the society respond to monetary policy and the macroeconomic implications of such heterogeneity is a key issue. Second, U-shaped consumption responses also hold for any shock with a significant impact on both the labor market and the stock market. Therefore, this work can be relevant more broadly in the context of inflationary demand and supply shocks. Third, understanding the interactions between the wealth distribution and monetary policy is important to analyze how long-run trends in wealth inequality shape the macroeconomy and the effectiveness of monetary policy.

To study the heterogeneous effects of monetary policy I use a quantitative HANK model with capital and equity prices. The model allows for household income and wealth heterogeneity due to uninsurable idiosyncratic income risk. Following the literature on income and wealth inequality I introduce extraordinary earning states to this framework. This generates exceptionally high earning levels for a few households that accumulate large fortunes increasing the wealth concentration. Households also face a potentially binding borrowing limit depending on the realizations of income shocks. This is critical to generate a fraction of constrained households and a precautionary saving motive. As a result, the consumption of low-wealth households is sensitive to temporary fluctuations in current and future income: constrained households live hand-to-mouth and unconstrained households internalize that they might face a binding borrowing limit in the future. I model investment using Tobin's q theory. This introduces equity prices and capital gains in the model. Specifically, households can trade bonds and accumulate capital through equity shares of an investment fund. Since in the model there is no aggregate risk or liquidity frictions the returns on these assets are equalized. For the remaining blocks of the model, I employ a New Keynesian framework: firms operating in monopolistic competition set prices subject to price adjustment costs, and a central bank follows a Taylor rule.

I calibrate the model with US micro data. The model reproduces the distributions of earnings and wealth in the US and is consistent with the micro evidence on households' consumption responses to stimulus policies. In particular, the average Marginal Propensity to Consume (MPC) in the model is close to the empirical estimates. This is an important result since it is well known that incomplete markets models feature a tension between MPCs and wealth accumulation, as a result jointly matching high wealth inequality and MPCs is a challenge in these models (Kaplan and Violante (2021)). The presence of top earners and a calibration that only targets financial wealth allows me to relax this trade-off.

In this paper, I study the direct and indirect effects of monetary policy. The direct effects are due to changes in real interest rates that affect household consumption-saving decisions, interest rate expenses for borrowers, and interest rate revenues for creditors. The indirect effects are due to changes in household earnings. In turn, the earning channel is due to labor market adjustments, changes in business income and profits, and changes in asset prices. The labor market adjustments consist of changes in real wages and employment levels. These effects reflect a general increase in labor demand after an expansionary monetary policy that stimulates economic activity. Since I do not model unemployment the effects on employment levels capture an intensive margin of adjustment. Finally, the asset price channel consists of an increase in equity prices that generates capital gains for stockholders. I focus on these channels as they are often emphasized in the quantitative and empirical literature (Kaplan, Moll, and Violante (2018), Slacaleky, Tristani, and Violante (2020)). Home equity is another important transmission channel extensively studied in the literature that I do not model in this paper.

I leverage the model to quantify the impact of different wealth groups on the aggregate consumption response and on the transmission mechanism of monetary policy. First, I show that households at the tails of the wealth distribution account for most of the aggregate consumption response to monetary policy. If households are ranked by financial wealth the differences in wealth among the bottom 50% are small and therefore I consider all these households in the same group. Moreover, to measure the contribution of each group to the aggregate I use the consumption responses to monetary policy weighted by the steady state consumption shares of each wealth group. I find that the consumption responses are U-shaped across the wealth distribution with peaks at the bottom 50% and top 10%. In the model, households at the top 10% explain more than 30% of the aggregate consumption response to an expansionary monetary policy shock. Therefore, wealthy households, in the top 10% of the distribution, have a disproportionately strong influence on aggregate consumption relative to the middle class from the 50th to the 90th wealth percentile and the bottom 50% of the wealth distribution. The reason for this result is that households at the top mostly benefit from higher equity prices and relative to other wealth deciles these households have the largest share of nondurable consumption.

To better understand these responses I analyze the transmission mechanism of monetary policy across wealth groups. To this end, I decompose the aggregate consumption responses between direct and indirect effects. Households in the bottom 50% of the wealth distribution have high MPCs because they are at the borrowing limit or close to the borrowing limit and have a strong precautionary saving motive. As a result, temporary labor income gains feeds into consumption. A substantial fraction of the increase in earnings is due to higher employment levels, in line with the empirical evidence. Moreover, since a large fraction of these households are net borrowers lower interest rates directly stimulate consumption at the bottom of the distribution. Households in the top 10% instead mostly benefit from higher equity prices and capital gains. In particular, since on impact the equity price increases the market value of households' wealth increases. This valuation effect results in an endogenous change in the wealth distribution on impact. Moreover, as monetary policy reduces the real interest rate, households respond by reducing savings and anticipating consumption expenditures. This is the intertemporal substitution channel often emphasized in the literature. To separate the effect of capital gains and wealth dynamics from intertemporal substitution, I feed the equilibrium path of the real interest rate in the household consumption problem while keeping all other variables constant including household wealth. I find that most of the response of households at the top 10% of the wealth distribution depends on wealth dynamics due to asset prices. Intuitively, there are two effects of higher asset prices on household consumption, there is an income effect from realized capital gains and a wealth effect from unrealized capital gains. On one hand, households that sell their assets at a higher price realize a capital gain that partly feeds into consumption as emphasized in Fagereng, Gomez, et al. (2022). On the other hand, those households who hold on to their assets become wealthier and this increases consumption through a standard wealth effect. In the model, a substantial fraction of households do not adjust asset holdings. As a result, the wealth effects account for most of the effects of equity prices.

In conclusion, while the role of low-wealth groups is well understood, to the best of my knowledge this is the first paper to study the importance of the dynamics of the wealth distribution and top wealth groups within the HANK framework. These results highlight a link between wealth concentration and the effects of monetary policy. Wealth inequality amplifies the exposure of households at the top of the distribution to monetary policy shocks through equity prices. Moreover, wealth inequality is associated with sizable consumption shares at the top of the wealth distribution, as a result the expenditure decisions of wealthy households have a large impact on aggregate consumption.

**Literature**. This paper is related and contributes to several strands of the literature. First, it contributes to the literature investigating the interactions between household heterogeneity and monetary policy. Second, this paper is related to the empirical literature on monetary policy transmission. Third, the paper adds to the literature studying the importance of household heterogeneity and idiosyncratic risk for the macroeconomy.

In the first strand of the literature, after the seminal contributions of McKay, Nakamura, and Steinsson (2016), Kaplan, Moll, and Violante (2018), several papers study how household heterogeneity shapes the aggregate effects of monetary policy and fiscal policy and their distributional outcomes with quantitative HANK models (Gornemann, Kuester, and Nakajima (2021), Hagedorn, Manovskii, and Mitman (2019), Laibson, Maxted, and Moll (2021), Wolf (2021), Lee (2021)). These studies emphasize the importance of liquidity constrained households. I contribute to this literature by providing estimates of the impact of different wealth groups on the dynamics in aggregate consumption in a broad class of HANK models. I find a critical role of low-liquidity households as in previous studies. However, I show that the response of aggregate consumption substantially depends on the consumption response of top wealth groups and provide new empirical evidence consistent with this prediction. Moreover, I also show that in the HANK framework the dynamics of the wealth distribution due to valuation effects from equity prices amplify the effects of monetary policy on aggregate consumption. This paper also adds to studies focusing on the relationship between inequality and monetary policy. Some of these papers emphasize the macroeconomic implications of high-income household investment decisions (Luetticke (2021), Bilbiie, Kanzig, and Surico (2019), Melcangi and Sterk (2020)) and redistributive effects among wealth groups (Auclert (2019)). Other papers in this strand of the literature study the role of aggregate investment, risk premium, and liquidity premium as an additional demand amplification channel (Auclert, Rognlie, and Straub (2020), Kekre and Lenel (2022), Bayer, Luetticke, Pham-Dao, and Tjaden (2019)). Relative to these papers, I highlight the importance of the consumption responses at the top and connect these responses to changes in equity prices and in the wealth distribution. This paper focuses on the positive analysis of the monetary transmission mechanisms. Nevertheless, it is also connected to a strand of the literature that focuses on optimal monetary policy in the HANK framework. Recently, McKay and Wolf (2022) study some of the normative implications of the cross-sectional effects of monetary policy. Finally, this paper is also related to studies that analyze the interactions between wealth concentration and monetary policy (Fernández-Villaverde, Marbet, Nuño, and Rachedi (2022), Lin and Peruffo (2022)), or the role of the wealth distribution for the macroeconomy (Fernández-Villaverde, Hurtado, and Nuño (2023)).

The paper also relates to the recent empirical literature investigating the heterogeneous effects of monetary policy and the monetary transmission mechanism to household consumption. Overall, the findings in this paper are broadly consistent with the main results of these studies. In particular, Bartscher, Kuhn, Schularick, and Wachtel (2021) document that in the US the stock market response to expansionary monetary policy shocks leads to large wealth gains for wealthy households. Chang and Schorfheide (2022) using CE data show that expansioanry monetary policy shocks mostly increase consumption at the right tail of the distribution. The results in this paper also complement other empirical studies that use CE microdata to analyze empirically the effects of monetary policy (Cantore, Ferroni, Mumtaz, and Theophilopoulou (2023), Cloyne, Ferreira, and Surico (2020), Evans (2020)). Using European microdata Slacaleky, Tristani, and Violante (2020) find that the labor income channels are key drivers of changes in aggregate consumption. However, households at the top 10% own a substantial fraction of their wealth in equities and gain from increases in asset prices, especially stocks. These household experience large capital gains and so consumption increases even though they have a low MPCs out of these capital gains. The authors also find a substantial role of home equity, a transmission channel that I do not include in my analysis. Using administrative data from Norway Holm, Paul, and Tischbirek (2021a) find that the labor income channel outweights the interest income channel with a delay. They also document U-shaped consumption responses to monetary policy shocks across the distribution of liquid assets. All these findings are consistent with the monetary transmission and cross-sectional responses that I document in the US data and in the HANK framework. The authors also find that on impact changes in interest income feed into consumption even at the top of the distribution. Amberg, Jansson, Klein, and Rogantini Picco (2022a) using Swedish administrative data document substantial income gains at the top after interest rate cuts due to higher asset prices. These capital gains substantially outweigh the interest income losses. Andersen, Johannesen, Jorgensen, and Peydró (2021) using administrative data for Denmark also show that monetary policy leads to large income and wealth gains at the top through profits and stock prices. These effects tend to be an order of magnitude larger than the response of earnings and interest income. Overall, any comparison between the results in this paper and this recent empirical evidence should be taken with caution since I focus on the US while most of the evidence comes from Northern Europe. However, the results in this paper are broadly consistent with the existing evidence on the heterogeneous income and consumption responses to monetary policy.

This paper heavily relies on the literature on wealth inequality (Castañeda, Díaz-Giménez, and Ríos-Rull (2003), Poschke, Kaymak, and Leung (2021), Hubmer, Krusell, and Smith (2021)). These studies analyze the long-run properties of the wealth distribution in the US using the stationary wealth distribution of heterogeneous agents models. In the US the richest 10% of the population hold over two-thirds of all household wealth, and over the last decades researchers have documented a trend toward increasing concentration of income and wealth at the top (Kuhn, Schularick, and Steins (2019)). In this paper I introduce extraordinary earning states to generate an empirically realistic level of wealth inequality.

Finally, the paper contributes to studies analyzing the role of different elements for the quantitative properties of heterogeneous agents economies (Alves, Kaplan, Moll, and Violante (2020), Krueger, Mitman, and Perri (2016), Auclert, Rognlie, and Straub (2018)). These papers show the importance of low-liquidity households, MPC heterogeneity, and different MPC concepts, for aggregate consumption. I also find that top wealth groups have a disproportionately large influence on aggregate consumption. I show that this result holds for monetary policy shocks and also for other shocks with a substantial impact on the labor market and equity prices. While the effects at the bottom are driven by income risk and borrowing limits, the amplification effects at the top are due to changes in households' wealth and equity prices. The importance of such wealth effects on consumption is well established in the literature (Caballero and Simsek (2020)). I show that a large class of HANK models can capture these amplification effects through endogenous changes in the wealth distribution. More broadly, this contributes to theoretical and quantitative work that contrasts HANK models with more tractable models (Bilbiie (2021), Werning (2015)). In this spirit, Kaplan and Violante (2018) show that models with wealth in the utility function can improve the fit of the average MPC and aggreagte wealth. Berger, Bocola, and Dovis (2023), Debortoli and Galì (2022) show that by introducing wedges in the equilibrium conditions of representative agent models it is possible to replicate the outcomes of full-blown heterogeneous agents economies. Other studies investigate the monetary policy transmission mechanism using two-agents models (Debortoli and Galì (2018)) or the representative agent framework (Rupert and Sustek (2019)).

**Outline**. The remaining of the paper is organized as follows. Section 1.2 presents the model. Section 1.3 describes the parametrization, calibration strategy, and validation of the model. Section 1.4 provides empirical evidence on the consumption responses to monetary policy shocks across the distribution of liquid assets. Section 1.5 contains the main quantitative results on the effects and the transmission mechanism of monetary policy across the wealth distribution in the HANK framework. Section 1.6 concludes.

## 1.2 Model

For the analysis, I employ a Heterogeneous Agent New Keynesian model with capital. Markets are incomplete as in Huggett (1993), Aiyagari (1994). In the model households are heterogeneous in their income and wealth and subject to a borrowing limit. As is standard in the New Keynesian literature firms operates in monopolistic competition and face price adjustment costs à la Rotemberg (1982). The model also features investment adjustment costs and a Tobin's q. The latter element introduces equity prices and capital gains as an additional channel through which monetary policy can affect households' income and wealth. Finally, to match the micro evidence on economic inequality in the US, I augment the model by incorporating idiosyncratic labor income risk with extraordinary states.

### 1.2.1 The economy

Consider an economy in continuous time $t \in \mathbb{R}_+$ without aggregate risk. Markets are incomplete, households face idiosyncratic labor income risk $e_t$, and an exogenous borrowing limit $\phi \geq 0$. Households can trade real assets $a_t$ in positive net supply. Let $M = (X, \mathcal{X})$ be a measurable space where $(a, e) \in X = A \times E \subseteq \mathbb{R}^2$, $\mathcal{X} = \mathcal{B}(A) \otimes P(E)$ is the product $\sigma$-algebra generated by the Borel $\sigma$-algebra $\mathcal{B}(A)$, and the power set $P(E)$. Moreover, $\psi_t : M \to [0, 1]$ is the probability distribution over idiosyncratic states and $f_t$ the associated density. Despite the abscence of aggregate risk macro variables can change over time due to unexpected monetary policy shocks given by an exogenous and deterministic path for the nominal interest rate's innovations.

### 1.2.2 Households

Given a utility function $u(c_t, n_t)$ separable in consumption $c_t$ and labor supply $n_t \in [0, 1]$, and given real wages $w_t$, returns to wealth $r_t$, earnings defined as the sum of labor income and profits $y_t := w_t e_t n_t + d_t$, state variables and initial conditions, households decide consumption $c_t$ solving

$$\max_{(c_t)} \; \mathbb{E}_0 \int_0^\infty e^{-\rho t} u(c_t, n_t) dt, \tag{H.1}$$

$$\text{s.t.} \;\; da_t = (y_t + r_t a_t - c_t) dt,$$

$$a_t \geq -\phi.$$

I assume that firms' profits $D_t$ are distributed across households as lump-sum payments according to the following rule $d_t = (e_t / \int_X e_t d\psi_t) D_t$. This rule satisfies aggregate consistency as household business income $d_t$ integrate to $D_t$. According to this rule high-earnings households receive a larger share of profits as in the data.

Following the literature I introduce labor market unions that intermediate household labor supply. (Auclert, Rognlie, and Straub (2018), Hagedorn, Manovskii, and Mitman (2019)). Unions set nominal wages by maximizing the average welfare of the households, and determine household labor supply, which is assumed to be equal for all households and given by $n_t$. In particular, a competitive recruiting firm aggregates a continuum of differentiated labor services indexed by $j \in [0,1]$ by maximizing profits subject to a CES aggregator

$$\max_{N_{jt}} \; W_t N_t - \int_0^1 W_{jt} N_{jt} dj, \tag{H.2}$$

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

where $W$ is the nominal wage $N$ is the aggregate labor demand or hours, and $\epsilon_w$ is the elasticity of substitution across differentiated labor inputs. This implies a CES demand for labor services of type $j$ given by

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

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 $u'$ and the labor disutility $\upsilon$ as given. Let $C_t$ be aggregate consumption and $p_t$ the consumer price index, the union solve the problem

$$\max_{\dot{W}_{jt}} \; \int_0^\infty \left[ \exp\left( - \int_0^t r_s ds \right) \left( \int_0^1 \frac{W_{jt}}{p_t} N_{jt} - \frac{\upsilon(N_{jt})}{u'(C_t)} dj \right) \right] dt \tag{H.3}$$

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

Let $\mu_w := \epsilon_w / (\epsilon_w - 1)$, in a symmetric equilibrium with $W_{jt} = W_t$ and $N_{jt} = N_t$ and absent any nominal wage rigidity, we obtain a simple labor supply schedule given by

$$\frac{\upsilon'(N_t)}{u'(C_t)} = w_t \mu_w^{-1}.$$

This equation connects labor supply decisions to the real wage and the marginal rate of substitution between labor and consumption. Introducing labor market unions in the HANK framework implies a clean separation between consumption decisions and labor supply decisions. This simplifies the analysis and allows me to concentrate the complexity of the model on the consumption decisions and on the wealth distribution.[2] For reasons that I will discuss in detail later in this section, also assuming flexible wages simplifies the model without generating counterfactual implications on how household earnings respond to monetary policy shocks.

[2] At the same time, removing unions and allowing for direct labor suply decisions by households does not substantially change the main results.

### 1.2.3 Firms

A representative firm produces a final good $Y_t$ with price $p_t$ using a Constant Elasticity of Substitution (CES) technology that aggregates a continuum of intermediate inputs $Y_{it}$, indexed by $i \in [0, 1]$, with price $p_{it}$. The elasticity of substitution of intermediate goods is given by $\epsilon_p > 1$. The representative firm operates in a perfectly competitive market and solves the following profit maximization problem

$$\max_{Y_{it}} \; p_t Y_t - \int_0^1 p_{it} Y_{it} di, \tag{F.1}$$

$$\text{s.t. } Y_t = \left( \int_0^1 Y_{it}^{\frac{\epsilon_p - 1}{\epsilon_p}} di \right)^{\frac{\epsilon_p}{\epsilon_p - 1}},$$

This optimization problem yields the iso-elastic demand for intermediate good $i$,

$$Y_{it} = \left( \frac{p_{it}}{p_t} \right)^{-\epsilon_p} Y_t.$$

together with the price index $p_t = (\int_0^1 p_{it}^{1-\epsilon_p} di)^{\frac{1}{1-\epsilon_p}}$. See Appendix **??** for the analytical derivations associated to (**??**).

Input producers operate in monopolistic competition. They demand capital $K_{it}$ and labor $N_{it}$ to minimize production costs given real wages, the rental rate of capital $r_t^k$, and the production function $F$ with constant returns to scale.

$$\min_{K_{it}, N_{it}} w_t N_{it} + r_t^k K_{it}, \tag{F.2}$$

$$\text{s.t. } Y_{it} = F(K_{it}, N_{it}),$$

This optimization problem implies that all firms operate with the same capital-labor ratio and face the same marginal costs. Moreover, they set prices to maximize the present value of nominal profits subject to the market demand and a price adjustment cost function $\Phi_t$. The latter feature introduces nominal rigidities in the model. Let $m_{it}$ denote nominal marginal costs and let $i_t$ be the nominal interest rate. Then, intermediate producers solve the following problem

$$\max_{\dot{p}_{it}} \int_0^\infty \left[ \exp\left( - \int_0^t i_s ds \right) \left( (p_{it} - m_{it}) Y_{it} - \Phi_t \left( \frac{\dot{p}_{it}}{p_{it}} \right) \right) \right] dt \tag{F.3}$$

$$\text{s.t. } Y_{it} = \left( \frac{p_{it}}{p_t} \right)^{-\epsilon_p} Y_t.$$

From the characterization of the solution to (**??**), (**??**), (**??**) we can derive a New Keynesian Phillips curve relating nominal variables to the real side of the economy. Appendix **??** presents the analytical derivations of the price Phillips curve and of the firms' profit function.

### 1.2.4 Financial sector

In the financial sector there is an investment fund that collects household savings, owns the economy capital stock $K_t$, rents capital to the input producers and invests in new capital facing investment adjustment costs $\chi_t$. Let $\iota_t = I_t/K_t$ be the investment rate. The investment fund solves the problem

$$V_0 := \max_{\iota_t} \int_0^\infty \left[\exp\left(-\int_0^t r_s ds\right)\left((r_t^k - \iota_t)K_t - \chi_t(\iota_t)\right)\right]dt \tag{F.4}$$

$$\text{s.t. } \dot{K}_t = (\iota_t - \delta)K_t.$$

The value of the fund $V_t$ is given by $V_t = q_t K_t$ where $q_t$ is the Tobin's q and $q_t K_t$ is the market value of the aggregate stock of capital. Moreover, in equilibrium an arbitrage condition between the return on wealth and the return on capital holds. See the solution to (**??**) in Appendix **??**.

### 1.2.5 Monetary policy

The nominal interest rate $i_t$ and the real interest rate $r_t$ are related through a Fisher equation, i.e. $i_t = r_t + \pi_t$ where $\pi_t := \dot{p}_t/p_t$ is the infaltion rate. The central bank sets nominal interest rates according to the simple Taylor rule

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

where $r$ is the steady state level of the real interest rate and $\{v_t\}_{t\geq 0}$ is an interest rate policy given by $v_t = e^{-\eta t}v_0$. At the steady state $v_0 = 0$. In this paper I study the response of the economy to unexpected monetary policy innovations $v_t$.

### 1.2.6 Equilibrium

The equilibrium of the economy is given by paths for household decisions $\{c_t, n_t\}_{t\geq 0}$, aggregate variables $\{K_t, N_t, Y_t, I_t, C_t, D_t\}_{t\geq 0}$, prices $\{r_t, r_t^k, q_t, w_t, \pi_t\}_{t\geq 0}$, and monetary policy $\{v_t\}_{t\geq 0}$ such that in every period: (i) households solve (**??**), (**??**), (**??**) given equilibrium prices, (ii) firms solve (**??**), (**??**), (**??**), (**??**) given equilibrium prices, (iii) the sequence of density functions $\{f_t\}_{t\geq 0}$ is consistent with the household policy functions and aggregate variables, (iv) monetary policy follows a Taylor rule, and (v) financial and labor markets clear

$$V_t = \int_X a_t d\psi_t, \tag{1.1}$$

$$N_t = \int_X e_t n_t d\psi_t. \tag{1.2}$$

### 1.2.7 Discussion of the model

In this section, I discuss in detail specific aspects of the model and some of the assumptions. Specifically, I begin with the role of equity prices and how asset prices interact with the wealth distribution. Then, I discuss the assumption of flexible wages and the cyclical properties of profits. Finally, I provide an overview of the solution methods.

First of all, note that the equilibrium on financial markets connects the supply of saving by households to the demand of saving by firms. Thus, households' total wealth equals the market value of the capital demand by firms. To see this note that in equilibrium $K_t = \int_0^1 K_{it} di$ and $V_t = q_t K_t$. It is important to highlight that the presence of a Tobin's q in the model has implications for the dynamics of the wealth distribution. Specifically, after a monetary policy shock $q_t$ changes on impact while agrgegate capital is a predetermined variable that does not changes on impact and slowly adjusts to the shock over time. Thus, from $V_t = q_t K_t$ and Equation (**??**) we can see that household market wealth $a_t$ has to "jump" as monetary policy induces a valuation effect via $q_t$. Following the literature I assume that households to accumulate wealth trade equity shares of the investment fund which I denote by $k_t$ at price $q_t$, namely $a_t = q_t k_t$. This implies that the model generates endogenous changes in the wealth distribution due to variations in asset prices after a monetary policy shock. Wealth concentration implies that these capital gains due to changes in equity prices are concentrated at the top. Therefore, this simple formulation can capture the effects of the stock market response to monetary policy on the wealth distribution. In this paper I leverage the model to assess the importance of these effects on aggregate demand.

In the baseline version of the model I also assume flexible nominal wages. A widely known result is that with flexible wages price markups are counter-cyclical conditional on a monetary policy shock because of the slower adjustment of prices relative to production costs. In most calibrations counter-cyclical markups lead to counter-cyclical profits. However, empirical studies on the effects of monetary policy typically find a large and significant increase in profits, while the effects on real wages are an order of magnitude smaller. Introducing sticky wages in models with nominal price rigidities can prevent the counterfactual cyclicality of profits. However, this also complicates the analysis and introduces additional degrees of complexity outside of the main scope of this paper.[3] Here, I focus on the response of household earnings $y_t = w_t e_t n_t + d_t$, with flexible wages changes in business income balance the response of labor income and imply a realistic response of earnings. Following Hagedorn, Manovskii, and Mitman (2019) I also assume that price adjustment costs are virtual, namely these costs only affect firms' optimal decisions but not real resources.

The recursive formulation of the household optimization problem and the law of motion of the density $f_t$ are given by Hamilton-Jacobi-Bellman (HJB) and Kolmogorov forward (KF) equations, see Appendix **??**. These are two partial differential equations and their exact for-

[3] Introducing sticky wages is an important extension for models in which the cyclical properties of profits can affect investment decisions. For example, this is the case when profits are not distributed lump-sum to all households, but instead are given only to capital owners.

mulation depends on the parametrization of the stochastic process for earnings $e_t$ presented in Section **??**. In this paper I analyze the steady state and dynamics of the fully nonlinear model using global methods. The algorithms share the same basic structure: an inner loop solves the HJB and KF equations using finite difference methods as in Achdou, Han, Lasry, Lions, and Moll (2017), and an outer loop implements a fixed point iteration over equilibrium prices. The HJB and KF solution method leverages the sparsity of the matrices used to approximate these equations. Since I rely on a flexible continuous time Markov process for income risk $e_t$ the HJB and KF equations feature expected values. However, despite the presence of integrals in the HJB and KF equations increases the computational burden the algorithms to solve these equations remain efficient. The Appendix **??** contains further details on the numerical solutions.

## 1.3 Parametrization

In this section I outline the parametrization of the model, the calibration strategy, and assess the model empirical performance. I quantify the parameters of the model with two goals. The model should reproduce the US wealth distribution and MPCs consistent with micro evidence.

### 1.3.1 Functional forms and stochastic processes

I parametrize preferences and production technology using standard functional forms. In particular, for the instantaneous utility I use a CRRA function given by

$$u(c_t, n_t) = \frac{c_t^{1-\gamma}}{1-\gamma} - \frac{n_t^{1+\nu}}{1+\nu},$$

with $\gamma \geq 0, \nu \geq 0$, where $1/\gamma$ is the elasticity of intertemporal substitution and $1/\nu$ is the Firsch elasticity of labor supply. The production technology is given by a Cobb-Douglas production function, $Y_{it} = K_{it}^{\theta} N_{it}^{1-\theta}$ and adjustment costs, $\chi_t = \frac{\kappa}{2}(\iota_t - \delta)^2 K_t$, $\Phi_t = \frac{\Psi_p}{2}(\pi_{it})^2 p_t Y_t$.

Labor income risk follows a continuous-time markov process. I specify this process following the approach of Castañeda, Díaz-Giménez, and Ríos-Rull (2003), Poschke, Kaymak, and Leung (2021) that combines normal states with extraordinarily high states. In particular, the idiosyncratic component of labor income follows a Poisson process. The process jumps from normal states to extraordinary earning states with arrival rate $\lambda_1$, and switches back from top states to any of the normal states with arrival rate $\lambda_2$. There are two extraordinary earning states $e_1, e_2$ with transition probabilities $\theta_1, \theta_2$ such that $\theta_1 + \theta_2 = 1$. The new income realization is draw from the distribution $\Phi_e$ with probability function $\phi_e$. Moreover, households transit between normal states at the rate $\lambda_e$ according to the conditional distribution $F_e$ characterized by a stochastic matrix. I obtain these transition probabilities between normal states from a discrete-state approximation to an AR(1) process for $\ln e_t$. The process is parametrized by an autoregressive coefficient equal to $1 - \nu_e$ and a standard deviation rate $\sigma_e$ of quarterly shocks $\hat{w}_{e,t} \sim N(0, 1)$. This substantially reduces the number of parameters that characterize

$F_e$. Given the transition probabilities I compute the stationary probabilities over the normal states $\phi_e$ from which households that leave the top states draw their new normal income state.

### 1.3.2 Calibration

The model is calibrated at quarterly time frequency to US micro data in 2004, before the Great Recession. The main data source for the joint distribution of income and wealth is the Survey of Consumer Finances (SCF).[4] Following the recent literature I define wealth as the difference between assets and liabilities excluding home equity, privately held business, and mortgages and focus on more liquid financial wealth. Specifically, assets are given by bank deposits, corporate and government bonds and stocks. Liabilities are given by consumer credit. Earnings are given by wages, salaries, and business income. Market income is the sum of earnings, financial income, and capital gains or losses. I first choose the values of a set of parameters following the literature. Then, I jointly calibrate the remaining parameters describing earning dynamics to reproduce key features of the distributions of earnings and wealth in the US. Table **??** reports the parameters' values.

**External calibration**. I set the preference parameters $\gamma, \nu$, the borrowing limit $\phi$, the capital share $\theta$, depreciation rate $\delta$, and the Taylor coefficient $\phi_\pi$ to values common in the literature. In the data we observe that the mode of the wealth distribution is close to zero. Models with a potentially binding borrowing limit generate a mass of households at the constraint. The value for $\phi$ implies that the wealth distribution has a point mass of households close to zero as in the data. Following the New Keynesian literature I set the intermediate goods elasticity $\epsilon_p$ to match a steady state profit share of output $1/\epsilon_p$ equal to $10\%$, and the price adjustment cost parameter $\Psi_p$ to match a slope of the price Phillips curve $\epsilon_p/\Psi_p$ of $0.1$. Following the literature I use the same value of $\epsilon_p$ for the labor elasticity $\epsilon_w$. I set the Poisson arrival rate $\lambda_e = 1$ so that shocks arrive on average once in each quarter and the persistence of income risk is fully determined by its transition probabilities. The values for $\nu_e, \sigma_e$ imply an annual autocorrelation for $\ln e_t$ equal to 0.9 and a standard deviation rate of innovations equal to $0.2$. These values are consistent with typical estimates of AR(1) models at annual frequency.[5]

**Internal calibration**. I choose the discount rate $\rho$ and the parameters describing the labor income process $e_1, e_2, \lambda_1, \lambda_2, \theta_1$ to jointly match statistics characterizing wealth and income inequality. In particular, aggregate wealth-output ratio, the gini coefficients of earnings and wealth, the earning shares of the top $0.1\%, 1\%$, the fraction of low-wealth households.

[4] In particular, I use the extract from the SCF by Kaplan, Moll, and Violante (2018). This dataset it is based on the data constructed in Weidner, Kaplan, and Violante (2014). The sample restricts individual ages to 22-79.

[5] As in Guvenen, Kambourov, Kuruscu, Ocampo, and Chen (2019), Krueger, Mitman, and Perri (2016). In particular, the autocorrelation's value is on the lower bound of empirical estimates since I do not separately model transitory shocks. Moreover, as the main purpose of the labor income shocks is to produce sufficient dispersion in earnings I assume that the variance of innovations at the quarterly frequency is the same at the annual frequency.

Table 1.1: Model parameters

| Parameter | Description | Value | Source |
|---|---|---|---|
| *Households* | | | |
| $\gamma$ | CRRA/Inverse IES | 1 | External |
| $\nu$ | Inverse Frisch elasticity | 1 | External |
| $\phi$ | Borrowing limit | 0.5 | External |
| $\rho$ | Individual discount rate | 0.04 | Internally calibrated |
| *Income process* | | | |
| $\lambda_e$ | Arrival rate normal states | 1 | External |
| $\nu_e$ | Mean reversion coeff. | 0.0263 | External |
| $\sigma_e$ | S. d. of innovations | 0.2 | External |
| $\theta_1$ | Transition probability to $e_1$ | 0.6 | Internally calibrated |
| $\lambda_1$ | Arrival rate top states | 0.0028 | Internally calibrated |
| $\lambda_2$ | Arrival rate leave top states | 0.8 | Internally calibrated |
| $e_1, e_2$ | Top earnings states | 20, 70 | Internally calibrated |
| *Firms and policy* | | | |
| $\theta$ | Capital elasticity | 0.33 | External |
| $\delta$ | Depreciation rate (p.a.) | 5% | External |
| $\Psi_p$ | Adjustment cost | 100 | External |
| $\epsilon_p, \epsilon_w$ | Elasticities of substitution | 10 | External |
| $\kappa$ | Investment adjustment cost | 16 | Internally calibrated |
| $\phi_\pi$ | Taylor coeff. | 1.25 | External |

Aguiar, Bils, and Boar (2021) using PSID data find that around 40% of US households are liquidity constrained, Weidner, Kaplan, and Violante (2014) find a value around 30%. I target a fraction of constrained households of 30%, at the lower bound of empirical estimates.[6] This choice has advantages and limitations. On one hand, it allows the model to match the overall fraction of constrained households in the economy, and this delivers a realistic average marginal propensity to consume. On the other, the joint distribution of MPCs and liquid wealth features MPCs that sharply decline with liquid wealth. In a recent contribution Holm, Paul, and Tischbirek (2021a) find that in Norway MPCs slowly decline with liquid wealth.

[6]In the Appendix **??** I provide further details on the identification of low-liquidity households and their distribution across wealth deciles in the US.

Although the parameters affect all moments, the discount rate is more important for the wealth-output ratio and the share of liquidity constrained households. The parameters related to income risk are more important for the Gini coefficients and earning shares. Finally, I choose the value of $\kappa$ to match the investment response relative to the output response to a monetary policy shock. In particular, I target a ratio between the peak of the investment response and the peak of the output response to a 25 basis point interest rate cut of about 2 (Christiano, Eichenbaum, and Evans (2005), Christiano, Eichenbaum, and Trabandt (2016)). The calibration strategy delivers a total of 7 parameters and 7 targeted statistics.

### 1.3.3 Model performance and validation

Overall, the model captures the targeted statistics quite well. Table **??** shows that the aggregate amount of liquid financial wealth relative to annual output, the Gini coefficients of earnings and wealth, and the fraction of low-liquidity households in the model are close to their data counterparts. The top earning states $e_1, e_2$ are respectively 15, 55 times the average of the income process, and only 0.2%, 0.1% of households enjoy these states. The discount rate $\rho$ yields a discount factor of 0.96. The aggregate return to liquid wealth is 2.8%. In the remaining of this section I discuss how the model fits untargeted statistics that are relevant for my analysis: wealth shares including the very top of the distribution, the income distribution, and the MPCs across the wealth distribution.

Table 1.2: Targeted statistics

| Targeted Statistics | Data | Model | Targeted Statistics | Data | Model |
|---|---|---|---|---|---|
| Wealth-output ratio | 1.42 | 1.8 | Gini wealth | 0.87 | 0.81 |
| Top 0.1% earnings share | 6 | 6 | Gini earnings | 0.59 | 0.54 |
| Top 1% earnings share | 16 | 15.5 | Fraction with $a = \phi$ | 0.3 | 0.27 |

Note: data source: SCF 2004 and Weidner, Kaplan, and Violante (2014). The 2004 annual GDP is 12,300 billions dollars. For a precise definition of the variables see the main text.

The model generates realistic wealth shares at the top of the distribution, but understates the very top shares from the top 5% to the top 0.1%. I discuss in detail the wealth shares in the Appendix **??**. I calibratte the income process to generate realistic income dynamics rather than use it to match top wealth shares. The CE data does not allow to study the consumption response of the super wealthy, and it is unlikely that the response that we observe in the data for the top 10% is driven by these households.

**Wealth distribution**. I begin analyzing the wealth distribution in the model and in the SCF. Figure **??** shows on the left panel the wealth histogram in the model and on the right panel the wealth histogram in the SCF. In both cases wealth is measured relative to mean annual earnings. In the SCF sample the average annual earnings is \$68,738. In the right panel all wealth values above 1 milion or around 14.5 times average income are top-coded and reported as a fraction of the total population. The model successfully reproduces the right tail of the wealth distribution and the point mass of households with almost zero wealth.

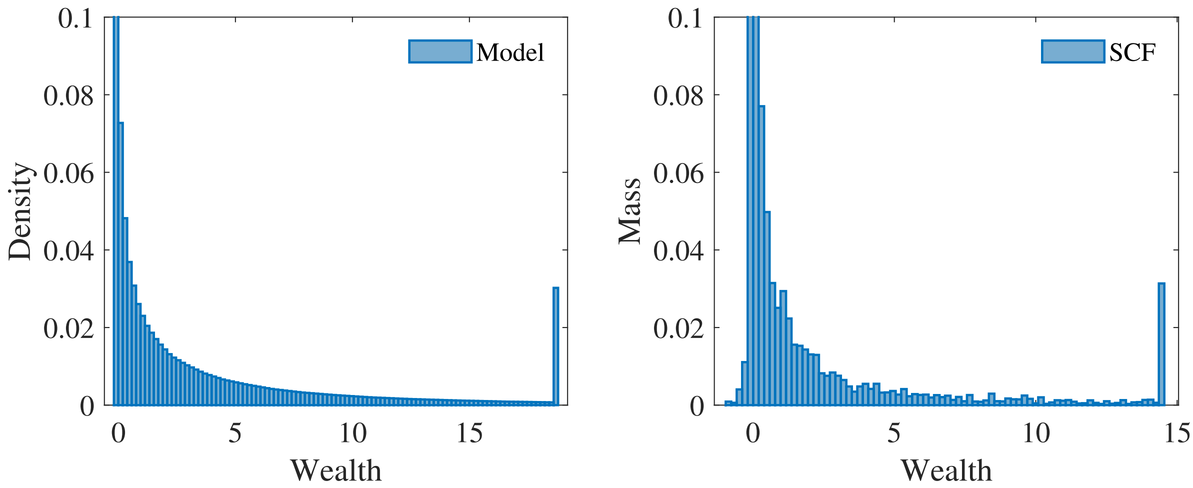


Figure 1.1: Wealth histograms

Note: Wealth values $\hat{a}$ are in terms of average annual income. The wealth distribution in the model is on the left panel, the wealth distribution in the SCF on the right panel. Fraction of households in different wealth bins: $P(\hat{a} \in [-0.1, 0.1]) \approx .3$ in the data and model, $P(\hat{a} \geq 15) \approx .03$ in the data and .04 in the model.

Table **??** reports additional wealth statistics. The model generates realistic wealth holdings for the median households and also top percentiles are close to their data counterparts.

Table 1.3: Wealth percentiles

| Wealth statistics | Data | Model | Wealth statistics | Data | Model |
|---|---|---|---|---|---|
| Mean wealth | 2.5 | 3 | 90th percentile | 5 | 8.4 |
| Median wealth | 0.17 | 0.28 | 95th percentile | 10 | 13 |
| 75th percentile | 1.3 | 2.7 | 99th percentile | 34 | 30 |

Figure **??** shows that the model broadly matches the distributions of earnings and wealth. The left panel shows the Lorenz curve for earnings in the SCF and in the model. The right panel shows the Lorenz curve for wealth. Each figure reports the share of total earnings or wealth on the y-axis and the population percentiles on the x-axis. The left panel shows that in the model the quintiles of earnings are close to the empirical quintiles. These estimates are less precise at the bottom of the earnings distribution. This is due to the fact that in the data the bottom $20\%$ of the distribution has almost zero market income and mostly rely on public transfers. On the other hand, the model captures almost exactly the earning shares of top percentiles, including those not targeted in the calibration. The right panel in Figure **??** shows that the wealth quintiles in the model also replicate well the empirical quintiles. In particular, the model generates sizable wealth shares of top percentiles, quantitatively however these estimates are lower than the data counterparts. This is especially the case at the 80th wealth percentile.

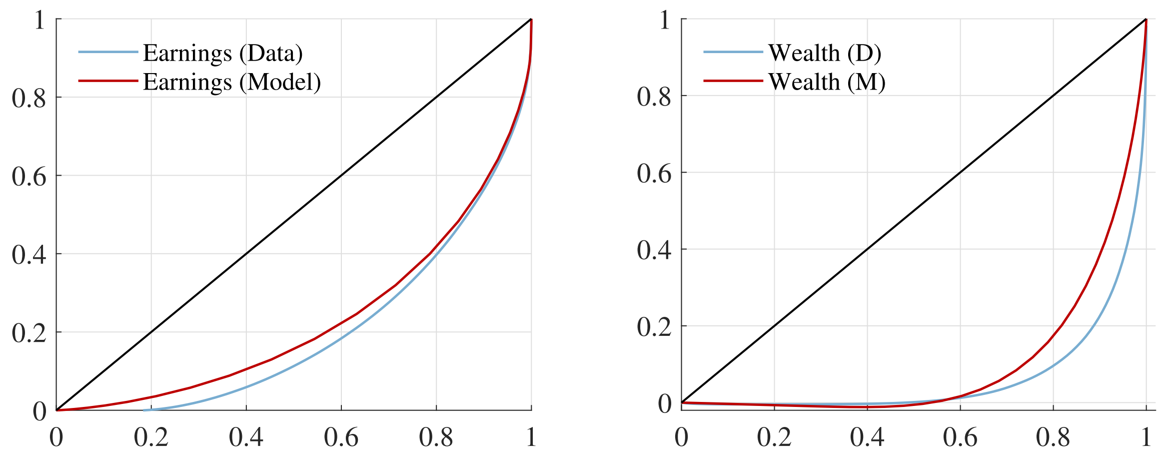


Figure 1.2: Lorenz curves

The ability of the model to match the top of the wealth distribution depends crucially on income dynamics. These can generate a high concentration of earnings, leading to a high concentration of wealth since earnings and wealth are positively correlated: households with persistently high income realizations accumulate large fortunes. There are calibrations of the model that can almost exactly match both the earnings distribution and the wealth distribution including the top $0.1\%$ without the need of additional channels such as bequests, heterogeneous returns to wealth or heterogeneous preferences.[7] However, these calibrations require implausibly high earning states. Moreover, since households in this section of the distribution are not the main focus of the paper I keep this calibration as the baseline case.

[7]This can be achieved by allowing for higher top wealth states.

**Consumption and wealth**. In the data top wealth groups tend to have the largest consumption share relative to other wealth groups of similar size. For example, Krueger, Mitman, and Perri (2016) using PSID data in 2006 report the shares of total consumption, including both durable and nondurable expenditure, by net worth quintiles. These shares are respectively around 11%, 12%,16%, 22%, and 37%. Using PSID data in 2004 I find a similar pattern for nondurable consumption by liquid wealth.[8] In the model as in the data households at the top 10% of the wealth distribution have the largest consumption share relatively to other wealth deciles. However, the model overstates the consumption share of wealthy households and underestimates the consumption share at the bottom of the wealth distribution. In the model the consumption share of households in the top 10% is almost 2 times higher than the share that I observe in the data.

An important statistic to evaluate the consumption response to temporary income changes is the MPC. The literature consider 15-25 percent as an empirical benchmark for the average quarterly marginal propensity to consume out of a transfer between 500 and 1000 dollars. This empirical benchmark comes from studies analyzing the 2008 fiscal stimulus payments in the US and lottery winnings in Norway (Broda and Parker (2014), Parker, Souleles, Johnson, and McClelland (2013), Fagereng, Holm, and Natvik (2021)). To compute this MPC in the model I follow the approach of Kaplan, Moll, and Violante (2018). Given the steady state consumption policy function $c(x_t)$ I simulate the cumulative consumption over $q$ quarters $C_q(x) = \mathbb{E}[\int_0^q c(x_t)dt|x_0 = x]$. This conditional expectation can be conveniently computed using the Feynman-Kac formula as explained in Achdou, Han, Lasry, Lions, and Moll (2017). Then, I simulate the model-equivalent of a 500 dollar transfer to all households at the steady state $\tau$. Finally, I express the consumption response as a fraction of the transfer to compute the model MPCs that are comparable to the empirical estimates $MPC_{\tau,q}(x) := \frac{C_q(a+\tau,e)-C_q(a,e)}{\tau}$ from these MPCs I compute the average. In the model the quarterly average MPC is 15%, in the middle range of the empirical estimates. This result crucially depends on the fact that the model matches the overall fraction of low-liquidity households in the economy. In models with idiosyncratic risk and borrowing constraint there is a well-known tension between matching high wealth-output ratios and MPCs estimates. The reason is that matching the wealth-output ratio often requires a high wealth target for a substantial fraction of agents moving them away from the borrowing limit and the concave region of the consumption policy functions. The average MPC masks substantial heterogeneity across income-wealth groups. In the model, the MPCs sharply fall with wealth. Households at the bottom 50% have an average MPC of 27%, households in the middle-class have an average MPC of 5%, while households in the top 10% have an average MPC of about 4%. Di Maggio, Kermani, and Majlesi (2020), Chodorow-Reich, Nenov, and Simsek (2021) study the MPC out of stock market wealth gains and find an average MPC around 3%. Therefore, the low MPCs at the top of the wealth distribution are consistent with these estimates.

[8]See the Appendix **??** for a comparison of the wealth distribution in the SCF and in the PSID in 2004 and further details on variables' measurement in the PSID. See also Appendix **??** for the consumption shares in the CE microdata.

## 1.4 Empirical Evidence

In this section I study households' consumption responses to monetary policy shocks in the data. I begin by describing the sample of US households and the identification of monetary policy shocks. Then, I estimate the consumption response to expansionary monetary policy shocks of different wealth groups.

### 1.4.1 Data

In my analysis I use micro data from the Consumption Expenditure Survey (CE), which is a US representative household survey conducted by the Bureau of Labor Statistics. The CE has a rotating panel structure and collects information on income, consumption, and wealth for US households between 1990 and 2017. The Online Appendix **??** contains details on variables, sample selection, summary statistics of the CE micro data. I use the micro data to construct quarterly consumption time series for different wealth groups. In particular, I focus on liquid financial assets such as bank deposits, corporate and government bonds, and stocks. The baseline sample period is 1991Q3-2016Q4. To identify the causal effect of conventional monetary policies I need exogenous changes in nominal interest rates. In this paper I use the series of monetary policy shocks identified by Jarociński and Karadi (2020), Romer and Romer (2004). The first time series relies on a high-frequency identification with instrumental variables (IV), the second leverages central bank macroeconomic forecasts. I use the first series in the main analysis and the second one as a robustness check. The Online Appendix **??** reports further details on the identification and construction of these monetary policy shocks.

One concern is that measurement errors may affect the empirical results. To mitigate this problem I winsorize the variables used in the construction of the consumption series at the top and bottom $1\%$ in each quarter. I also remove outliers by winsorizing at the top and bottom $1\%$ the series of consumption changes used in the estimation of monetary policy effects. To eliminate some of the noise of the survey data, I smooth consumption with a moving average of the current and previous three quarters. Another limitation of this analysis is related to the measurement of households' wealth. The CE survey is not specifically designed to measure households' wealth at the very top of the distribution, as a result I can only study the cross-sectional responses of broad wealth groups.

Households are assigned to $G$ wealth groups according to their liquid wealth in the previous twelve months. Specifically, an household $i$ in quarter $t$ is assigned to a group $g = 1, 2, ..., G$ according to the position of household's wealth in the wealth distribution of the previous year. Ordering households according to past wealth guarantees that the group allocation is not influenced by monetary policy shocks occurring in the quarter $t$. In the baseline analysis the wealth groups have similar size. In particular, there are on average more than 100 households in each wealth group. In the Online Appendix **??** I discuss several robustness checks related to the sample periods used in the analysis, the monetary policy shocks, and the econometric model.

### 1.4.2 Cross-sectional effects of monetary policy

To estimate how the effects of monetary policy shocks vary over the distribution of liquid wealth I use the following econometric model:

$$\frac{y_{g,t+h} - y_{g,t-1}}{y_{t-1}} = \alpha_{g,h} + \beta_{g,h} v_t + \sum_{p=1}^{L} \delta_p' x_{g,t-p} + u_{g,t}, \tag{1.3}$$

where $y_{gt}$ is the total quarterly consumption of group $g$, $y_t$ is the CE aggregate consumption at the quarterly freqeuncy, $v_t$ is the monetary policy shock, and $x_{gt}$ is a vector of controls with lags of the monetary policy shocks and quarterly consumption of the wealth group $g$. In the baseline specification I use four lags for the shocks and three consumption lags. The groups are defined using the distribution of liquid wealth at $t - 12$. The cross-sectional impulse response functions to a one percent interest rate hike are given by the coefficients $\beta_{g,h}$. Since the model is linear these estimates can be rescaled to obtain the effects of monetary policy shock of different size and sign. The dependent variable in equation (**??**) captures the interaction between cross-sectional responses and consumption shares. Therefore, this specification measures the contribution of each wealth group to the aggregate.

Figure **??** plots the consumption responses of different wealth groups to a 1% interest rate cut. The left panel shows the bottom 20% and sixth decile, the right panel displays the top 10% and seventh decile. The Online Appendix **??** reports the impulse response functions for the other groups. Throughout the wealth distribution the responses show similar dynamics. Consumption adjustments reach a peak in the second year after the monetary policy shock and fade out in the fourth year. Households at the bottom 20% and top 10% show the largest response.

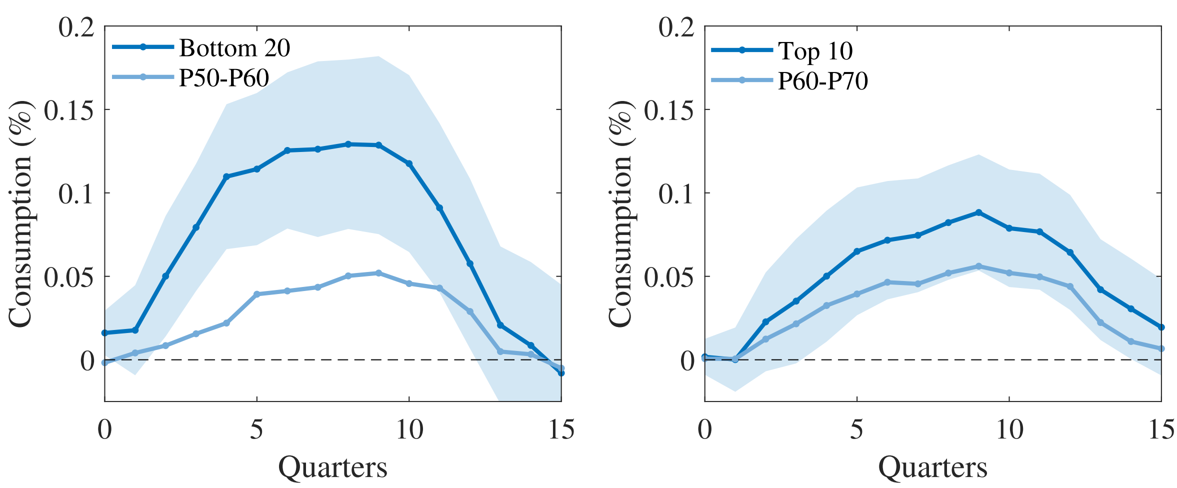


Figure 1.3: Consumption responses to monetary policy.

Note: The figure shows the consumption response to an interest rate cut of 100 basis points two years after the shock (left) and between one and two years from the shock (right) with 68% confidence bands.

Figure **??** shows the cross-sectional consumption responses across the distribution of liquid wealth at different time horizons. In particular, this figure reports the responses during the second year after the shock when the effects of monetary policy on households' expenditure reach the peak. Households at the tails of the wealth distribution display the largest responses leading to U-shaped cross-sectional effects. The response at the top 10% is more than 1.5 times the response of any other decile in the middle section of the wealth distribution. The effects at the bottom are even more pronounced. The response of the bottom 20% is more than twice the response of any other decile in the middle section of the distribution. Hence, there is a substantial heterogeneity in the cross-sectional effects of monetary policy.

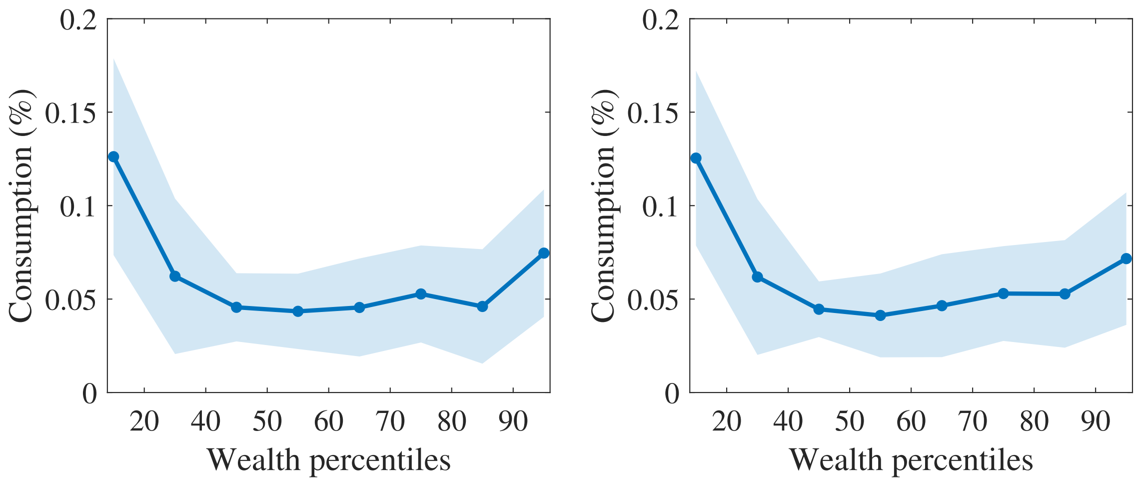


Figure 1.4: Consumption responses to monetary policy.

Note: The figure shows the consumption response to an interest rate cut of 100 basis points two years after the shock (left) and between one and two years from the shock (right) with 68% confidence bands.

As discussed in the introduction these empirical results are broadly consistent with the recent and growing empirical evidence on the heterogeneous effects of monetary policy that document similar cross-sectional patterns for consumption and income. These responses also confirm the mixed results in the literature on the effects of monetary policy on consumption inequality. Assuming that the increase in total consumption is equally distributed within each group, consumption increases both for low-wealth households and high-wealth households. As a result, the net effect on consumption inequality remains unclear and it could vary with the economic conditions of each specific event.

These results imply that to fully understand the consequences of monetary policy, it is important to look at its impact over the entire wealth distribution. To this end, I study the consumption responses across wealth groups in the quantitative HANK framework and show that this class of models can explain the cross-sectional dynamics observed in the data.

## 1.5 Quantitative Analysis

This section contains the main quantitative results of the paper. As discussed, the model is consistent with key aspects of the distribution of consumption, income, and wealth in the US. I now use the model to map this micro evidence into consumption responses to monetary policy. This allows me to quantify the relative importance of different wealth groups for the response of aggregate consumption to monetary policy and for the transmission mechanisms of monetary policy. Throughout this section I study the impulse responses to an unexpected monetary policy shock. The policy shock is a 25 basis point reduction in the nominal interest rate or a 1% annualized cut in the nominal interest rate. The corresponding quarterly innovation at $t = 0$ is given by $v_0 = -0.0025$. The shock mean-reverts at rate $\eta = 0.5$ so that the quarterly autocorrelation $e^{-\eta} = 0.61$, as in the empirical estimates (Christiano, Eichenbaum, and Evans (2005), Gertler and Karadi (2015)). This section of the paper is organized as follows. First, I present the impulse responses of aggregate variables to monetary policy with a particular focus on the response of aggregate consumption, and on the response of the variables that primarily affects households' balance sheets such as interest income, equity prices and earnings. Then, I study the transmission channels of monetary policy to aggregate consumption that operate in the model. Next, I explore the cross-sectional consumption responses of the model and their implications for aggregate consumption dynamics. Finally, I discuss distributional effects.

### 1.5.1 Aggregate responses

I begin by analyzing the response of aggregate variables to the expansionary monetary policy shock. After the interest rate cut the real interest rate falls, which stimulates consumption and investment. In response to an increase in aggregate demand, firms raise their prices and the production because of nominal price rigidities. The demand of capital and labor inputs increases, as firms increase production, and this leads to higher income for households that further stimulates investments and consumption.

In the model the rise in firms' labor demand leads to higher real wages and employment levels. These are the most important components driving the increase of household earnings. On impact, earnings increase by 0.8%. On the financial side lower interest rates benefit net borrowers and reduce the interest income of wealthy households. This is in line with the empirical evidence on the effects of monetary policy shocks. Importantly, the equity price $q_t$ increases by more than 0.4% on impact, and because the distribution of wealth is highly concentrated, these capital gains are very unequally distributed and mostly benefit households at the top 10% of the distribution. Bauer and Swanson (2022), Bartscher, Kuhn, Schularick, and Wachtel (2021) estimate that a 100 basis point reduction in the policy rate increases the S&P 500 stock market index by five percentage points. The corresponding effect for a 25 basis point interest rate cut is around 1.25%. So, the model understates the average stock market response to monetary policy.

Figure ?? shows the responses of prices and aggreagte demand components to the expansionary monetary policy shock. For completeness I report the responses of the other variables in the Appendix ??. Investment responds more than output that responds more than consumption. This is qualitatively in line with the empirical evidence.[9]

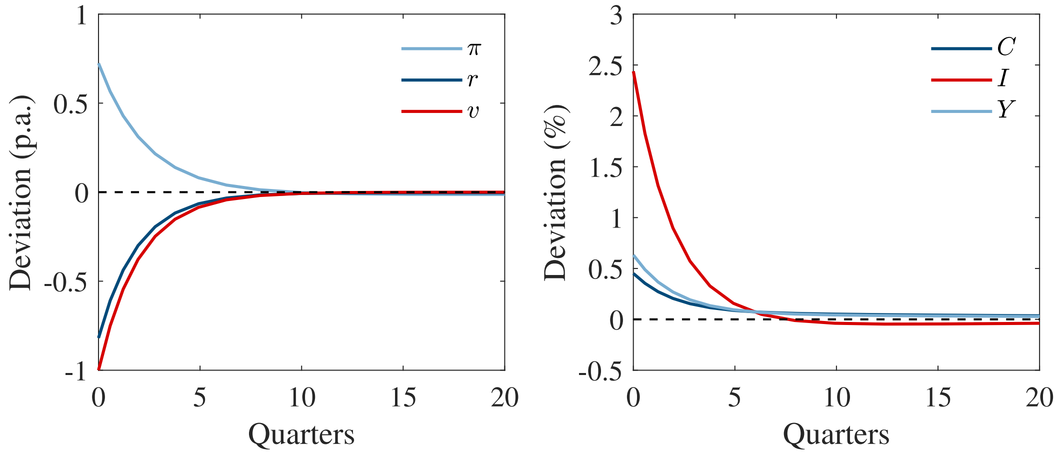


Figure 1.5: Impulse responses to $1\%$ reduction in nominal interest rate.

Note: the left panel shows the responses of inflation, real interest rate, and monetary policy shock in the model. The right panel shows the responses of consumption, investment, and output. Deviations from steady state.

Christiano, Eichenbaum, and Evans (2005) find that the magnitude of the responses' peaks for investment, output, and consumption are approximately about $1\%$, 0.5%, $0.2\%$. Relative to these estimates the model overstates the response of the aggregate demand. However, this is mostly due to investment rather than consumption. The empirical upper bound for the peak response of consumption is around $0.3\%$. The peak response of consumption in the model is $0.45\%$. Despite these limits the objective of this work is to assess to what extent the propagation of monetary policy to aggregate consumption depends on different wealth groups rather than providing also a thorough description of the aggregate effects of monetary policy.

### 1.5.2 Transmission mechanisms

To study the transmission mechanism of monetary policy I use the decomposition from Kaplan, Moll, and Violante (2018). Let $f_t$ be the density function over the space $X$ of individual states $x_t$, and $c_t$ the household consumption decisions, and $\{r_s, y_s\}_{s=0}^{\infty}$ the path of interest rates and earnings. Aggregate consumption is $C_t(\{r_s, y_s\}) = \int_X f(x_t; \{r_s, y_s\}_{s\leq t})c(x_t; \{r_s, y_s\}_{s\geq t})dx_t$.

[9] The model does not capture hump-shaped dynamics typically observed the data. However, to keep the model as simple and transparent as possible I do not introduce additional mechanisms such as consumer habits and information frictions that can generate hump-shaped dynamics.

Totally differentiating delivers

$$dC_t = \int_0^\infty \frac{\partial C_t}{\partial r_s} dr_s ds + \int_0^\infty \frac{\partial C_t}{\partial y_s} dy_s ds.$$

The partial derivatives give the partial equilibrium response of consumption to a change in the equilibrium path of each variable. This equation provides a partial equilibrium decomposition of aggregate consumption response in a direct effect from interest income in the first integral and an indirect effects in the second integral due to changes in household earnings.

Table **??** studies in more detail the response of aggregate consumption over the first year after the monetary policy shock in column (1), and over the first two and a half years from the shock in column (2). In the model the first year average elasticity of consumption to interest rates is $-2.8$. For comparison Kaplan, Moll, and Violante (2018), Lee (2021) find respectively an elasticity of $-2.93$ and $-3.2$ over the first year.[10] The second part of Table **??** studies the transmission channels of monetary policy to aggregate consumption. In particular it reports the percentage of the aggregate consumption response that is due to direct and indirect effects. Initially, the response of aggregate consumption is split almost equally between direct and indirect effects. However, from the first year onwards indirect effects explain most of the consumption dynamics. As a result over the first two years from the monetary policy shock indirect effects already account for almost 60% of the aggregate consumption response. This result is due to the fact that indirect effects of monetary policy operating through the labor market gradually build up and eventually outweigh the direct effects. In line with the findings of the existing literature, Table **??** shows that the indirect effects explain a substantial fraction of the aggregate consumption response to monetary policy.

Table 1.4: Aggregate consumption response

| Total Effect | (1) | (2) | Decomposition | (1) | (2) |
|---|---|---|---|---|---|
| Interest rate change | $-0.46$ | $-0.49$ | Direct Effect | 49 | 42 |
| Consumption Elasticity | $-2.7$ | $-3.5$ | Indirect Effects | 51 | 58 |

Note: Average responses over the first year shown in column (1), average responses over the first two and a half years shown in column (2). The interest rate change is given in percentage points. Direct and indirect effects are shown as percentages of the aggregate consumption response.

[10] In particular, the average semi-elasticity of consumption with respect to the interest over the period $[0, \tau]$ is $\eta_{r,\tau} := (\int_0^\tau (dC_t/C)dt)/(\int_0^\tau dr_t dt)$, where the differentials are defined as infinitesimal changes with respect to the steady state equilibrium.

### 1.5.3 Consumption responses

In this section I explore households' consumption responses to monetary policy and illustrate their macroeconomic implications. To this end, I decompose the contributions of different wealth groups to the response of aggregate consumption and quantitatively assess the role of each wealth group for the transmission mechanism of monetary policy.

The quantile analysis is based on a definition of wealth groups that is independent from monetary policy. In particular, wealth groups are defined at the steady state using the stationary distribution of liquid wealth, before the monetary policy shock. As household wealth and income change over time the composition of wealth groups vary over time. The cross-sectional responses account for these dynamics at the household level. Figure **??** shows the consumption responses across wealth groups at different time horizons after the monetary policy shock. Households at the tails of the wealth distribution display large responses. As a result, the consumption response is U-shaped across wealth groups.

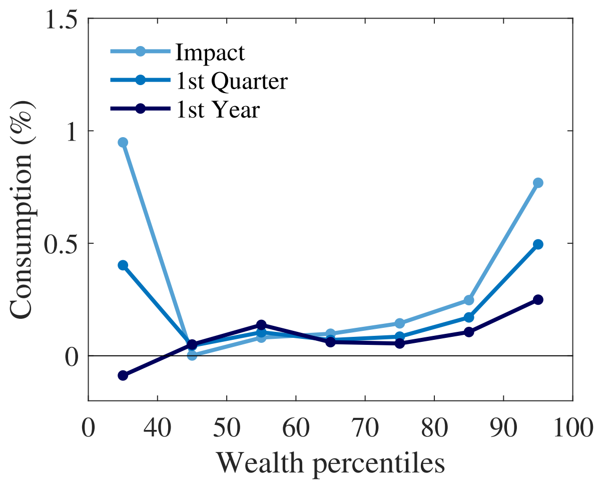


Figure 1.6: Consumption responses to a 1% reduction in nominal interest rate.

Note: The figure shows the consumption responses across the wealth distribution. Percent deviation from steady state consumption of each group shown.

Households at the bottom 50% of the wealth distribution are the most responsive to monetary shocks. All these households have a high marginal propensity to consume. This is due to the fact that they are either constrained or unconstrained but with a substantial precautionary saving motive since households closer to the constraint are more likely to hit the borrowing limit in the future. As a result, temporary income changes feeds into consumption by relaxing the borrowing limit or the precautionary saving motive. Since these households rely primarily on labor earnings, the increase of household earnings due in particular to higher employment levels is critical for the consumption response of this group. Within this group low-liquidity households a the bottom 30% have the highest MPCs and show the largest response. Importantly, some of these households at the bottom of the distribution are borrowers and benefit from an expansionary monetary policy since lower interest rates leads to lower interest expenses on the debt. As a result households at the bottom 50% also respond to interest rate changes relative to households in the next 40% that only respond to changes in earnings. Households at the top 10% show a much smoother consumption response relative to households at the bottom 50%. The initial response is relatively lower, but while consumption at the bottom quickly returns to the steady state the consumption response at the top is more persistent. On impact high-wealth households substantially benefit from the increase in asset values and equity prices. However, families at the top have small MPCs and do not adjust consumption expenditure as much. Households at the top 10% account for most of the direct effect of monetary policy while consumption at the bottom 90% of the wealth distribution mostly respond to the indirect effects.

In the remaining of this section I study the consumption response of each group as a fraction of steady state aggregate consumption. These consumption responses measure the contribution of each wealth group to the aggregate consumption response. To see this note that the response of aggregate consumption is a weighted average of consumption changes of different wealth groups with weights given by the steady state consumption shares of each group. Therefore, the consumption responses that I study in this section capture exaclty the interaction between consumption changes and consumption shares, exploring such effect is one of the focuses of this paper. These responses are U-shaped across wealth groups with peaks around 0.12% for the bottom 50% and 0.25% for the top 10%. Households in the middle section of the wealth distribution, from the 50th to the 90th percentile, are less affected by monetary policy and contribute for less than 0.1%. Therefore, in the model households at the top 10% explain most of the aggregate consumption response. There are two factors contributing to this result. First, among all wealth groups households in the top 10% have the largest consumption share. This amplifies the impact of their consumption response on aggregate consumption. Second, the capital gains from higher equity prices are concentrated at the top 10%.

Overall, these results show that a broad class of HANK models feature relatively large consumption responses to monetary policy shocks at the tails of the wealth distribution.

**Wealth dynamics**. Here, I study how wealth concentration, interest rates, and equity prices interact in the HANK framework. In order to illustrate the implications of equity price changes for aggregate consumption, I compute the consumption responses to the real interest rate without valuation effects, i.e. when household wealth remains constant on impact. In particular, I vary the real interest rate and fix the initial distribution of wealth when $t = 0$ at the steady state. Note that in the model $q_t$ has two effects on households' balance sheets. First, it affects the path of asset returns $r_t$. Second, on impact at $t = 0$ increases households' wealth $a_t$. Therefore, to isolate the asset price effect I feed into the household consumption problem the equilibrium path of the real interest rate and keep households' wealth constant at the steady state so that the initial distribution of wealth is the stationary distribution.

Table **??** shows that the direct effect is an order of magnitude smaller starting from the steady state distribution than starting from the wealth distribution with capital gains that arise in equilibrium. Households at the top 10% explain this reduction as their consumption contribution almost entirely depends on the effect of equity prices on their wealth. Importantly, asset price changes also redistribute consumption across wealth groups. To see this note that the increase of aggregate consumption from the top increases is 0.21%, while the increase in total is equal to 0.15%. The size of this asset price redistribution is 0.06%. The right panel of Figure **??** shows the same decomposition across wealth groups. Asset price changes benefit households at the top, but reduce consumption for the middle-class.

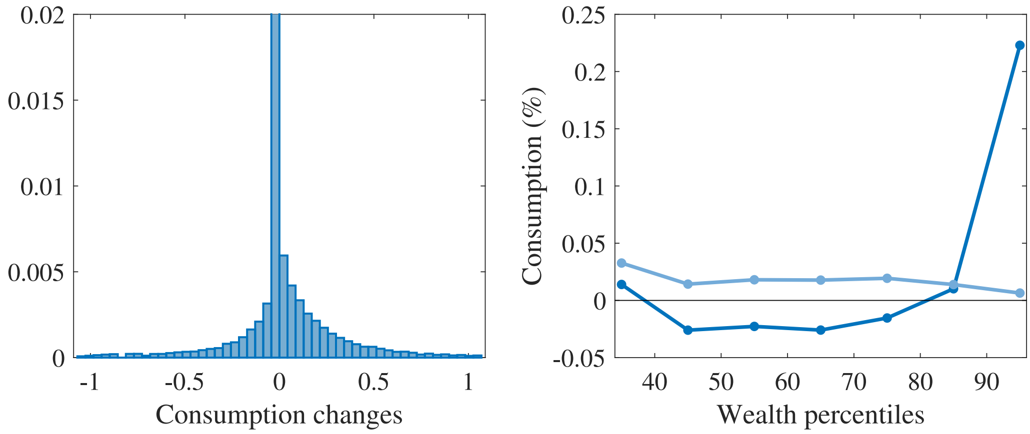


Figure 1.7: Consumption and asset prices.

Note: The left panel shows the histogram of consumption changes at $t = 0$ due to realized capital gains\losses in percentage deviation from the average steady state consumption. About 36% of the households have zero consumption gains. These households do not adjust their wealth holdings on impact. The right panel plots the direct effects of monetary in Figure **??** due to capital gains (blue line) and without capital gains (dark blue line) across the wealth distribution.

Table 1.5: Consumption response and initial distribution

| Direct Effect | Total | No capital gains | Amplification |
|---|---|---|---|
| Aggregate consumption | 0.27 | 0.12 | 0.15 |
| Top 10% consumption | 0.22 | 0.01 | 0.21 |

Note: The table shows the direct effect at the aggregate level and for the top 10% on impact. Percentage deviations from steady state aggregate consumption.

To better understand these results note that asset prices increase consumption either through realized capital gains or through unrealized capital gains. In the former case there is an income effect on consumption because households sell assets at an higher value, in the latter case there is a wealth effect on consumption due to the fact that household consumption increases as wealth increase. The income effects are purely redistributive. This is the result of households' trade. Households at the top of the wealth distribution sell assets at an higher price while middle-class households accumulate wealth and buy equity at an higher price.[11] The left panel of Figure **??** shows the distribution of consumption gains and losses from realized capital gains in the model.[12] The total amount of resources redistributed across households is exaclty 0.06%, the net effect on aggregate consumption is exaclty zero. The size of the asset redistribution can also be computed from the right panel of Figure **??** as the absolute value of the sum of all the consumption losses in the bottom and middle sections of the wealth distribution. Finally, note from the right panel in Figure **??** that without capital gains the consumption responses to real interest rate changes are small and stable across wealth groups. Thus, while households at the bottom 50% of the wealth distribution gain from lower real interest expenses, the consumption response of households at the top is driven by asset price dynamics. Overall, these results show the effects of asset price changes in HANK models.

The consumption responses are also heterogeneous within the top 10%. Consumption increases by less at the very top because these households also face the largest decline in financial income. Over time higher asset prices reduce asset returns. As a result the negative income effect of interest rate changes increases relative to the substitution effect. Therefore, the response of wealthy households at the top 10% does not reflect a disproportionately high response of the top 1%. Finally, it is important to stress two limitations of the analysis. First, the model matches the consumption share of the middle-class, but overestimates the consumption share at the top 10% and underestimates the consumption share at the bottom. This observation hardly changes the qualitative conclusions. However, this can be important for the quantitative implications about the relative size of the contributions to aggregate consumption from households at the tails of the wealth distribution. Second, the model feature a simple asset structure with an equal incidence of asset prices across the wealth distribution. In the Appendix **??** I discuss household portfolio composition by liquid wealth.

Existing studies often emphasize the role of constrained households and bottom wealth groups more broadly for the amplification and propagation of aggregate shocks, including monetary policy shocks, (Kaplan, Moll, and Violante (2018), Krueger, Mitman, and Perri (2016)). The cross-sectional patterns in Figure **??** confirm this prediction. However, the wealth dynamics highlighted in this section show that also income and wealth effects at the right tail of the wealth distribution play a role for the aggregate effects of monetary policy.

[11] Households at the top of the distribution have large asset holdings relative to their wealth targets, while households in the middle-class tend to have asset holdings below their wealth targets and plan to accumulate wealth.

[12] To compute the realized gains define wealth $a_t = q_t k_t$, the real return $r_t = (u_t + dq_t)/q_t$ where $u_t$ is a yield component of the return, and gross saving $da_t = dq_t k_t + q_t dk_t$. Then, rewriting household balance sheets as $dq_t k_t + q_t dk_t = (y_t + r_t q_t k_t - c_t)$ where $y_t$ is nonfinancial income, $k_t$ is the equity share I obtain $dc_t = -dk_t dq_t$.

### 1.5.4 Effects of monetary policy on inequality

In this section I investigate the distributional implications of monetary policy for consumption, income, and wealth. In principle U-shaped consumption responses can increase or decrease consumption inequality depending on whether consumption gains are more concentrated at the top or at the bottom. The empirical evidence on the distributional effects of monetary policy is still mixed. Using data from the Consumer Expenditure Survey, Coibion, Gorodnichenko, Kueng, and Silvia (2017) find that expansionary policy decreases consumption inequality, while Chang and Schorfheide (2022) conclude that inequality increases.

Table 1.6: Response of Gini indices.

| Gini response | Consumption | Income | Wealth |
|---|---|---|---|
| On impact | −0.06 | −0.2 | −0.01 |
| 2 years cumulative | −0.12 | −0.5 | −0.08 |

Note: Percentage points deviations of each Gini index from steady state.

In the model inequality decreases over all dimensions. Table **??** shows the percentage deviations of Gini indices from steady state. Therefore, if for example the Gini index falls from 60.2 to 60.0, then this corresponds to a 0.2 decrease in the columns of Table **??**. In the model wealth inequality barely moves on impact and over time. There are several factors contributing to this result. On one hand, capital gains from asset prices increase wealth inequality. However, wealthy households are those who reduce their savings the most both on impact and over time contributing to to the decrease in inequality. The effects of household saving decisions on wealth holdings tend to be quite persistent, as a consequence the wealth distribution adjusts slowly over time. Therefore, the changes in the wealth distribution over the first and second year after the monetary policy shock mainly reflect past household saving decisions. Over time middle-class households accumulate enough assets and further reduce the wealth gap. The decrease in the Gini coefficient of income is mainly driven by a reduction in the concentration of financial income, reflecting the lower wealth inequality. In turn, the lower income inequality leads to lower consumption inequality. In the model after a monetary policy expansion low-wealth households increase their consumption the most with respect to their initial level. This is consistent with the results of the previous section. The reason is that households at the bottom of the wealth distribution also have low consumption shares and the impact of these consumption changes on the aggregate is weaker than for top wealth groups.

## 1.6 Conclusion

In this paper, I build a quantitative HANK with equity prices to study the income and consumption responses of different wealth groups to monetary policy and assess the macroeconomic implications of wealth concentration at the top. I show that the calibrated model reproduces key features of the distributions of consumption, income, and wealth in the US. I also provide evidence on the distribution of low-liquidity households along the wealth dimension and show that the model is broadly consistent with this evidence and with the estimates of MPCs from external studies. So, the model generates realistic MPCs and wealth inequality.

In my quantitative analysis, I find that the dynamics of the wealth distribution can have a substantial impact on aggregate consumption. In particular, I show that households at both tails of the wealth distribution display the largets responses and account for most of the aggregate effects of monetary policy, leading to U-shaped consumption responses across the wealth distribution. In the model wealthy households in the top $10\%$ have the largest impact on aggregate consumption. This result depends on the high exposure of wealthy households with sizable consumption shares to changes in equity prices.

The results provide new quantitative insights on the role of household heterogeneity and changes in the wealth distribution for the effects of monetary policy. These findings demonstrate that wealth concentration at the top of the distribution can shape the aggregate effects of monetary policy. The important role of top wealth groups calls for a deeper analysis of the consumption responses to monetary policy and the transmission channels that are particularly relevant for the middle-class and wealthy households, such as mortgage rates and business income. These other dimensions can be investigated in future research and will be useful to guide the development of HANK models.

# Chapter 2

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

Valerio Pieroni[1]

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:* D31, E32, Q43.

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## 2.1 Introduction

The energy crisis is one of the most critical issues facing European societies today. What is the impact on output, employment, and inflation of energy shortages and who bears the economic costs? This paper seeks to answer these questions. 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 fully 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 $\sigma$. 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.[2]. 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

[2] 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 (2017).

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.

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 HANK model with flexible wages and energy consumption only for production. These assumptions simplify the analysis and make the model more transparent without significantly changing the range of estimates that can be obtained from the model. I find that in the model energy shortages lead to a GNI decline in range between 0.8% and 3.4%. Table **??** reports the quantitative results from the model for different values of the elasticity of substitution $\sigma$. 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 2.1: 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 into 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 **??** 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 **??** the economic cost remains manageable. In particular, I will show that social insurance can mitigate the unequal effects and the aggregate income loss.

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 accommodative 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 other 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 harmonized 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. Third, given that the paper focuses on short run effects the model abstract from capital accumulation and investment. Introducing investment in the model can further amplify the aggregate demand effects. Since the model features sizable marginal propensities to consume, lower investments can reduce household income leading to an additional reduction in aggregate consumption. However, the investment channel is more likely to have a larger effect over time rather than on impact. Finally, the critical role of labor market adjustments for consumption dynamics that I highlight in this paper calls for an analysis that explicitly includes unemployment and an extensive margin of adjustment. In the model the labor supply decisions can be interpreted as hours worked or number of workers, both interpretation are isomorphic and allows me to capture labor market adjustments on the intensive margin. Therefore, while the model features variations in the employment rate, the presence of an extensive margin can provide a more complete quantification of the labor income effects.

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

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), Luetticke (2021), Kaplan and Violante (2021), Auclert, Rognlie, and Straub (2020), Wolf (2021), Auclert, Rognlie, Souchier, and Straub (2021)). Relative to these papers I introduce energy consumption in the HANK framework to quantify the business cycle implications of energy shortages due to fluctuations in aggregate demand through general equilibrium effects. Importantly, I illustrate quantitatively how these results depend on several dimensions of economic inequality and on the energy elasticity of substitution by households and firms. I find that the unequal consumption and income effects of energy supply shocks substantially increase the aggregate costs. Finally, this paper provides a new macroeconomic framework to study other topical problems related to energy consumption such as the transition to clean energy and its implications for macroeconomic policies.

In the second strand of the literature I add to the work of 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 supply 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 used in the estimation.

This paper is also related and contributes to a recent and growing literature on energy prices and economic inequality (Douenne, Hummel, and Pedroni (2022), Fried, Novan, and Peterman (2022), Goulder, Hafstead, Kim, and Long (2019)). This literature extensively studies the distributional effects of carbon taxes. In a recent work Känzig (2022) finds evidence that carbon taxation has a larger impact on low-income households. So far, the literature has mostly focused on carbon pricing, in this paper instead I study energy shortages. While some of the mechanisms are the same there are fundamental differences to highlight. First, the energy shock studied in this paper reduces the quantity of energy inputs that are available in the economy and at the same time increases energy prices. Therefore, one critical issue studied in the paper is to what extent households and firms can reduce energy consumption. Second, the literature mostly focuses on shocks that increase energy prices by $1\%$. In this paper I study a shock that increases energy prices by more than $100\%$. To study such a significant deviation from the steady state I rely on global methods and solve for the dynamics of the nonlinear model. The literature on carbon pricing finds that even small changes in energy prices have significant macroeconomic effects in normal times. I study to what extent is possible to save on energy consumption and substitute energy inputs during exceptional times. Third, in the context of carbon pricing policymakers might face a trade-off between efficiency and equity objectives. On one hand, the carbon tax reduces the externalities generated by carbon emissions. On the other hand, the tax burden might fall mostly on low-income households that consume a larger share of polluting goods. In the case of energy shortages social insurance does not generate such trade-offs. I show that targeted social insurance programs leave relative prices and substitution incentives unchanged and do not lead to higher inflation avoiding regressive effects.

**Outline**. The remaining of the paper is organized as follows. Section **??** presents the model. Section **??** describes the parametrization and validation of the model. Section **??** contains the main quantitative results. Section **??** explores policy implications. Section **??** concludes.

## 2.2 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 $\sigma$-algebra generated by the Borel $\sigma$-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.

### 2.2.1 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 $\sigma$, and $\alpha$ 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

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

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

$$a_t \geq -\phi,$$

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 $\sigma_e$ is the standard deviation rate of the log-income process, $\nu_e$ 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 $\theta_w$ 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 $v(n) := n^{1+\nu}/(1+\nu)$ 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

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

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

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

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

See Appendix **??** 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

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

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

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

### 2.2.2 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 $\sigma$ is the elasticity of substitution between production factors and $\alpha$ 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 **??** for further details. Note that the distribution parameter $\alpha$ and the elasticity of substitution $\sigma$ 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 **??**.

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 households 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.

### 2.2.3 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 $\epsilon_t$ 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 $\phi_\pi$. In Section **??** 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 $\pi$ is a national inflation rate while the nominal interest rate $i$ depends on the EA harmonized 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 **??** I also explore the sensitivity of the results to this third assumption.

### 2.2.4 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 $r_t B$ and profit margins. 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.

## 2.3 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 $\gamma, \nu$, the borrowing limit $\phi$, and the Taylor coefficient $\phi_\pi$ to values common in the literature. The value for $\phi$ 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 $\theta_p$ to match a steady state profit share of income $1/\theta_p$ equal to $10\%$, and the price adjustment cost parameter $\Psi_p$ to match a slope of the Phillips curve $\theta_p/\Psi_p$ of $0.1$. Following the literature I set the parameters of the wage Phillips curve $\theta_w, \Psi_w$ 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 $\nu_e, \sigma_e$ 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 $\sigma, \alpha$ 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 **??** shows the calibrated parameters in the baseline case.

Table 2.2: Model parameters

| Parameter | Description | Value | Source |
|---|---|---|---|
| *Households* | | | |
| $\gamma$ | CRRA/Inverse IES | 1 | External |
| $\nu$ | Frisch elasticity of labor supply | 1 | External |
| $\phi$ | Borrowing limit | 1 | External |
| $B$ | Net asset supply | 5.8 | Internal |
| $\rho$ | Discount rate (p.a.) | 8% | Internal |
| $\underline{c}$ | Minimum consumption | 0.0015 | Internal |
| $\nu_e$ | Mean reversion coeff. | 0.0263 | External |
| $\sigma_e$ | S. d. of innovations | 0.2 | External |
| *Firms and policy* | | | |
| $\sigma$ | Elasticity of substitution | 0.1 | External |
| $\alpha$ | Distribution parameter | 0.04 | External |
| $E$ | Energy supply | 0.067 | Internal |
| $\Psi_p$ | Price adjustment cost | 100 | PC slope of 0.1 |
| $\Psi_w$ | Wage adjustment cost | 100 | External |
| $\theta_p$ | Intermediate goods elasticity | 10 | Profit share of 0.1 |
| $\theta_w$ | Labor inputs elasticity | 10 | External |
| $\phi_\pi$ | 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 **??** 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 **??** 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.

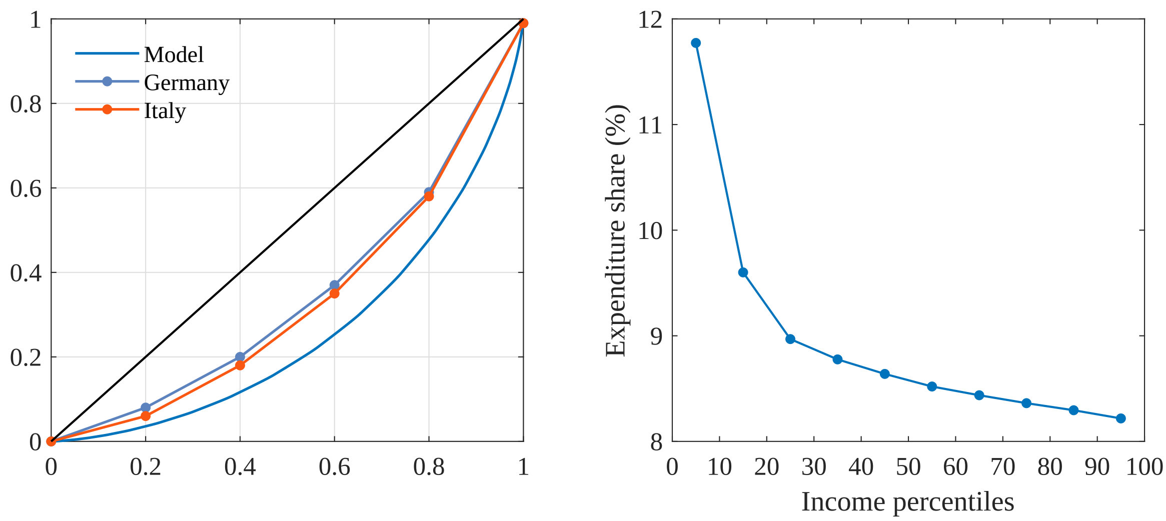


Figure 2.1: Income distribution and energy consumption.

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 **??** 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 **??** 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 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.

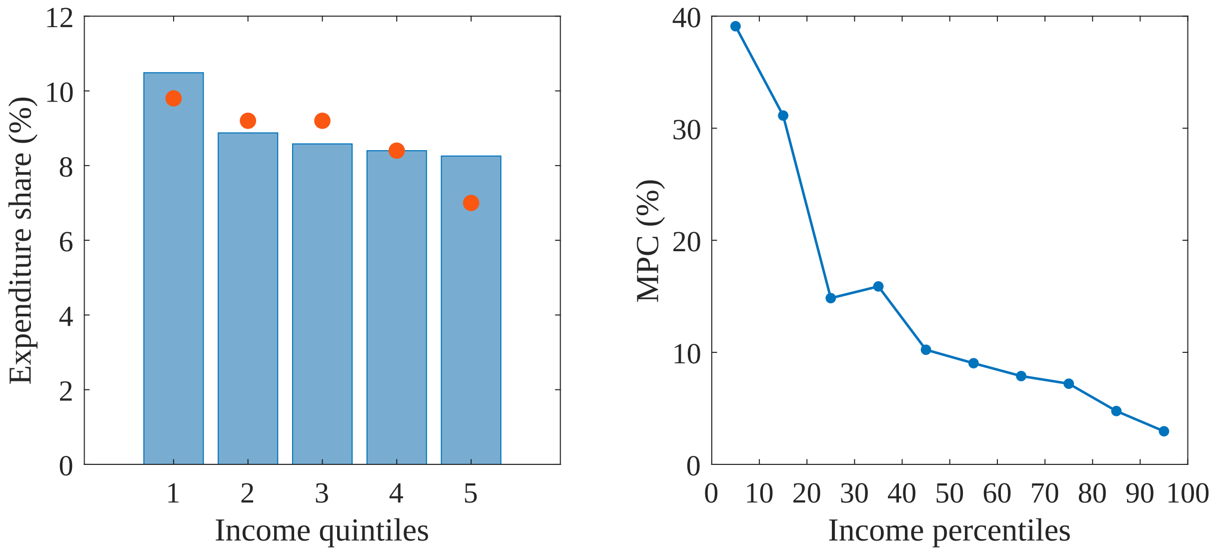


Figure 2.2: Energy expenditure and MPCs across the income distribution.

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.

## 2.4 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.

### 2.4.1 Quantitative results

Figure **??** 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.

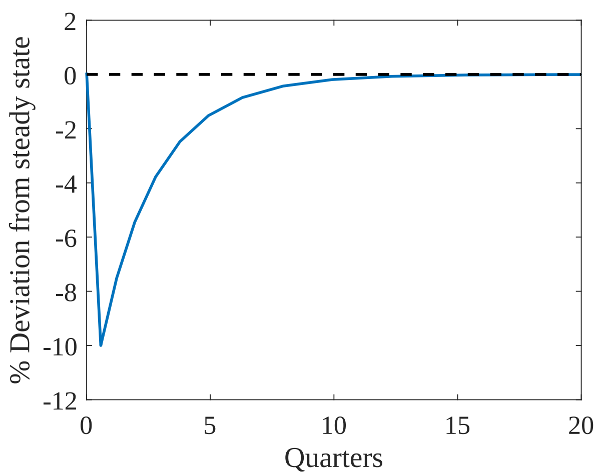


Figure 2.3: Energy supply shock.

Figure **??** 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 **??** I evaluate the importance of each channel.

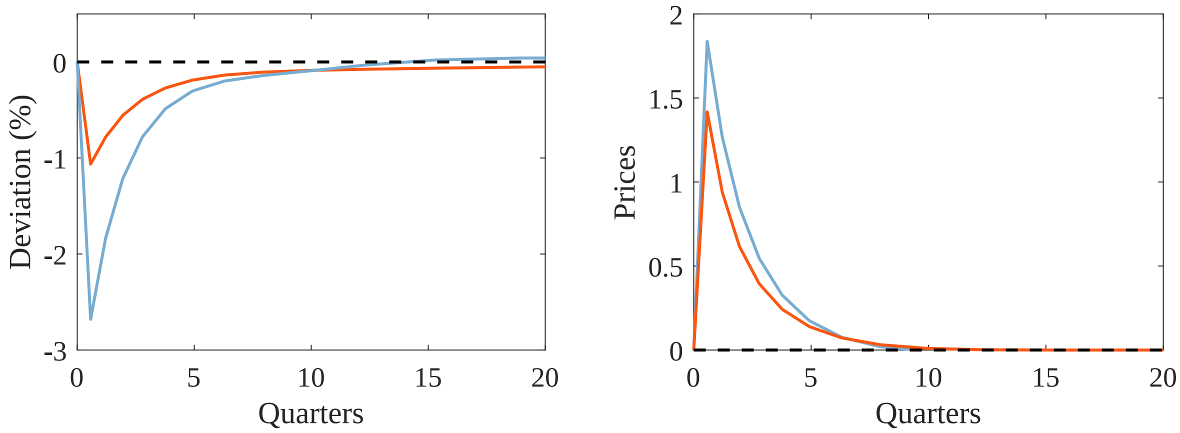


Figure 2.4: Impulse response functions to the energy shock.

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 **??** 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 140% or by a factor of 2.4. The inflation rate is 3.2% over the first year, this is the contribution of the shock to annual inflation. 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 **??** 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.

The costs of energy supply shortages are not borne equally 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 **??** shows the cross-sectional effects of the energy supply shock.

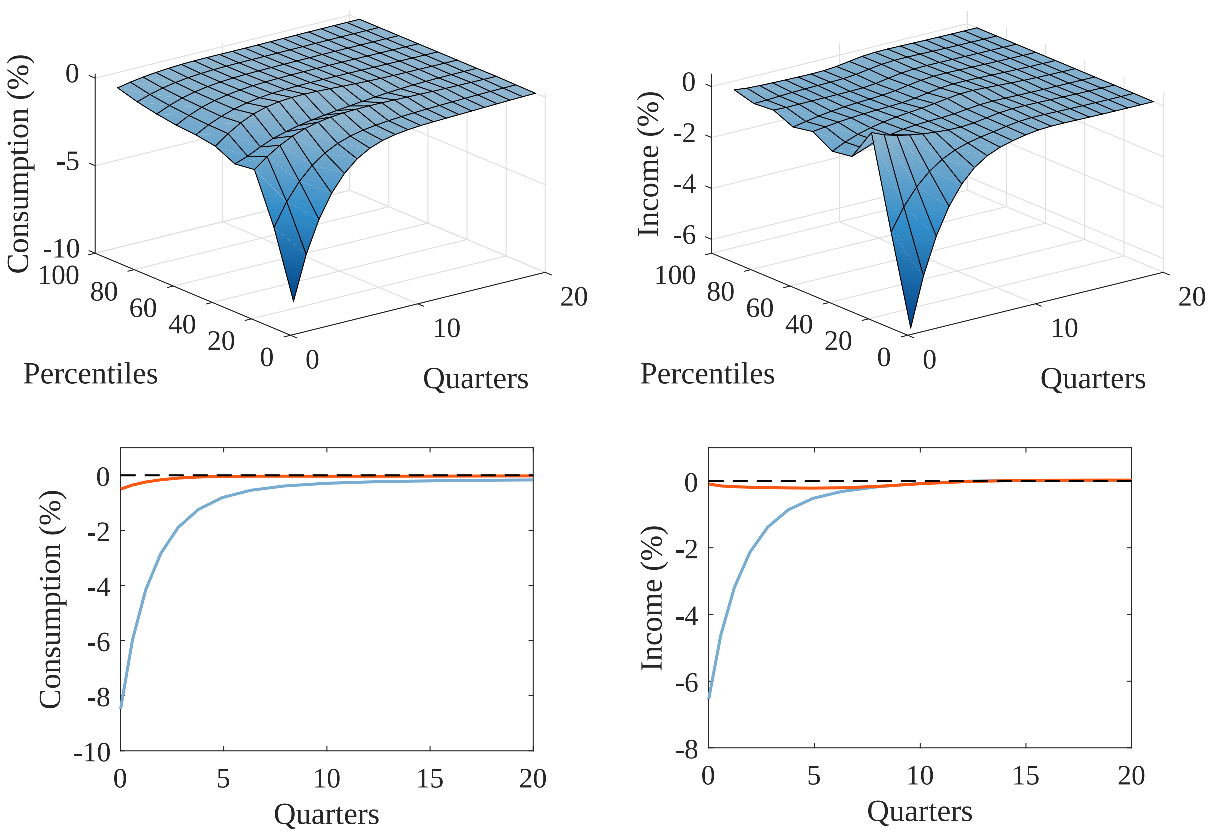


Figure 2.5: Consumption and income responses across the income distribution.

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 ?? 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%.[3] 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 2.3: The effects on inequality

| | Consumption | Income | Wealth |
|---|---|---|---|
| $\Delta$ Gini coefficient | 0.5 | 0.6 | 0.2 |

Table ?? 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.

[3]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.

### 2.4.2 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 $N_t$.

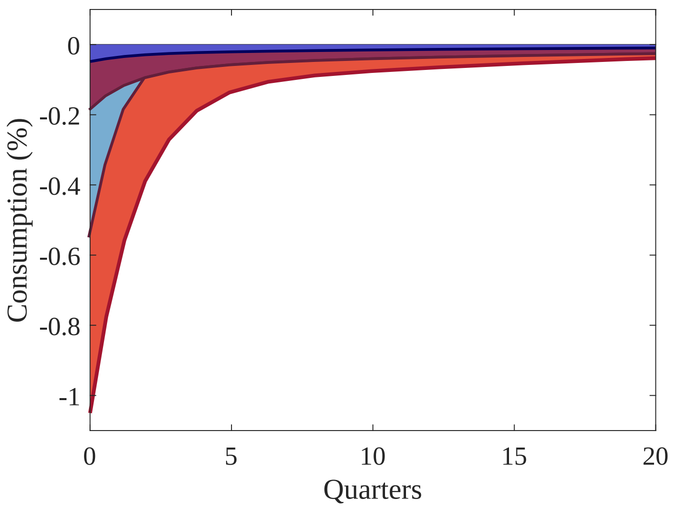


Figure 2.6: Consumption decomposition.

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

Figure **??** shows the decomposition of the aggregate consumption response.[4] 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 **??**, 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.

[4]The Appendix **??** contains further details on this decomposition.

### 2.4.3 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 with fully flexible 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 follow the same calibration strategy as for the 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 **??**. Also, the targeted statistics generated by the model are almost unchanged. In the 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 **??** all these values are at the lower bound of empirical estimates. Figure **??** and Figure **??** 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 several 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 version of the model wages are fully flexible.

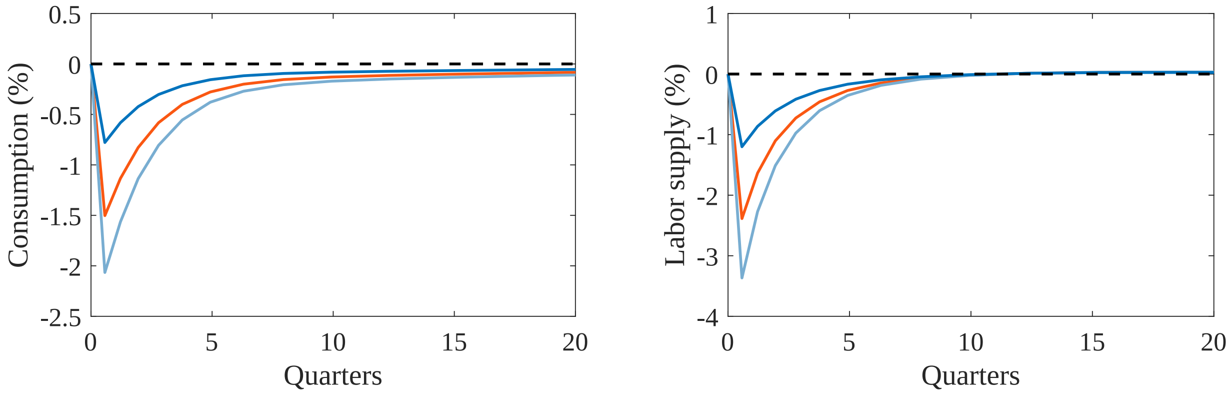


Figure 2.7: Impulse response of quantities to energy supply shock.

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).

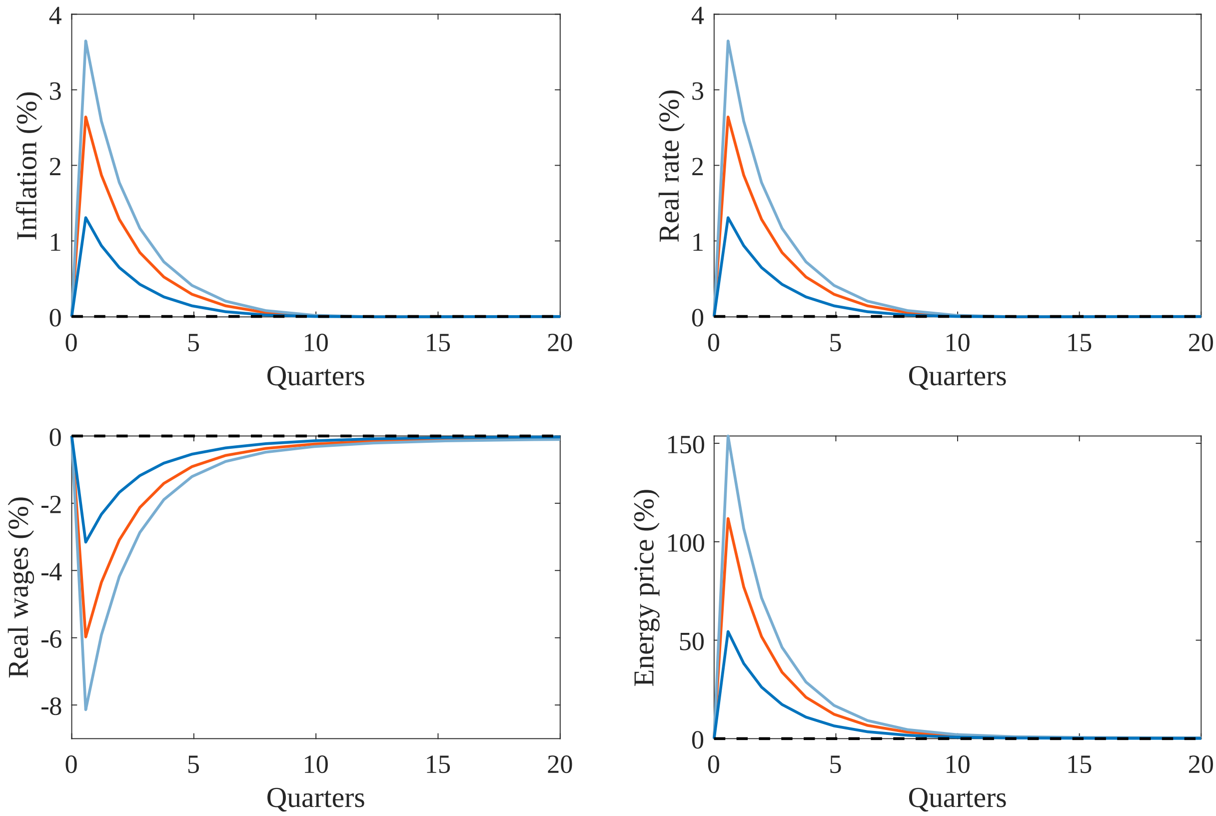


Figure 2.8: Impulse response of prices to energy supply shock.

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 **??** shows the impulse response functions. Aggregate 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.

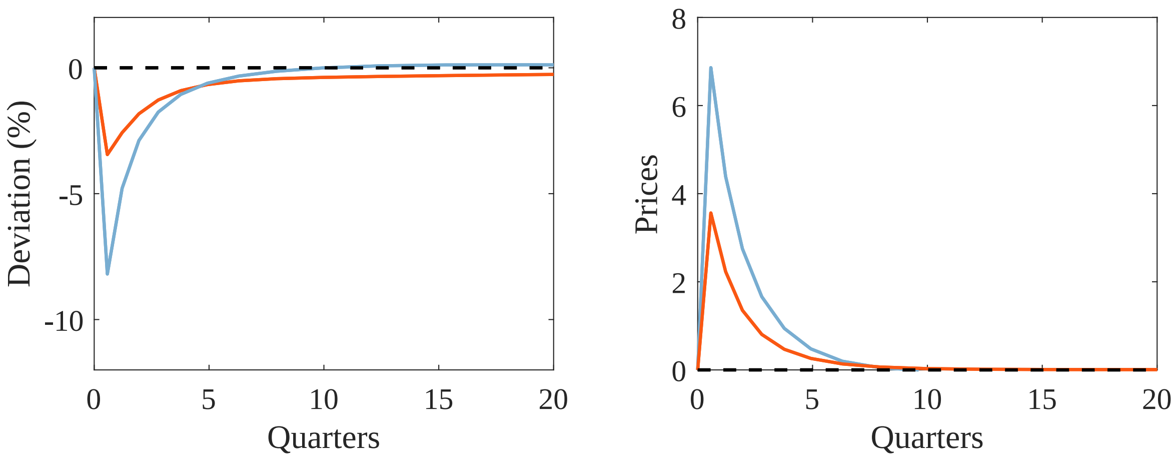


Figure 2.9: Impulse responses to a $-30\%$ energy shock.

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. $\sigma = 0.16$.

## 2.5 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.

### 2.5.1 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 **??** 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 accommodative monetary policy stance relative to the baseline where the central bank also respond to changes in the economic activity.

Figure **??** shows the response of aggregate consumption, employment, real interest rates, and inflation to the energy supply shock across Taylor rules. Under the more accommodative 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.

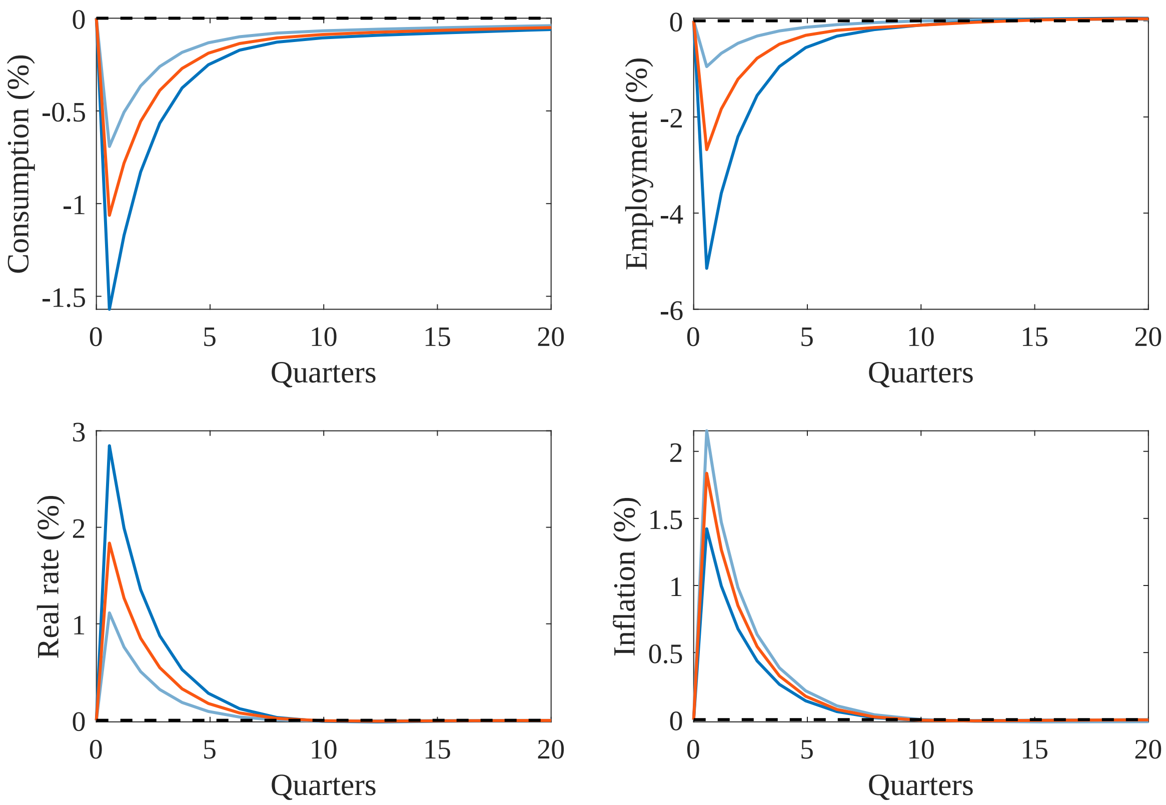


Figure 2.10: Monetary policy and energy shortages.

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 accommodative 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 accommodative 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 accommodative 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 supply shortfall.

### 2.5.2 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 **??** 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 amount 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 **??** 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.

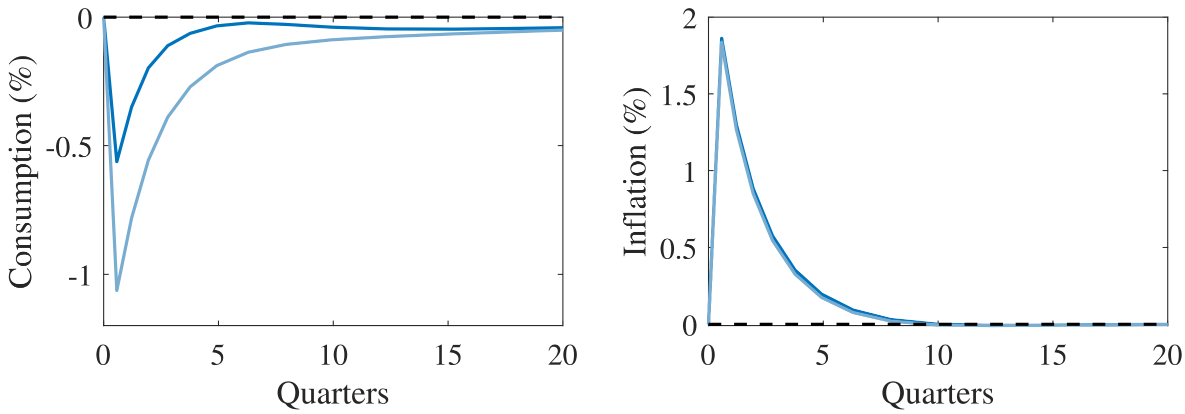


Figure 2.11: Fiscal policy and energy shortages.

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 **??** 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.

Figure ?? shows the cross-sectional responses of market income and consumption to the social insurance transfers at the bottom 20% of the income distribution. In particular, I study the responses of the two bottom deciles targeted by the social insurance policy depending on the size of the transfer $b_0$. First, note that the transfer, regardless of its size, has little impact on market income. The only effect with respect to the case without policy is due to a lower labor supply and its impact is quantitatively small. On the other hand, the transfer provides consumption insurance. If the initial transfer is equal to 5% of average income as in Figure ?? consumption of low-income households increases. This stimulus effect reflects a large increase in household disposable income as this initial transfer corresponds to 50% of the average income at the bottom 10% of the distribution and 25% of the average income of the next decile. In the bottom panels I study the effects of a smaller transfer that eliminates the consumption loss of the bottom 10% and brings the consumption loss of the second decile to 1%, in line with the consumption loss of other income groups. This policy reduces the aggregate loss by 0.2 percentage points or by 20%. Therefore, even a modest social insurance program if targeted to the most exposed and vulnerable households can have substantial aggregate effects and mitigate the amplification effects of energy shortages without generating additional inflation.

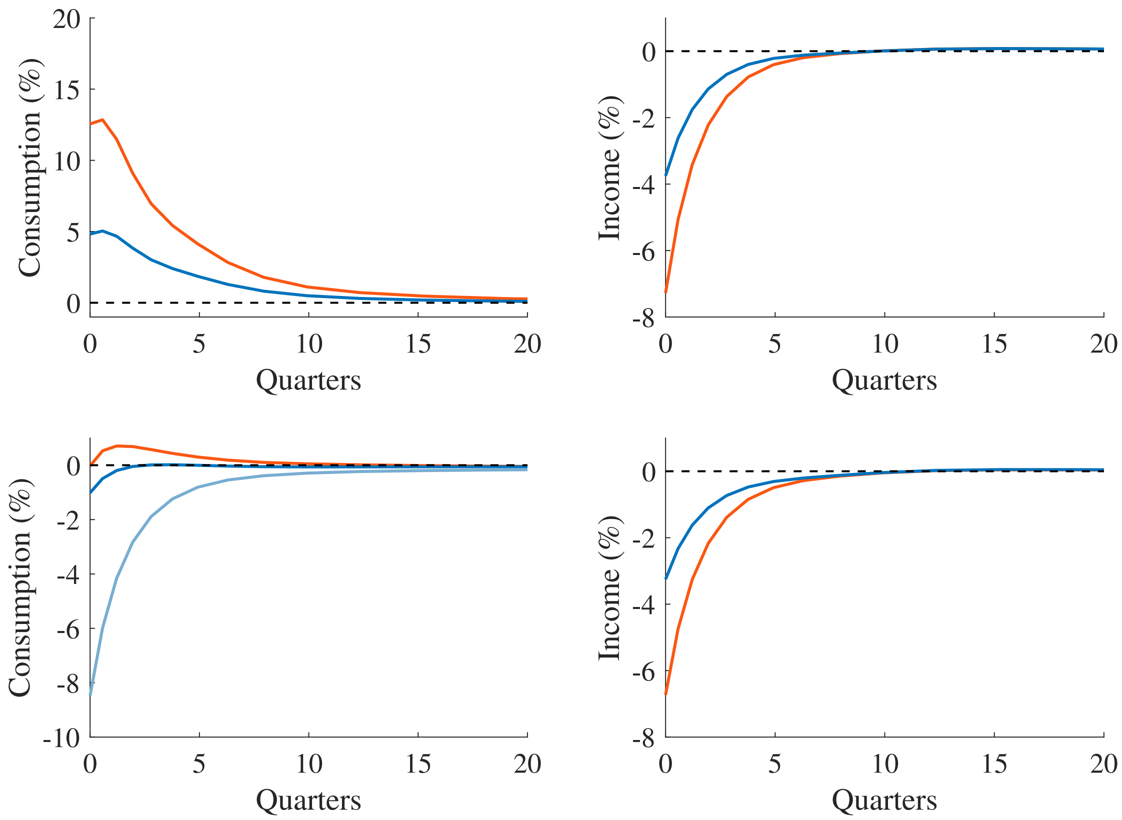


Figure 2.12: Cross-sectional responses.

Note: The figures show the average consumption and income responses to social insurance transfers of the first decile (orange) and second decile (blue) of the income distribution. In the upper panels $b_0$ is 5% of average income. In the lower panels $b_0$ is 1.5% of average income. The third panel also shows the consumption response of the bottom 10% without fiscal policy (light blue line) as in Figure ??.

## 2.6 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.

# Chapter 3

# Monetary Policy Betas: Evidence from Italy

Valerio Pieroni[1]

This paper provides new empirical evidence on the heterogeneous effects of monetary policy. Using a series of identified monetary policy shocks and the Italian Survey on Household Income and Wealth (SHIW), I estimate the responses of households' consumption and income to monetary policy by net worth. I find that high-wealth and low-wealth households show large consumption responses. I show that interest rate cuts increase employment opportunities for low-wealth households. At the same time, expansionary monetary policy shocks lead to capital gains at the top of the distribution.

*Keywords:* Income, Consumption, Wealth, Monetary Policy, Inequality.
*JEL:* E21, E40, E52.

[1]I would like to thank Raul Santaeulalia-Llopis for his guidance and support. I thank all the participants at Macro Club of Universitat Autonoma de Barcelona for helpful feedback and comments. All errors are my own.

## 3.1 Introduction

In recent years, researchers have documented important macroeconomic implications of household heterogeneity using micro evidence and structural Heterogeneous Agents New Keynesian (HANK) models (Kaplan, Moll, and Violante (2018), Lee (2021)). This work emphasizes several transmission channels of monetary policy to household consumption operating through financial income, business profits, and labor market effects. As a result empirical research on the distributional outcomes of monetary policy has become an important issue in monetary economics (Amberg, Jansson, Klein, and Rogantini Picco (2022b), Holm, Paul, and Tischbirek (2021b)). The aim of this project is to provide new evidence on the cross-sectional effects of monetary policy.

In this paper I construct a time series of monetary policy shocks for the European Central Bank, and using the Survey of Household Income and Wealth (SHIW) from the Bank of Italy I investigate income and consumption responses to monetary policy across the wealth distribution. The microdata is particularly useful as it measures the joint distribution of consumption, income, and wealth over an extended period of time and has a large panel component. These information, not always available for many advanced economies, allow me to document the effects of monetary policy by households' net worth. This paper presents two main findings. First, I document U-shaped consumption responses across the wealth distribution. Households at the bottom 20% and at the top 20% show the largest consumption adjustments. These responses are almost two times the response of the wealth group that contains the median household. Second, I connect these consumption dynamics to changes in the unemploymnet rate for low-wealth households and to capital gains due to changes in stock prices for households at the top of the wealth distribution. These results are important because they provide new evidence on the transmission mechanisms of monetary.

The key advantage of the SHIW is that it provides comprehensive information on household consumption, income, and wealth. The limitation is that the microdata is a biannual survey and therefore has a low frequency. As a consequence, in this paper I try to exploit mostly the cross-sectional dimension rather than the time dimension. I begin with a descriptive analysis of the main variables in the SHIW. In particular, I focus on nondurable consumption, household earnings from wages and self-employment income, and net worth. Therefore, my analysis includes both liquid and illiquid assets such as housing and private business ownership. Moreover, the microdata allows me to compute asset holdings across broad asset classes and study households' portfolio composition by net worth. I document a substantial heterogeneity in asset holdings. In summary, households at the bottom 50% of the wealth distribution tilt their portfolios toward liquid assets such as bank deposits and government bonds. Housing is the asset of the middle-class, from the 50th to the 90th wealth percentile. Wealthy households at the top 10% of the distribution invest their savings in stocks and equities. This evidence is consistent with the findings of the most recent literature (Fagereng, Holm, Moll, and Natvik (2021)). Since the literature has extensively studied the role of home equity, mortgages, and business profits for the transmission of monetary policy is important to include these elements in my analysis and study households' responses by net worth.

To study the effects of conventional monetary policies I first need exogenous variations in the main policy rate. I identify monetary policy shocks with the high-frequency approach (Jarociński and Karadi (2020)), using financial data from the Euro Area Monetary Policy Event Study Database (Altavilla, Brugnolini, Gürkaynak, Motto, and Ragusa (2019)). I employ the SVAR with external instruments (SVAR-IV) framework (Stock and Watson (2012), Mertens and Ravn (2013)) to estimate the aggregate effects of interest rate changes and validate the construction of the monetary policy shock series. Then, I study the cross-sectional impulse response functions to monetary policy estimated using a set of local projections with instrumental variables (LP-IV) (Jordà (2005), Stock and Watson (2018), Jordà, Schularick, and Taylor (2020)). This is the main econometric framework that I use for my analysis of the heterogeneous effects of monetary policy.

My main finding is that consumption of households at the bottom and at the top of the wealth distribution increases substantially relative to other wealth groups. These effects tend to be present after two years from an expansionary monetary policy shock, when the effect of monetary policy on aggregate variables reaches its peak. To better understand these effects I also study the response of household disposable income. I find a hump shaped response across the wealth distribution. Together with the U-shaped consumption response this implies that households tend to save most of these income gains. Then, I also decompose the response of income between nonfinancial income sources and financial income sources excluding capital gains that are not reported in the SHIW. I find that labor earnings drive most of the total income effects. Mortgages and house prices can be important to account for the response of middle-class households, but the large consumption changes at the tails of the distribution require to also investigate alternative transmission channels. Thus, since household labor earnings cannot explain the consumption effects of monetary policy at the tails of the wealth distribution I consider different channels.

The first channel works through changes in the unemployment gap between low-wealth households and the other wealth groups. In particular, I define an household as unemployed if the household head, namely the major income earner of the family, is unemployed. First, I document a large unemployment gap between households at the bottom 20% of the wealth distribution and households in the middle-class. The share of unemployed households at the bottom 20% is more than twice the fraction of unemployed households in the middle-class. A linear probability model shows that households at the bottom 20% of the distribution are more likely to find an occupation after expansionary monetary policy shocks. While this effect is somewhat weak the unemployment response of the other wealth groups is almost null. Therefore, this evidence suggest that accomodative monetary policies do have positive effects on the unemployment gap increasing the employment opportunities for low-income workers at the bottom of the wealth distribution seeking for an occupation. These effects are consistent with the findings of the literature studying the effects of monetary policy in the context of heterogeneous agents models with labor market frictions (Gornemann, Kuester, and Nakajima (2021)).

The second channel is given by the effect of monetary policy on households' wealth through changes in stock prices. In advanced economies wealth tend to be highly concentrated at the top of the distribution in the form of equity holdings (Hubmer, Krusell, and Smith (2021)). Since wealthy households hold most of the publicly traded equity, changes in stock prices can have a substantial effect on households' wealth. These effects can stimulate consumption directly through a standard wealth effect or increase the income of prospective sellers as emphasized in Fagereng, Gomez, et al. (2022). I try to quantify these effects using the response of stock prices to monetary policy shocks and the SHIW data on households' portfolios. First, I estimate a set of local projections with a monthly time series for stock prices and monetary policy shocks. I find that on average after two years from an interest rate cut of 25 basis points stock prices rise by 1.1%. Then, I leverage the portfolio shares from the SHIW mcirodata to estimate the total capital gains in each year following the expansionary monetary policy shock. I find that in the second year the average capital gain for households at the bottom 20% of the wealth distribution is well below 100 euro, and households in the middle-class gain around 400 euro. On the other hand, wealthy households around the 80th wealth percentile gain more than 1,500 euro. These effects can be as large as 10,000 euro at the top 5%. Di Maggio, Kermani, and Majlesi (2020) also provide an empirical analysis on the wealth effects out of stocks and find small Marginal Propensities to Consume (MPCs) out of unrealized capital gains for Sweden. However, even if one use 3% as a benchmark consumption response out of capital gains, wealth effects can account for part of the consumption responses because the total capital gains can be very large. Moreover, some of these capital gains can generate income for those households that sell their stocks and the MPC out of this income gains can be even higher. Therefore, these estimates suggest that wealth effects can account for a significant fraction of the consumption responses at the top 20% of the wealth distribution.

At the current stage there are several limitations in my analysis that are important to highlight. First, measurement errors can be contributing to the sample variability of the estimates. However, note that in this application the measurament errors do not generate an attenuation bias on the estimates given the way in which monetary policy shocks are identified. For the same reason it is unlikely that measurament errors on the outcome variables are correlated with monetary policy shocks and therefore they do not induce a correlation between residuals and monetary policy innovations. Second, since the public microdata contains jackknife weights only for a limited sample period the estimated standard errors do not take properly into account the survey design of the SHIW.

In this paper I explore empirically the relationship between monetary policy and wealth inequality. I provide new empirical evidence on the effects of monetary policy at the tails of the wealth distribution and supporting evidence for transmission mechanisms of monetary policy that can account for at least part of these effects. This evidence is useful to guide the development of quantitative models with heterogeneous agents. Additionally, the findings in this paper complement the existing evidence and extend its validity across countries. Overall, by contributing to the empirical investigation of the transmission mechanisms of monetary policy this paper seeks to provide an improved understanding of how monetary policy shapes the economy.

**Literature**. This paper is related to a recent and growing literature on the distributional consequences of monetary policy. The existing literature focuses mostly on income and consumption inequality and the evidence is quite mixed. Coibion, Gorodnichenko, Kueng, and Silvia (2017) find that in the United States an expansionary monetary policy shock decreases income and consumption inequality. Instead Chang and Schorfheide (2022) find that expansionary monetary policy shocks reduce earnings inequality, but widen consumption inequality. Maffei Faccioli (2020) finds that interest rates cuts decrease income inequality. Studies based on administrative microdata respectively from Denmark and Sweden find that a more accomodative monetary policy increases income inequality (Andersen, Johannesen, Jorgensen, and Peydró (2021), Amberg, Jansson, Klein, and Rogantini Picco (2022b)). Recent papers have examined the effect of monetary policy on consumption and wealth. Bartscher, Kuhn, Schularick, and Wachtel (2021) document that in the United States expansionary monetary policy shocks lift black households out of unemployment, but also generate large capital gains for white households. Cloyne, Ferreira, and Surico (2020) find that the consumption response to monetary policy of households with a mortgage is larger than the response of outright home owners and renters. The reason is that mortgagors tend to have low liquid asset holdings and therefore high MPCs. Almgren, Gallegos, Kramer, and Lima (2022), Slacaleky, Tristani, and Violante (2020) also investigate the effects of monetary policy in the Euro Area with a focus on the role of liquid wealth. Holm, Paul, and Tischbirek (2021b) using administrative data from Norway find that the response of household expenditure is U-shaped across the distribution of liquid assets. So far the literature has focused on liquidity positions. In this paper I complement this work by studying the consumption responses throughout the wealth distribution including illiquid assets and household debt. These responses are informative about the transmission mechanisms of monetary policy given the systematic portfolio differences across wealth groups. The idea is that large consumption responses from middle-class households suggest an important role of house prices and mortgages for the transmission of monetary policy, while strong responses at the top indicate a critical role of the stock market. I document large consumption responses at the tails of the wealth distribution and provide evidence on the transmission mechanisms of monetary policy that can explain these consumption responses.

**Outline**. The paper is organized as follows. In Section **??** I present a descriptive analysis of household consumption, income, and wealth in the SHIW including household portfolio composition across broad asset classes. I also discuss the identification of monetary policy shocks. Section **??** presents the econometric framework. Section **??** contains the main results of the paper. Section **??** concludes.

## 3.2 Data

In this paper I estimate cross-sectional impulse response functions (IRFs) for consumption and income across the wealth distribution using Italy's Survey of Household Income and Wealth (SHIW) from the Bank of Italy, and a series of monetary policy innovations of the European Central Bank.

### 3.2.1 Household micro data

The Survey on Household Income and Wealth (SHIW) from Bank of Italy is the Italian component of the Household Finance and Consumption Survey (HFCS) from the European Central Bank (ECB). The SHIW is a biannual survey. The main advantage of the SHIW is that it provides comprehensive information on household income, consumption, and wealth. The analysis in this paper includes all waves from 2000 to 2016.

The interviews are collected in the first months of the calendar year. Income and consumption flows refer to the previous year, assets and liabilities are end-of-year values. Consumption is defined as household expenditure on nondurable goods. Disposable income is the sum of net earnings (labor income and self-employed income net of taxes), business profits and dividends, interest income net of interest expenses. Following the literature on heterogeneous agents models I focus on liquid wealth and net worth. Liquid wealth is given by liquid assets (bank deposits, government and corporate bonds, stocks and other financial assets). Total wealth or net worth is given by assets (real estates, private businesses, valuables, and liquid wealth) minus liabilities (mortgages, consumer debt).

The SHIW is a representative sample of the Italina resident population. The sample is drawn in two stages, at municipality and household level, with a stratification of municipalities by region and demographic size. Cross-sectional sampling weights are provided to obtain point estimates.[2] Cross-sectional Jackknife replication weights are provided to compute standard errors. Over the years the sample size reached 8,000 households and 20,000 individuals. The average participation rate across waves is around 50 percent for the whole sample and 80 percent for panel households. Since 1998 almost all the interviews are computer based. The average duration of an interview is 50 minutes. Questions concerning the whole household are addressed to the person most knowledgeable about the family finances. Jappelli and Pistaferri (2010), provide a comparison between national accounts and SHIW aggregates for consumption and income variables and find a close match.

I restrict the sample to households with more than one observation during the period 2000-2016, and with positive income and consumption. I also restrict the sample to families in which the household head, defined as the major income earner, is between 25 and 65 years old. The result is a pooled cross-section with 27,076 observations, that span from a minimum of 1,927 households in 2016 to a maximum of 3,614 households in 2012. The average number of house-

[2]The design variables in the public datasets are not provided to protect confidentiality.

holds per year over the sample period is 3,087. Demographic characteristics are defined relative to the household head. All monetary variables are adjusted for inflation with 2010 as a base year. Table **??** reports descriptive statistics. These are global statistics for the whole sample, that is they are constructed using family-year cells.

Table 3.1: Summary statistics.

| | Mean | Std. Deviation | 10th P. | Median | 90th P. |
|---|---|---|---|---|---|
| Consumption | 24,410 | 12,892 | 12,147 | 21,738 | 39,526 |
| Disposable income | 24,635 | 21,782 | 4,189 | 20,398 | 45,869 |
| Earnings | 23,982 | 21,223 | 1,865 | 20,098 | 44,939 |
| Profits and dividends | 586 | 5,926 | 0 | 0 | 0 |
| Interest income | 67 | 2,738 | -1,286 | 55 | 1,136 |
| Liquid assets | 26,470 | 90,045 | 0 | 7,459 | 58,609 |
| Illiquid assets | 222,614 | 408,801 | 0 | 147,591 | 479,535 |
| Total debt | 14,692 | 62,880 | 0 | 0 | 42,625 |
| Wealth | 239,423 | 438,626 | 2,141 | 151,375 | 516,975 |
| Age | 46.5 | 10.4 | 32 | 47 | 61 |
| Education | 3.5 | 0.8 | 3 | 3 | 5 |

Note: Summary statistics (weighted) for the overall sample in euro, 2010 prices. Data source: SHIW 2000-2016. See main text for variable definitions. Education can be equal to 1 (no education), 2 (elementary school), 3 (middle school), 4 (high-school), 5 (college), 6 (master or PhD).

In this paper I focus on the effects of monetary policy on different wealth groups. The remainder of the section illustrates characteristics of the income and asset composition of households along the wealth distribution.

Figure **??** shows the income and asset composition across wealth groups. Wealth groups are defined using the quantiles of the cross-sectional distribution of wealth. Namely, for each survey year $t$, I assign household $i$ to a wealth group $g$ if its wealth in $t$ is between the $(g-1)$-th and $g$-th ventile of the wealth distribution. Income sources are given as a percentage of disposable income and portfolio shares as a percentage of total assets. The figure shows group means averaged across years.

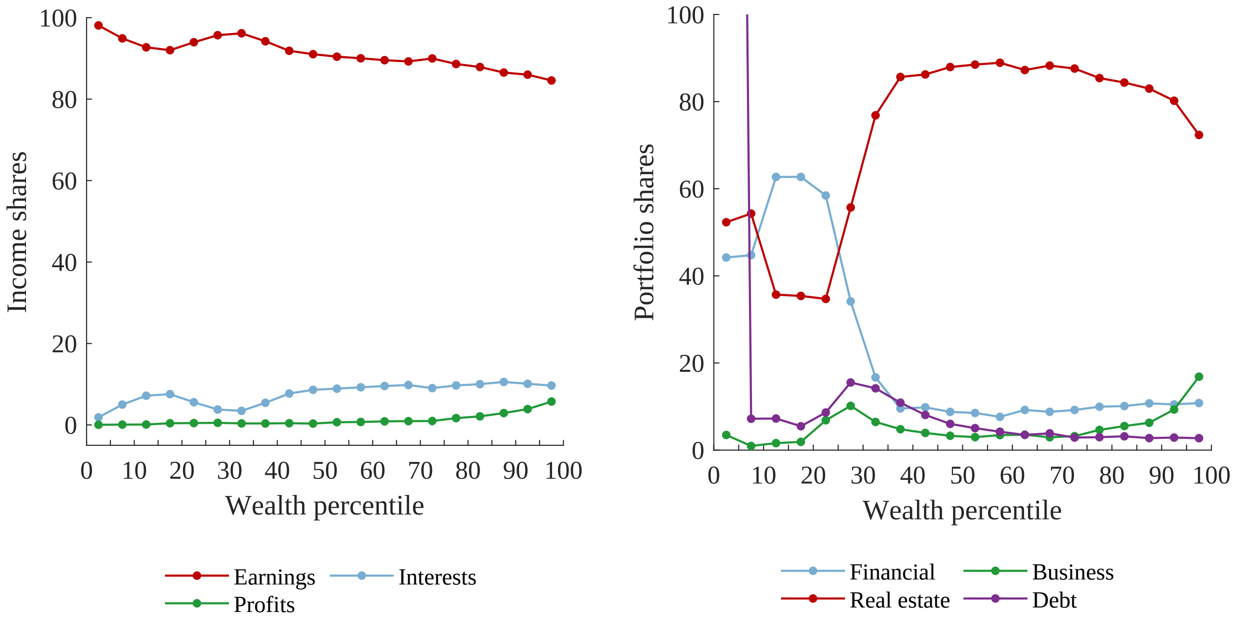


Figure 3.1: Income and assets by wealth.

Note: The left panel shows income sources as a share of disposable income. The right panel shows asset holdings as a share of total assets. Group averages shown.

Households rely almost entirely on labor earnings, either as workers or self-employed, throughout the wealth distribution. Capital income provides a substantial contribution to household incomes only at the top 10%. Among these households the income share of interests and dividends is around 15%. Households at the bottom 5% have negative wealth as the value of debt exceeds that of total assets. Overall, at the bottom of the distribution households wealth is held in the form of bank deposits. The increase in home equity and debt between the 20th and 40th percentiles, suggests that households in this wealth group take mortgages to become homeowners. Housing is the most important asset for the middle class, between the 50th and the 90th percentiles. At the top 10% there is a substantial increase in the share of private equity confirming the important role of entrepreneurs for top wealth groups.

### 3.2.2 Monetary policy shocks

Most of the variation of policy rates is due to the systematic response of policy to economic conditions. Then, to estimate causal effects of the policy on economic activity we need to isolate interest rate changes that are exogenous to economic conditions. I rely on the Euro Area Monetary Policy Event Study Database constructed in Altavilla, Brugnolini, Gürkaynak, Motto, and Ragusa (2019). The idea of this approach is to use high-frequency financial markets data around policy announcements to extract exogenous changes in the policy interest rate. The identifying assumptions are that in the narrow time window that goes from the ECB press release to the press conference changes in asset prices are not systematically affected by other news, and that monetary policy does not respond to asset price changes in this time window. I use changes in the 1-month Overnight Index Swap (OIS) rate to measure financial market surprises to monetary policy and the ECB interest rate on the Main Refinancing Operations (MRO) as the main policy rate.

I further clean monetary policy surprises from additional information released in the time window between the ECB press release and press conference by means of the sign restriction in Jarociński and Karadi (2020). The idea is to consider only meetings in which stock prices move in the opposite direction of interest rate surprises. The reason is that in the conventional monetary transmission mechanism of theoretical models stock prices increase in response to lower interest rates. A positive comovement suggests that the interest rate response to the announcement could be due to other news about the economy. To measure stock prices I employ the Eurozone stock index Stoxx50. Then, I regress changes in the ECB main policy rate decided in each meeting on the monetary policy surprise in that meeting

$$\Delta i_m = \alpha + \beta \Delta s_m + u_m.$$

The OIS rate time series contains information on both conventional and unconventional policy measures. To isolate the effects of the former type of measures I focus on the years from 2000 to 2014, before the ECB quantitative easing. The details of the estimation results are reported in the Appendix **??**. The monetary policy shocks are given by the fitted values $\epsilon_m := \Delta \hat{i}_m$ from this regression. I convert the frequency of monetary policy innovations observed at each ECB meeting into an annual time series summing up all the shocks within each year $\epsilon_t = \sum_{m \in t} \Delta \hat{i}_m$. Figure **??** shows the resulting time series of monetary policy innovations.

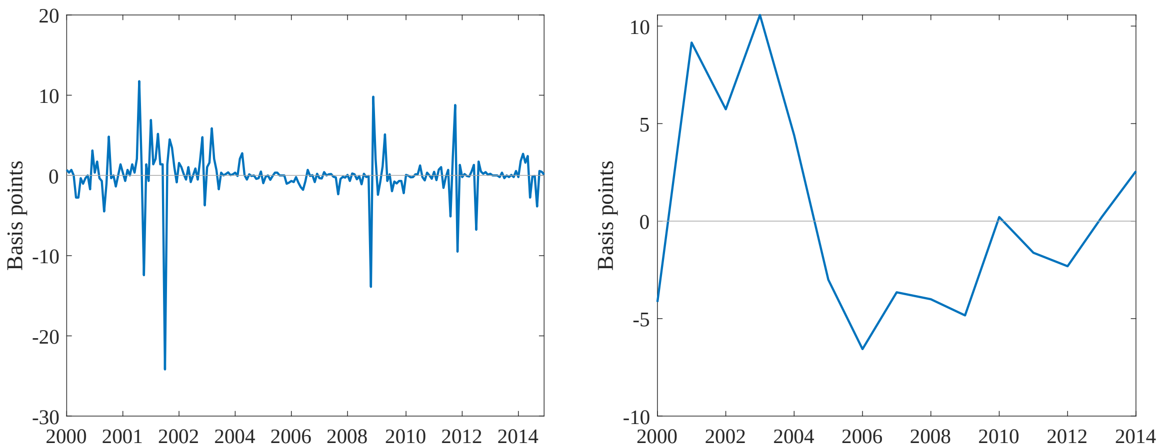


Figure 3.2: Monetary policy shock series.

Note: The left panel shows the time series of monetary policy innovations at daily frequency. The right panel shows the same time series at annual frequency.

### 3.2.3 Aggregate effects of monetary policy

I analyze the aggregate effects of monetary policy using a proxy SVAR with policy surprises as an external instrument (proxy). I use monthly time series for the period 2000M1-2016M12 from the ECB and Eurostat. The monetary policy surprise series is given by OIS rate changes. The VAR includes the following variables: the MRO rate, the log of industrial production, the unemployment rate, and inflation.[3] The VAR includes 12 lags and a constant. I estimate the model by ordinary least squares (OLS). I use a wild bootstrap to compute confidence bands from 1,000 bootstrap repetitions. The first-stage F-statistics is 16.6, so weak instrument problems are unlikely to be a major concern. The model delivers impulse responses that are broadly in line with the standard monetary policy transmission mechanism. Figure **??** shows that an exogenous 25 basis points interest rate cut increase economic activity and inflation.

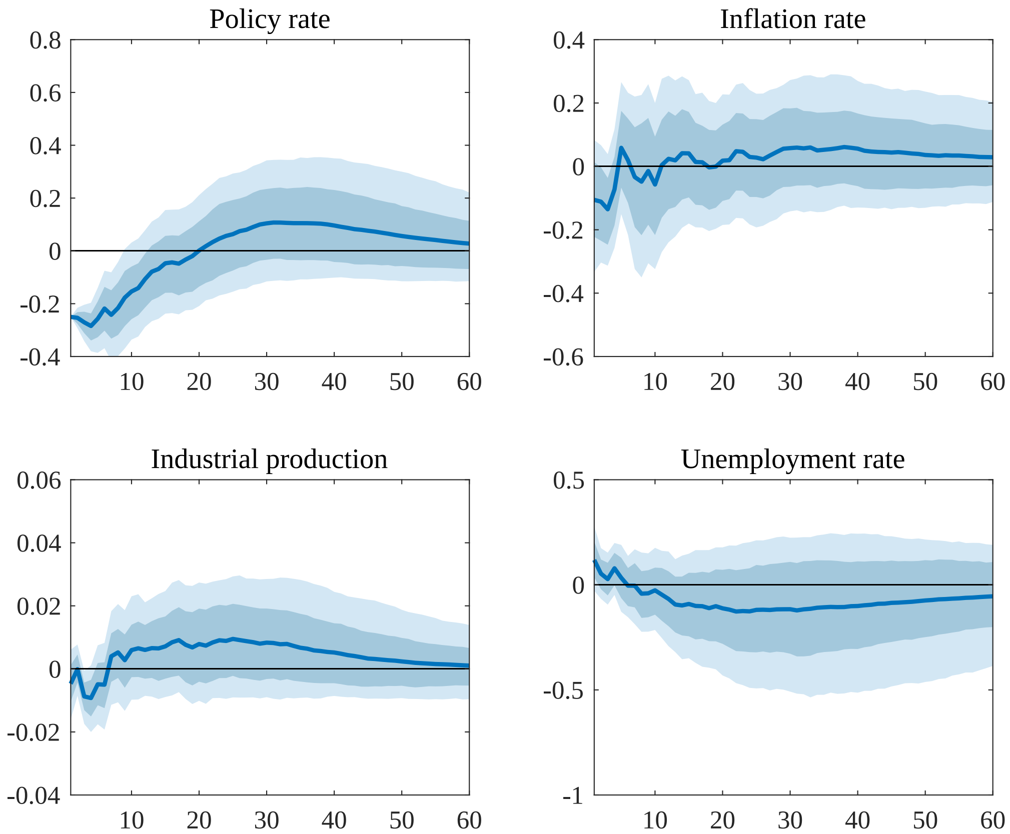


Figure 3.3: Aggregate responses to monetary policy.

Note: Solid lines show the estimates of the response to an exogenous reduction in the MRO rate by 25 basis points on impact. Shaded areas indicate 68% and 90% bootstrapped confidence intervals.

[3]To obtain the monthly time series of policy surprises, I aggregate daily OIS rate changes in each month. Similarly, I aggregate MRO rate changes in each month to construct a monthly time series for the level of the ECB policy rate. As a robusteness check I also consider the sample period 2000M1-2014M12, and find that the results do not substantially change.

This evidence is reassuring regarding the construction of the monetary policy shock series. Moreover, the estimated responses display a peak after around two years from the monetary policy shock. Therefore, I focus on the cross-sectional effects of monetary policy shocks at a two-year horizon. Finally, there are some caveats that is important to highlight. First, the confidence intervals of almost all the responses include the zero. This is a common finding the literature (Amberg, Jansson, Klein, and Rogantini Picco (2022b)). Second, moving block bootstrap provides more accurate estimates than the wild bootstrap. Third, despite the fact that the cumulative response of inflation is positive there is a price puzzle on impact as inflation seems to decrease in the initial periods. There are several solutions to this problem such as include the more volatile components of inflation, i.e. energy and food prices, in the VAR. However, despite these limitations the main objective of this estimation exercise is to broadly charcterize the macroeconomic effects of the monetary policy surprises used to identify monetary policy innovations rather than providing a precise quantification of the effects of monetary policy.

## 3.3 Econometric model

In this section I present the econometric framework that I employ in the main empirical analysis. I begin by dividing households into wealth groups and then I estimate the impulse responses for each group $g = 1, 2, ..., G$. Specifically, I set $G = 5$ so that household $i$ is allocated to group $g$ in year $t$ according to the quintiles of the wealth distribution in the previous years. In particular, I use average wealth in $t-2$ and $t-4$, and when a complete wealth history is not available I simply use wealth in $t-2$. This definition has two advantages. First, the recent literature on heterogeneous-agent models makes predictions on the cross-sectional effects of monetary policy based on the stationary or "long-run" wealth distribution. Second, ordering household according to lagged wealth guarantees that the group allocation is not influenced by shocks occurring in period $t$. Having defined wealth groups, I estimate the following set of local projections

$$\frac{y_{it+h} - y_{it-2}}{y_{it-2}} = \alpha_g + \beta_g \epsilon_t + \sum_{k=1}^{L} \delta_{g,k} \epsilon_{t-k} + \gamma_g x_{it-2} + u_{it} \quad \forall t, \forall i \in g. \tag{3.1}$$

The dependent variables is the percent change in income or consumption between years $t+h$ and $t-2$. The estimation horizon is $h = 0, 2, 4$. I set $L = 2$ to control for the lagged monetary policy shocks $\epsilon_{t-1}, \epsilon_{t-2}$. The control $x_{it-2}$ is the lagged percent change in the outcome between years $t-2$ and $t-4$. The coefficient of interest $\beta_g$ captures the average percentage change in income or consumption of household in group $g$ due to a one percentage point increase in the policy rate.[4] Therefore, these coefficients deliver the impulse response functions of consumption and income to monetary policy innovations. I estimate the model by pooled OLS. The standard errors are clustered at the household and year levels. Respectively to account for serial correlation in

[4]From Equation (**??**) we have $\beta_g = \mathrm{E}[100(\Delta y_{it+h}/y_{it-2})|\epsilon_t = 1\%] - \mathrm{E}[100(\Delta y_{it+h}/y_{it-2})|\epsilon_t = 0\%], \forall i \in g$.

the dependent variable for each household and correlation in the monetary policy shock across households in each year. To avoid any outlier to drive the results the dependent variables and the control $x$ are winsorized at the $1\%$ and $99\%$ cutoffs in each year. I also drop observations for which income growth exceeds 500 percent.

## 3.4 Results

This section presents the main results of the empirical analysis. First, I study the cross-sectional responses of consumption and disposable income to expansionary monetary policy shocks at a two-year horizon. Then, I provide supportive evidence from the response of unemployment and households' wealth to monetary policy. This additional results allow to better understand the transmission channels of monetary policy.

### 3.4.1 Consumption responses to monetary policy

The impulse response functions of consumption and income to a 25 basis point expansionary monetary policy shock are given by $-0.25\beta_g$. Figure **??** reports these responses. The left panel shows that monetary policy shocks have large and statistically significant effects on consumption at the tais of the wealth distribution, while the responses around the median are small. Consumption of the poorest households rise by 0.41 percent, household close to the median increase their consumption by 0.21 percent, and wealthy households increase their expenditure by 0.36 percent. These effects lead to a U-shaped cross-sectional pattern in the consumption responses with the largest adjustments at the top and at the bottom of the wealth distribution.

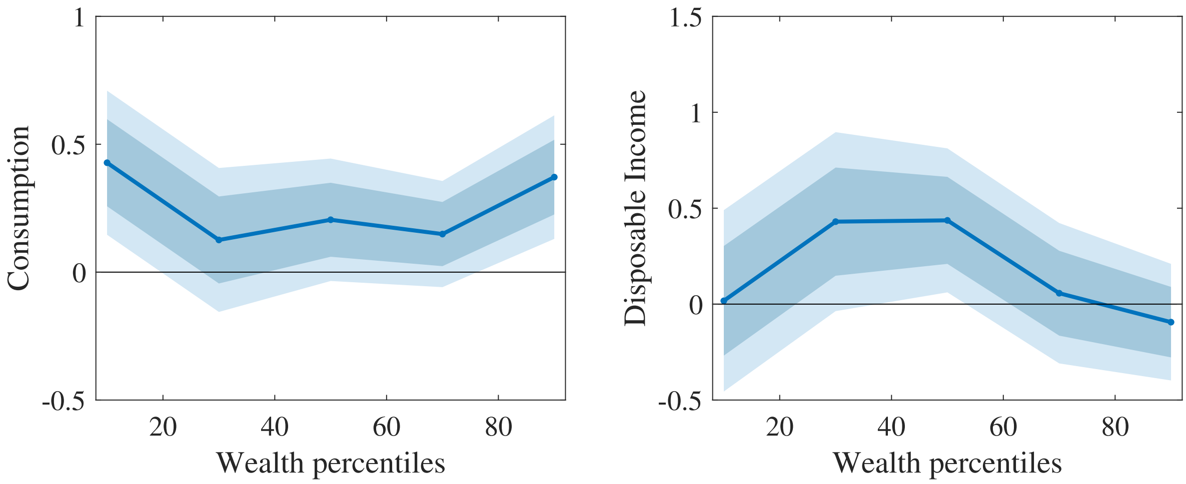


Figure 3.4: Consumption and income responses to monetary policy.

Note: Solid lines show the estimates of the response to an exogenous reduction in the MRO rate by 25 basis points on impact. Shaded areas indicate 68% and 90% confidence intervals.

The differential consumption responses between the top and bottom groups and the middle-class are broadly consistent with previous findings of the recent empirical literature on the heterogeneous effects of monetary policy. However, existing studies mostly focus on the income dimension or can only report imputed consumption from income and wealth data. Instead, in this paper I document the effects of monetary policy on a direct measure of nondurable consumption across the distribution of household net worth. This provides novel evidence that can be useful to test the predictions of a large class of quantitative HANK models, including models with liquid and illiquid assets.

Since wealth is weakly but positively correlated with consumption. These responses also suggest that the effect of monetary policy on consumption inequality is on average small since it increases consumption of households at the bottom and at the top almost by the same amount. This could also be the result of the fact that monetary policy increases consumption inequality in some periods but reduces it in other periods. So far, the empirical literature presents mixed results on the effects of monetary policy on consumption inequality. For example, Coibion, Gorodnichenko, Kueng, and Silvia (2017) find that interest rate cuts decreases consumption inequality, while Chang and Schorfheide (2022) suggest that inequality increases.

On the income side the results are less clear and this is likely due to limitations in the income measure. The responses are hump-shaped but with large confidence intervals. In particular, income in the second and third quintiles increases by almost 0.4%. As a result the estimates are only weakly significant even in the middle section of the wealth distribution. This substantially limit the interpretation of the income responses. This problem could be related to measurament errors on income growth. More importantly the definition of income excludes capital gains that are an important income source for households at the top of the distribution. This can explain the missing income response at the top of the distribution. I decompose the income response in Figure **??** by income sources and as expected I find that the response of disposable income is essentially driven by household earnings from wages and self-employment income while financial income shows little variation with monetary policy. The reason is that while interest rate cuts increase profits and dividends they reduce net interest income throughout the wealth distribution. As a result the two effects offset each other and financial income show little variation. Since the SHIW data allows to further disentangle interest expenses from interest revenues this is an important dimension to further explore to better understand the income responses. However, given the relative size of labor earnings and financial income from interest payments, it is unlikely that income effects from the latter can explain the size of the consumption movements at the tails. Finally, at the current stage there are also some other limitations to highlight. First, the standard errors do not properly take into account the survey design since the jaccknife weights for the estimation of the standard errors are only available until 2008, leaving uncovered a substantial part of the sample. A first step would be to compare the estimates before 2008 and then use clusters across years, regions, and municipalities for the remaining sample periods. Second, some households leave the sample well before the final sample period and others only enter in later sample periods.

### 3.4.2 Unemployment gap and monetary policy

In this section I investigate the effects of monetary policy on unemployment by household net worth. Since the consumption response of low-wealth households cannot be explained by the effects of monetary policy on the intensive income margin, I explore whether it reflects an adjustment on the extensive margin that draws low-income workers in the labor market. In the SHIW unemployment is concentrated at the bottom of the wealth distribution. Specifically, unemployed households at the bottom 20% of the wealth distribution are 34% of the total number of unemployed households in the economy. This number is 13% in the wealth group that contains the median household and only 7% at the top 20%. Since there is a significant unemployment gap between wealth groups, unemployment can be an important channel through which an accomodative monetary policy stimulates consumption of low-wealth households.

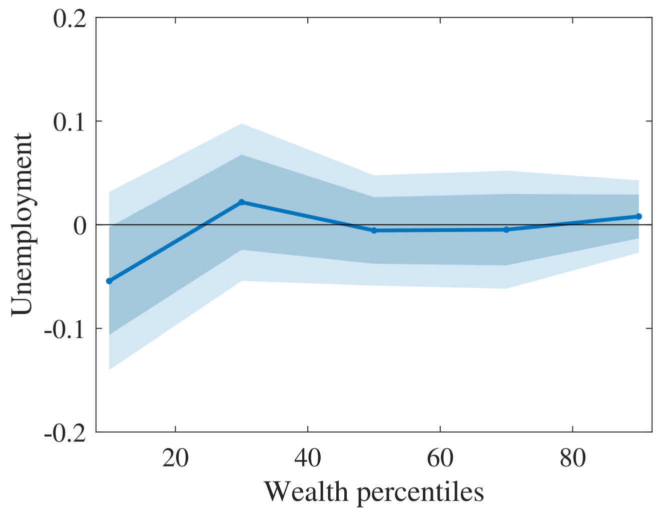


Figure 3.5: Unemployment responses to monetary policy.

Note: Solid lines show the estimates of the response to an exogenous reduction in the MRO rate by 25 basis points on impact. Shaded areas indicate 68% and 90% confidence intervals.

I estimate a version of model (**??**) with unemployment as the outcome variable. Figure **??** shows the effects of an interest rate cut of 25 basis point on the probability of unemployment across the wealth distribution. Households at the bottom 20% of the wealth distribution are less likely to be unemployed with an expansionary monetary policy. On the other hand, the effect for households in other wealth groups is clearly zero. Note that the 90% confidence interval contains the zero throughout the wealth distribution. The aim of this exercise is to document a potential mechanism driving the consumption responses of low-wealth households, I leave a more precise quantification of the unemployment channel and its effects on households' income for future research. Overall, I find evidence in the microdata that an accomodative monetary policy shrinks the unemployment gap between wealth groups.

### 3.4.3 Wealth effects of monetary policy

Households at the top of the wealth distribution show a large and significant consumption response to monetary policy, unfortunately the income measure from the microdata does not include capital gains, which are an important income source for households at the top of the distribution. To overcome this drawback I try to indirectly quantify the capital gains from publicly traded equity across the wealth distribution. To this end, I first estimate the effect of monetary policy innovations on stock prices. Then, I combine these estimates with the portfolio data from the SHIW to determine the households' capital gains from equity holdings.

As a first step I need to estimate the effects of monetary policy on stock prices. Since the monetary policy shocks are common in the Euro Area and households tend to hold diversified portfolios of stocks I use the Italian stock index FTSE MIB to measure stock prices. The outcome variable $y_t$ is given by stock price changes, and the covariate of interest $\epsilon_t$ is the time series of monetary policy innovations from Section **??**. I aggregate these data at the month level over nine years from 2006 to 2014 and estimate the following set of local projections

$$y_{t+h} = \alpha_h + \beta_h \epsilon_t + \sum_{k=1}^{L_1} \delta_{h,k} \epsilon_{t-k} + \sum_{k=1}^{L_2} \gamma_{h,k} y_{t-k} + u_t.$$

Then, from the response of stock prices to monetary policy shocks I compute the capital gains at the household level using the equity holdings from the SHIW. In particular, the measure of real financial wealth that I use contains stocks and a set of private bonds. This add some noise in the estimation, however the main objective of this section is to measure possible wealth effects at the top of the distribution and wealthy households tend to tilt their portfolios toward stocks increasing the accuracy of the estimates.

Figure **??** shows the results of these computations. The left panel plots the response of stock prices to monetary policy, in the right panel I leverage the portfolio data from the SHIW to compute the implied changes in households' wealth across the distribution. According to these estimates after one year from a 25 basis points reduction in the ECB policy rate stock prices increase by $1.1\%$. This implies a total capital gain of more than 2000 euro for households in the top $5\%$ of the wealth distribution over the first year from the shock. The capital gains for the bottom half of the distribution are well below 100 euro. The capital gains for households at the top $20\%$ are around 500 euro and about one-fourth as much for the median household. Therefore, the wealth effects of monetary policy appear to be concentrated at the top $20\%$ of the distribution exactly where we observe the largest consumption response. From the left panel of Figure **??** we clearly observe that stock prices rise over the three years. Table **??** reports the total capital gains across different wealth groups in each year. The effects at the bottom are quantitatively small and overestimated as these households are more likely to have more bonds than stocks in their portfolios. The gap between the top and other wealth groups is much larger. The wealth effect at the 90th percentile is more than 10 times the wealth gain of the median households. The wealth gap is even larger with respect to the top $5\%$ where the capital gains are more than 20 times the effects at the median. These results suggest that portfolio effects and capital gains from equity holdings can explain at least part of the consumption responses that I document in Section **??**. According to the consumption estimates the average response at the 90th percentiles could be around 1,400 euro. Therefore, even if households consume a small fraction of these capital gains this could explain a significant part of the increase in consumption at the top of the distribution. More broadly, the findings in this section show that wealth concentration determines large differences in households' exposure to monetary policy shocks.

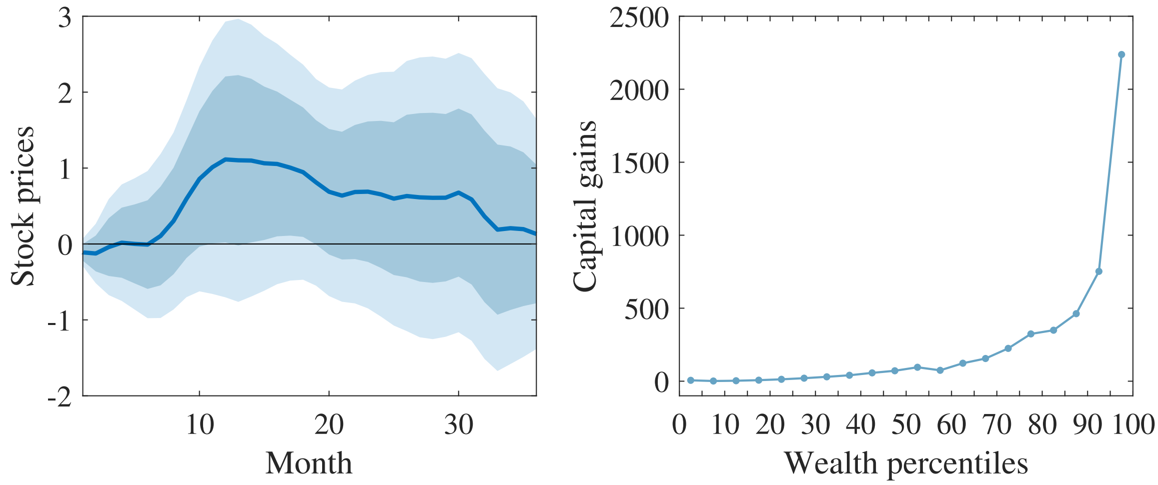


Figure 3.6: Stock prices and portfolio effects of monetary policy.

Note: On the left panel the solid lines show the estimates of the response to an exogenous reduction in the MRO rate by 25 basis points on impact. Shaded areas indicate 68% and 90% confidence intervals. The right panel plots the implied capital gains computed from SHIW equity holdings.

Table 3.2: Portfolio effects over time.

| Total capital gain | 20-25 | 50-55 | 80-85 | 90-95 | 95-100 |
|---|---|---|---|---|---|
| 1 year | 12 | 95 | 349 | 752 | 2,237 |
| 2 years | 57 | 422 | 1,544 | 5,497 | 9,898 |
| 3 years | 27 | 201 | 738 | 1,591 | 4,734 |

Note: The table shows the average wealth effects due to a reduction in the MRO rate by 25 basis points in each year after the shock.

## 3.5 Conclusion

This paper aims to provide novel evidence on the heterogeneous effects of monetary policy across different wealth groups using consumption and wealth measures from the SHIW and monetary policy shocks identified from monetary policy surprises with the high-frequency approach. I find U-shaped consumption responses by household net worth. This evidence can be useful to test the predictions of quantitative HANK models. However, the underlying transmission mechanisms are critical to guide the development of these models. For this reason, I explore two transmission channels that can explain the large consumption responses at the tails of the distribution. First, accomodative monetary policy by stimulating the economic activity can draw marginal workers in the labor market. Second, expansionary monetary policies rise stock prices. Since household systematically differ in equity holdings across different wealth groups, rising equity prices have different effects on households' wealth and mostly benefit wealthy households at the top of the distribution. I find supportive evidence for these channels of monetary policy transmission.

The SHIW can be useful to investigate the importance of heterogeneoity in other dimensions for the consumption effects of monetary policy, for example by liquid wealth, age, and education. These estimates are particularly useful as they can provide further direct evidence regarding the transmission mechanisms through which monetary policy causes the consumption movements across wealth groups documented in this paper.

# Appendix A

## Appendix

### A.1 Analytical Derivations

In this section I characterize the solution to (**??**), (F.2), (F.3), (**??**) under the parametrization presented in Section **??**, i.e. a Cobb-Douglas production technology $Y_{it} = K_{it}^{\theta} N_{it}^{1-\theta}$, quadratic price adjust costs $\Phi_t = \frac{\Psi_p}{2}(\pi_{it})^2 p_t Y_t$, and investment adjustment costs $\chi_t = \frac{\kappa}{2}(\iota_t - \delta)^2 K_t$. I conclude this section with a list of the resulting equilibrium conditions.

#### A.1.1 Phillips curve

**Final good firm**. The first order condition associated to (**??**) is given by

$$p_t \frac{\epsilon_p}{\epsilon_p - 1}\left(\int_0^1 Y_{it}^{1-\epsilon_p^{-1}} di\right)^{\frac{1}{(\epsilon_p - 1)}} \frac{\epsilon_p - 1}{\epsilon_p} Y_{it}^{-\epsilon_p^{-1}} - p_{it} = 0$$

Dividing the first order condition of two intermediate goods $i$ and $j$ yields

$$p_{jt} = \left(\frac{Y_{it}}{Y_{jt}}\right)^{\frac{1}{\epsilon_p}} p_{it}.$$

Rewriting $p_{jt}Y_{jt} = p_{it}Y_{it}^{\epsilon_p^{-1}} Y_{jt}^{1-\epsilon_p^{-1}}$ and integrating over $j$ we have $p_t Y_t = p_{it} Y_{it}^{\epsilon_p^{-1}} \int_0^1 Y_{jt}^{1-\epsilon_p^{-1}} dj$ from the zero profit condition $p_t Y_t = \int_0^1 p_{jt} Y_{jt} dj$. Substituting for $Y_t$ from the CES technology and solving for $Y_{it}$ yields the optimal demand of intermediate inputs

$$Y_{it} = \left(\frac{p_{it}}{p_t}\right)^{-\epsilon_p} Y_t,$$

which together with the zero profit condition implies

$$p_t = \left(\int_0^1 p_{it}^{1-\epsilon_p} di\right)^{\frac{1}{1-\epsilon_p}}.$$

**Intermediate producers**. The first order condition of problem (F.2) are

$$r_t^k = mc_{it}\theta K_{it}^{\theta-1}N_{it}^{1-\theta},$$

$$w_t = mc_{it}(1-\theta)K_{it}^{\theta}N_{it}^{-\theta}.$$

The Lagrange multiplier is the marginal cost $mc_t = \frac{d}{dY_{it}}(w_tN_{it} + r_t^kK_{it})$. Combining the first order conditions yields $K_{it}/N_{it} = \theta(1-\theta)^{-1}(w_t/r_t^k)$. Therefore, all firms choose the same capital-labor ratio and have the same real marginal costs $mc_{it} = mc_t$.

The production technology implies the factor demands

$$K_{it} = Y_{it}\left(\frac{\theta}{1-\theta}\frac{w_t}{r_t^k}\right)^{1-\theta},$$

$$N_{it} = Y_{it}\left(\frac{\theta}{1-\theta}\frac{w_t}{r_t^k}\right)^{-\theta}.$$

Substituting the demands in the cost function and differentiating with respect to $Y_{it}$ yields

$$mc_t = \left(\frac{w_t}{1-\theta}\right)^{1-\theta}\left(\frac{r_t^k}{\theta}\right)^{\theta}.$$

Finally, intermediate producers set prices in monopolistic competition subject to price adjustment costs to maximize discounted profits. Define $m_{it} := p_{it}mc_{it}$. The Hamiltonian associated to (F.3) with control $\dot{p}_{it}$ and state $p_{it}$ taking $Y_t, p_t, i_t$ as given is

$$\begin{aligned} H_t(\dot{p}_{it}, p_{it}, \mu_t) &= \exp\left(-\int_0^t i_s ds\right)\left((p_{it} - m_{it})\left(\frac{p_{it}}{p_t}\right)^{-\epsilon_p}Y_t - \frac{\Psi_p}{2}\left(\frac{\dot{p}_{it}}{p_{it}}\right)^2 p_tY_t\right) + \lambda_t\dot{p}_{it} \\ &= \exp\left(-\int_0^t i_s ds\right)\left((p_{it} - m_{it})\left(\frac{p_{it}}{p_t}\right)^{-\epsilon_p}Y_t - \frac{\Psi_p}{2}\left(\frac{\dot{p}_{it}}{p_{it}}\right)^2 p_tY_t + \mu_t\dot{p}_{it}\right). \end{aligned}$$

In the second line I used $\mu_t := \lambda_t \exp(\int_0^t i_s ds)$. The first order conditions are given by

$$H_{\dot{p}_{it}} = -\Psi_p\left(\frac{\dot{p}_{it}}{p_{it}}\right)\frac{p_t}{p_{it}}Y_t + \mu_t = 0,$$

$$H_{p_{it}} = \left(1 - \epsilon_p + \epsilon_p mc_t\right)\left(\frac{p_{it}}{p_t}\right)^{-\epsilon_p}Y_t + \Psi_p\left(\frac{\dot{p}_{it}}{p_{it}}\right)^2\frac{p_t}{p_{it}}Y_t = i_t\mu_t - \dot{\mu}_t,$$

$$H_\mu = \dot{p}_{it}.$$

In equilibrium all the firms charge the same price equal to $p_t$ and produce the same output.

Then, solving for $\mu_t$ we derive a New Keynesian Phillips curve and firms' profits

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

$$D_t = (1 - mc_t)Y_t - (\Psi_p/2)(\pi_t^2)Y_t,$$

where $\mu_p = \epsilon_p/(\epsilon_p - 1)$. The Phillips curve connects the real side of the economy, namely $w_t, r_t$ to inflation and other nominal variables. The cyclical behavior of profits with respect to output $Y_t$ crucially depends on the term $(1 - mc_t)Y_t$ where the mark-up, $(1 - mc_t)$, is countecyclical when input prices are procyclical and increase more rapidly than consumer prices due to the presence of nominal rigidities. In standard calibrations with flexible wages the change in mark-ups is larger than the variation of aggregate output leading to countecyclical profits.

### A.1.2 Investment

The Hamiltonian associated to (**??**) with control $\iota_t$ and state $K_t$ taking $r_t, r_t^k$ as given is

$$H_t(\iota_t, K_t, q_t) = \exp\left(-\int_0^t r_s ds\right)\left((r_t^k - \iota_t - \chi_t(\iota_t))K_t + q_t(\iota_t - \delta)K_t\right).$$

The first order conditions are givne by

$$r_t = \frac{\dot{q}_t}{q_t} + (\iota_t - \delta) + \frac{r_t^k - \iota_t - \chi_t(\iota_t)}{q_t},$$

$$q_t = 1 + \chi_t'(\iota_t).$$

Together with a transversality condition $\lim_{t\to\infty} e^{-\int_0^t r_s ds} q_t K_t = 0$. The Tobin's q is the shadow price of capital $q_t = dV_t/dK_t$. The discount rate $r_t$ is the sum of two components: the capital gains due to market valuations $\dot{q}_t/q_t$ and firm's growth $\dot{K}_t/K_t$, and the yields from capital rents $(r_t^k - \iota_t - \chi_t(\iota_t))/q_t$. Solving forward the arbitrage condition in the first equation above we find

$$q_t = \int_t^\infty \exp\left(-\int_t^\tau (r_s - \iota_s + \delta)ds\right)\left(r_\tau^k - \iota_\tau - \chi_\tau(\iota_\tau)\right)d\tau,$$

and $K_\tau = K_t \exp(-\int_t^\tau (\iota_s - \delta)ds)$. Hence, $V_t = q_t K_t$.

### A.1.3 Equilibrium conditions

To summarize, the equilibrium conditions that characterize the solution to (**??**), (F.2), (F.3), (**??**) are given by the following 7 equations in 7 unknowns $Y_t, K_t, N_t, mc_t, \pi_t, \iota_t, q_t$.

$$r_t^k = \theta mc_t K_t^{\theta-1} N^{1-\theta},$$

$$w_t = (1-\theta) mc_t K_t^{\theta} N^{-\theta},$$

$$Y_t = K_t^{\theta} N_t^{1-\theta},$$

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

$$D_t = (1 - mc_t) Y_t,$$

$$r_t = \frac{\dot{q}_t}{q_t} + \frac{r_t^k - \iota_t - \chi_t(\iota_t) + (\iota_t - \delta) q_t}{q_t},$$

$$q_t = 1 + \chi_t'(\iota_t).$$

The remaining variables in the system are prices and the optimal value of the objective function in the maximization problem of intermediate good producers.

## A.2 HJB and KF Equations

Here I present the households' HJB equation and the KF equation. Define the indicator function $1_Q : E \to \{0,1\}$ for any $Q \subseteq E$, let $e_2 > e_1$, $N = \{e : e < e_1\}, S_j = \{e_j\}, \forall j = 1,2$. Let $v_t$ denote the value function, $f_t$ the density function, and $y_t$ household market income. The Hamilton-Jacobi-Bellman equation is

$$\begin{aligned}\rho v_t(a,e) = \max_{c_t} \Bigg\{ & u(c_t, n_t) + \frac{\partial v_t}{\partial a}(y_t - c_t) + \frac{\partial v_t}{\partial t} + 1_N \lambda_1 \sum_{j=1}^{2} \theta_j (v(a,e_j) - v(a,e)) \\ & + \sum_{j=1}^{2} 1_{S_j} \lambda_2 \int (v(a,e') - v(a,e_j)) d\Phi_e(e') + 1_N \lambda_e \int (v(a,e') - v(a,e)) dF_e(e'|e) \Bigg\},\end{aligned}$$

where $\Phi_e$ is the distribution associated to $\phi_e$ and $e' \in N$. Let $P_t(e'|e) := P(e_{t+s} = e'|e_s = e), \forall s \geq 0, \forall t \geq 0$ be the probability function associated to $F_e(e'|e)$, the dynamics of the cross-sectional distribution are given by the Kolmogorov forward equation

$$\begin{aligned}\frac{\partial f_t}{\partial t} = & -\frac{\partial}{\partial a}(f_t(y_t - c_t)) + \sum_{j=1}^{2} 1_{S_j} \left( \lambda_1 \theta_j \sum_{e'} f_t(a,e') - \lambda_2 f_t(a,e_j) \right) \\ & + 1_N \left( \lambda_e \sum_{e'} f_t(a,e') P_t(e|e') - \lambda_e f_t(a,e) + \lambda_2 \sum_{j=1}^{2} \phi_e(e) f_t(a,e_j) - \lambda_1 f_t(a,e) \right).\end{aligned}$$

## A.3 Numerical Solution

This section contains further details on the numerical methods used to solve the model. First, I discuss the solution of the HJB and KF equations, and then I provide a summary of the algorithms used to solve for the steady state and dynamics of the model.

### A.3.1 Finite difference methods

The model's solution methods are based on the finite difference approach developed in Achdou, Han, Lasry, Lions, and Moll (2017) to solve HJB and KF equations. I consider a non-uniform grid for each state and index with $i = 1, ..., I, j = 1, ..., J$ the grid points for respectively $a, e$. Moreover, I use the index $n$ for the iteration scheme. I'll focus on the stationary version of the HJB and KF equations. The state constraint $a \geq -\underline{a}$ gives rise to the boundary condition

$$\partial v(\underline{a}, e)/\partial a := v_a(\underline{a}, e) \geq u'(wen + r\underline{a} + d).$$

Note that since $u'(c) = v_a(a,e)$ the condition above implies that savings $s(a,e) := wen + ra + d - c \geq 0$ at $a = \underline{a}$ and the constraint is never violated.

To solve the HJB equation I use an implicit upwind scheme. Let $(x)^+ := \max(x,0)$, $(x)^- := \min(x,0)$, $p_{j',j}$ the transition probabilities associated to $F_e$, $p_j$ the probabilities associated to $\phi_e$. The discretized version of the HJB equation is given by

$$\begin{aligned}\frac{v_{ij}^{n+1}-v_{ij}^{n}}{\Delta}+\rho v_{ij}^{n+1} &= u(c_{ij}^n)+\frac{v_{i+1j}^{n+1}-v_{ij}^{n+1}}{\Delta a_i}(s_{ij,F}^n)^+ + \frac{v_{ij}^{n+1}-v_{i-1j}^{n+1}}{\Delta a_i}(s_{ij,B}^n)^- \\ &+ 1_N\left(\lambda_e\sum_{j'=1}^{J-2} v_{ij'}^{n+1}p_{j'j}-\lambda_e v_{ij}^{n+1}+\lambda_1\theta_1(v_{iJ-1}^{n+1}-v_{ij}^{n+1})+\lambda_1\theta_2(v_{iJ}^{n+1}-v_{ij}^{n+1})\right) \\ &+ 1_{S_1}\left(\lambda_2\sum_{j'=1}^{J-2} v_{ij'}^{n+1}p_{j'}-\lambda_2 v_{iJ-1}^{n+1}\right)+1_{S_2}\left(\lambda_2\sum_{j'=1}^{J-2} v_{ij'}^{n+1}p_{j'}-\lambda_2 v_{iJ}^{n+1}\right),\end{aligned}$$

where $c_{ij}^n = (u')^{-1}(v_{a,ij}^n)$. We can update the value function solving a system of $I\times J$ linear equations in $I\times J$ unknowns $v_{ij}^{n+1}$. Let $v^{n+1} := (v_{11}^{n+1}, v_{21}, ..., v_{I1}, v_{12}, v_{22}, ..., v_{IJ})'$. The system can be written in matrix notation as

$$\frac{1}{\Delta}(v^{n+1}-v^n)+\rho v^{n+1} = u^n + A^n v^{n+1},$$

where $u^n = (u(c_{ij}^n)), v^n = (v_{ij}^n)$ are vectors of dimension $IJ\times 1$ and $A^n = T+B$ is a matrix with dimension $IJ\times IJ$. The matrix $T$ has the standard structure given by a central diagonal $(y_{11},...,y_{I1},y_{12},...,y_{I2},...,y_{1J},...,y_{IJ})$ with the coefficients of $v_{ij}^{n+1}$, a lower diagonal $(x_{21},...,x_{I1},0,x_{22},...,x_{I2},0,...,x_{2J},...,x_{IJ})$ with the coefficients of the backward terms $v_{i-1j}^{n+1}$, and an upper diagonal $(z_{11},...,z_{I-11},0,z_{12},...,z_{I-12},0,...,z_{1J},...,z_{I-1J})$ with the coefficients of $v_{i+1j}^{n+1}$, and zero elsewhere. We impose $x_{1j}=z_{Ij}=0,\forall j$ so that $v_{0j}, v_{I+1j}$ are never used. The matrix $B$ has the following block structure

$$B=\begin{bmatrix} B^N_{I(J-2)\times I(J-2)} & 0_{I(J-2)\times 2I} \\ 0_{2I\times I(J-2)} & 0_{2I\times 2I}\end{bmatrix}+\begin{bmatrix} B^1_{I(J-2)\times I(J-2)} & B^2_{I(J-2)\times 2I} \\ B^3_{2I\times I(J-2)} & B^4_{2I\times 2I}\end{bmatrix}.$$

Let $P$ be the transition matrix associated to $F_e$. $B^N = \lambda_e P_{(J-2)\times(J-2)}\otimes I_{I\times I}-\lambda_e I_{I(J-2)\times I(J-2)}$ gives the transitions between normal states. The second matrix in the sum gives the transition between normal and extraordinary states. Let $\iota$ be a column vector with 1 in each row. Then, the remaining blocks are given by $B^1=-\lambda_1 I_{I(J-2)\times I(J-2)}$, $B^2=\iota_{J-2}\otimes[\lambda_1\theta_1 I_{I\times I}\quad \lambda_1\theta_2 I_{I\times I}]$, $B^3=\iota_2\otimes[\lambda_2 p_1 I_{I\times I}\quad ...\quad \lambda_2 p_{J-2}I_{I\times I}]$, $B^4=-\lambda_2 I_{2I\times 2I}$.

Let $A^n$ be the matrix obtained from the last HJB iteration, $f$ a $IJ\times 1$ density vector. From the discretized KF equation we see that the density can be obtained by solving

$$(A^n)'f=0,$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} f_{ij}\Delta a_i = 1.$$

Transition dynamics can be computed extending the solution presented here to the case in which $v_{ij}^n = v(a_i, z_j, t_n)$. In this case I solve backward for $v^n$ the HJB equation

$$\rho v^n = u^{n+1} + A^{n+1} v^n + \frac{1}{\Delta t}(v^{n+1} - v^n),$$

given a terminal condition $v^N$. Then, I solve forward for $f^{n+1}$ the KF equation given an initial condition $f^0$ with an implicit method

$$\frac{f^{n+1} - f^n}{\Delta t} = (A^n)' f^{n+1}.$$

I use a power grid with the curvature parameter equal to 3 to increase accuracy in the low-wealth regions of the state space where the policy functions display the largest nonlinearities.

## A.4 Further Details on the Calibration

### A.4.1 Top wealth shares

The left panel in Figure **??** shows the marginal distributions for top percentiles of earnings and wealth in the model and compares them to the data (SCF). The model captures almost exactly the earning shares of top percentiles, including those not targeted in the calibration. Importantly, the model generates large wealth share at the top 10% of the wealth distribution. This statistic is 77% in the data and 63% in the model. The model misses the wealth shares above the top 5%, however the results in the paper are not driven by these households.

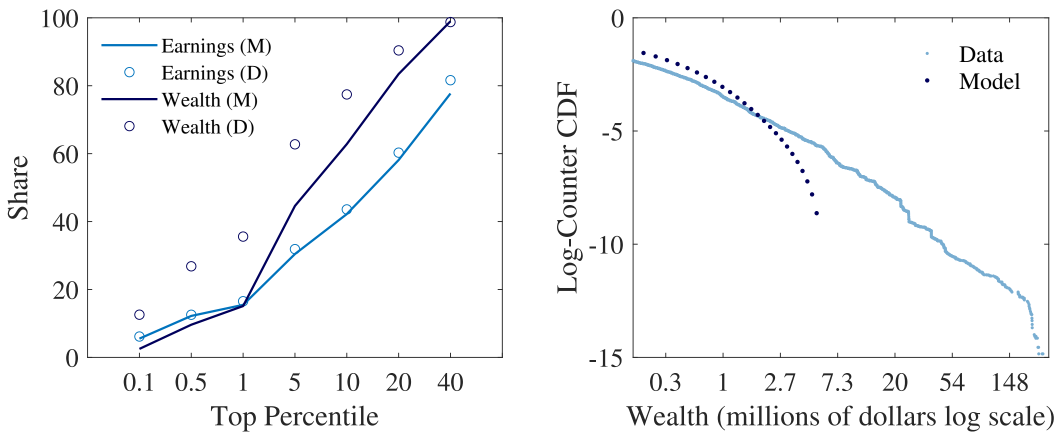


Figure A.1: Top earnings and wealth shares.

The right panel in Figure **??** shows the Pareto tail of the wealth distribution. Specifically, if the points in the plot form straight line then the right tail of the distribution can be approximated with a Pareto distribution and the slope of the line is the Pareto coefficient. We can clearly see that in the data the wealth distribution has a Pareto right tail, while the model can match this tail up to the 99th wealth percentile. These results are expected considering that the income process is not calibrated to match top wealth shares and that the model does not include heterogeneous return to wealth. Nevertheless, the model generates realistic wealth inequality at the top 10%.

### A.4.2 Income dynamics

In this section I empirically assess the predictions of the model on income dynamics. Guvenen, Karahan, Ozkan, and Song (2021) analyze the distribution of income changes in the US and document substantial deviations from lognormality. One important deviation from the Gaussian distribution is a high kurtosis, i.e. a higher mass around the mean and on the tails, that produces more extreme observations than in the Normal case. To account for this evidence, I consider a version of the model with endogenous labor supply decisions $n_t(e_t, a_t)$ that are increasing in income risk $e_t$ and decreasing in wealth $a_t$. In the model, the presence of stochastic top earning states together with labor supply decisions that are increasing with the earning state can potentially account for this feature of the data. To investigate this, I simulate a panel of 10,000 workers over 50 years. Figure **??** displays the histogram of one-year log earnings changes generated by the model, overlaid with a Normal density with the same mean and variance. The leptokurtosis of annual income changes is evident from this figure. The estimated kurtosis is around 9, Kaplan, Moll, and Violante (2018) find a kurtosis of 17.8 in the data.

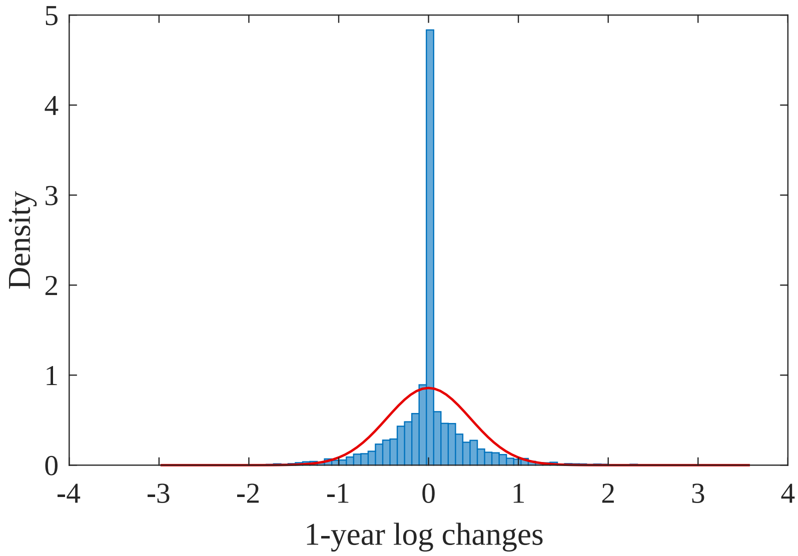


Figure A.2: Distribution of income changes

To compute the distribution of income changes I take the following steps. First, I simulate the continuous-time markov chain for $e_t$. The longitudinal dimension of the simulated data is high enough to remove any dependence on the initial conditions and to achieve convergence of the markov process to its stationary distribution. Having simulated the income risk process, I use steady state wages and households' labor supply decisions not intermediated by unions to compute earnings paths. As a final step, I integrate over time to aggregate the income time series at the year level, and use the last two years to compute the log-income changes.

### A.4.3 Wealth composition

In this section I study household portfolio composition across the distribution of financial wealth in the SCF and discuss how this relates to the main quantitative results of this paper.

Figure **??** shows the composition of households' wealth across ventiles of the wealth distribution. In this paper I define wealth as financial wealth. Thus, I first compute the average portfolio shares of three broad asset classes relative to total financial assets. The first class is given by liquid assets and consists of cash holdings, deposits, and bonds. The other classes are given by stocks and revolving debts. Households at the bottom 20% have negative wealth as the value of debt exceeds the value of all the financial assets. Liquid assets dominate household portfolios at the bottom 50%. The portfolio share of public equity increases across the wealth distribution and reach its peak at the top of the distribution. The financial wealth of wealthy households consists of public equity that represents more than 80% of their total assets. The effects of the equity price in the model are broadly consistent with the cross-sectional composition of wealth as wealthy households benefit the most from higher equity prices while middle-class households face higher prices to accumulate equities. As emphasized by Kuhn, Schularick, and Steins (2019) the total capital gain in a portfolio with multiple asset categories is a weighted average of price changes on each asset category with weights given by the portfolio share of each asset class. Figure **??** shows that at the top 10% the portfolio share of equity is very close to one as in the model. Since in the model wealth highly concentrated at the top of the distribution, changes in equity prices have a large effect on households' wealth at the top 10%.

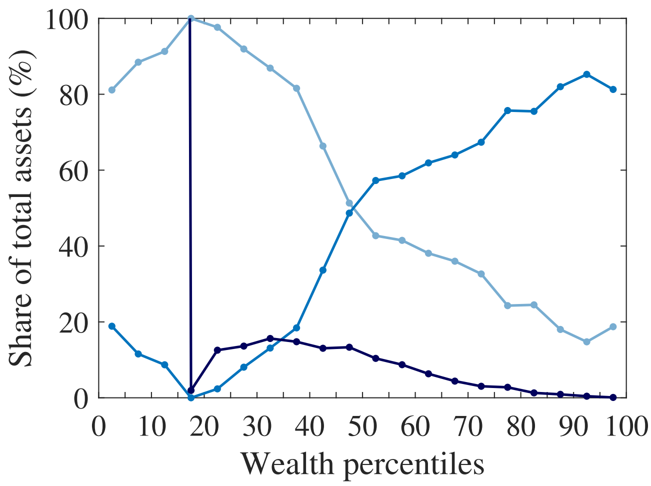


Figure A.3: Wealth composition.

Note: The figure shows the average portfolio shares of liquid assets (light blue line), public equity (blue line), and short term debt (dark blue line) relative to the total financial assets across the wealth distribution.

In summary, the evidence from the SCF on systematic differences in households' portfolio choices across the wealth distribution confirm that the composition of households' wealth can be important for the heterogeneous effects of monetary policy on household consumption. However, the main focus of this paper is to study the implications of wealth concentration at the top of the distribution and household at the top $10\%$ tilt their portfolios toward stocks.

### A.4.4 Low-liquidity households across the wealth distribution

This section provides additional empirical evidence on the distribution of low-liquidity households across wealth groups. Throughout this section I use the SCF data. This empirical analysis provides supporting evidence for the calibration of low-liquidity households in the model.

To measure low-liquidity households, i.e. households that have low liquid wealth within a pay-period, I follow the definition of Weidner, Kaplan, and Violante (2014). Let $b$ be household liquid wealth, $y$ monthly income. I assume a borrowing limit $\phi_b$ equal to 1 month of income. A household is classified as a low-liquidity household if one of the following conditions holds

$$b \geq 0 \quad \text{and} \quad b \leq y/2,$$

$$b < 0 \quad \text{and} \quad b \leq y/2 - \phi_b = -y/2.$$

This measure aims to capture two kinks in households' budgets either at zero liquid wealth, due to differences in saving and borrowing rates, or at the borrowing limit. The cut-off $1/2$ is due to the assumption that all resources are consumed at a constant rate. So, average balances over the pay-period are equal to half income. As noted by Weidner, Kaplan, and Violante (2014) using income before taxes can overstate the fraction of low-liquidity households by increasing the threshold. On the other hand, if an household starts the period with some positive savings and ends the period with zero liquid wealth its average balance would be above half earnings and the measure will miss these low-liquidity households. Liquid wealth is given by cash holding, deposits, government and corporate bonds net of credit card debt. I exclude from the sample households with zero or negative earnings and compute monthly earnings dividing annual before-tax wages and self-employment income by 12. All low-liquidity households are at the bottom $30\%$ of the wealth distribution. In particular, the shares of constrained households across the wealth distribution is around one-third for the bottom 3 deciles and zero for the other deciles. Similarly, the share of constrained households within each group is above $80\%$ at the bottom $30\%$ and zero for the other deciles. Thus, constrained households are a vast majority in the three bottom deciles. These results are consistent with the baseline calibration of the model.

### A.4.5 The wealth distribution in the SCF and PSID

The PSID is a biennial survey from 1999 to 2015. The main advantage of the PSID is that it provides measures of income, consumption, and wealth. In my analysis I consider the 2005 wave. As in the SCF sample financial wealth is measured as liquid wealth with public equity. In particular, wealth in the PSID is the sum of bank deposits, certificates of deposit, government bonds and treasury bills, public equity, corporate bonds and insurance policies, minus the value of financial debts excluding mortgages. I also add to this an estimate of cash holdings obtained multiplying bank deposits, certificates of deposit, and government bonds by 0.055, see Foster, Schuh, and Zhang (2013). My measure of nondurable consumption includes spending categories for food at home and away from home, trips, recreation activities, education, child care, health, clothing, insurance, and utilities. Consumption flows are reported for different time frames, whereas asset holdings are reported at the time of the interview. Food and utility expenditures are in terms of the household's typical monthly expenditures. I treat these variables as aligned with respect to the previous calendar year, with assets viewed as end of the year values.

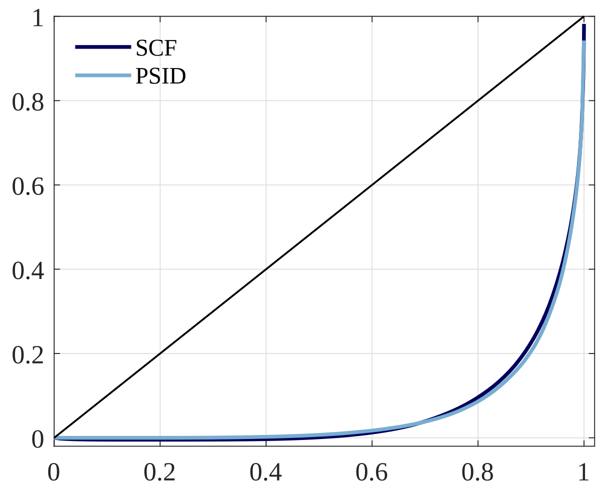


Figure A.4: Wealth distribution in the SCF and PSID.

Note: the figures shows the lorenz curve of wealth. The figure plots the share of total wealth on the y-axis and the population percentiles on the x-axis.

Figure **??** compares the distribution of wealth in the SCF and PSID. The match between the two distributions is almost exact. There are small differences at the very top of the distribution likely due to the fact that the SCF oversample households at the top. Overall, this allows me to use the SCF to measure the joint distribution of income and wealth and the PSID to recover the joint distribution of consumption and wealth. To construct the joint distribution of consumption and wealth I use a transformation of the original sample weights from the PSID survey. The results do not significantly change if I employ the original weights.

### A.4.6 Monetary policy IRFs

This section reports the impulse response functions (IRFs) of the key variables in the model to the 25 basis point expansionary monetary policy shock presented in Section **??**. In particular, Figure **??** shows the response of the variables that I discuss in the main text together with the response of capital, equity price, capital yield, and employment.

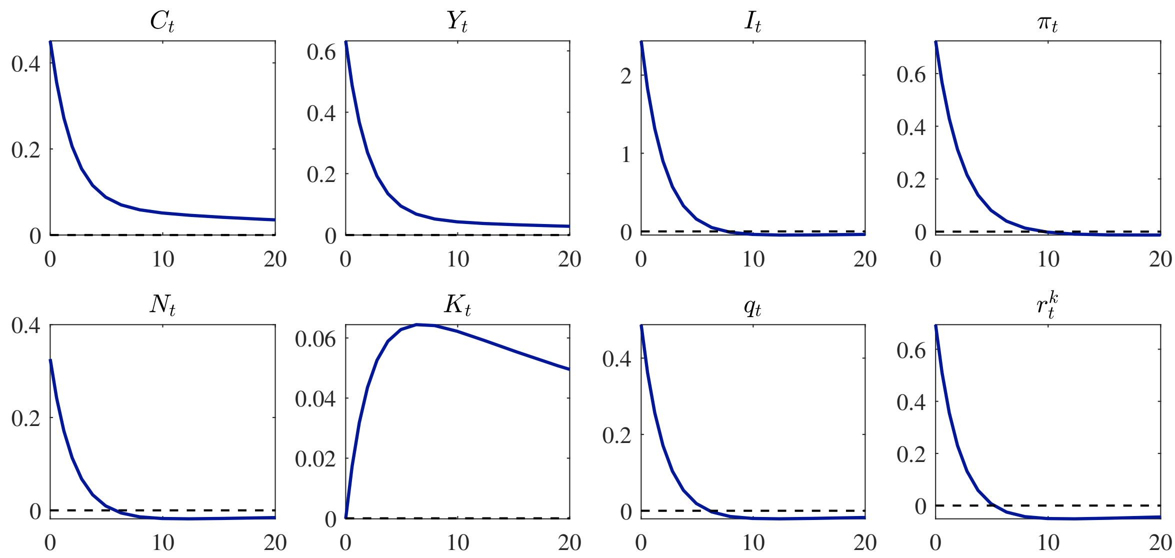


Figure A.5: IRFs to an expansionary monetary policy shock.

Note: The real interest rate, the marginal product of capital, and the inflation rate are shown as annualized deviations from steady state. All other variables are shown as percentage deviations from the steady state.

First, note that the equity price $q_t$ increases by more than $0.4\%$ on impact. As I discuss in Section **??**, this increase leads to substantial capital gains for wealthy households at the top of the wealth distribution. Higher employment levels raise the marginal product of capital and therefore the rental rate of capital increases. Since capital is a predetermined variable the stock of capital does not change on impact and increases over time showing a hump-shaped response. As I discuss in Section **??** the response of investment is large relative to the empirical estimates that find a response between $1\%$ and $2\%$. Increasing investment adjustment costs to exaclty match the investment response reduces capital accumulation and results in a even larger fall in the real interest rate. Since the asset return directly affects household budgets and aggregate consumption it is important for the objectives of this paper to generate realistic movements in the real interest rate. Moreover, I recalibrate the steady state discount rate to generate a realistic response of both investment and real interest rates. I find that these alternative calibrations do not change the main quantitative results on the consumption responses to monetary policy. The high investment volatility also implies a sizable response of equity prices.

## A.5 The CE Data and Monetary Policy Shocks

In this section, I provide full details about the variables used in my analysis, how the sample is constructed, and summary statistics. I also discuss the identification of the monetary policy shocks used in the main empirical analysis.

### A.5.1 Survey design, variables, and sample

The CE is a quarterly survey designed to measure households' expenditures and income. The survey also provides information on financial assets. Following the approach of Holm, Paul, and Tischbirek (2021a) I use this survey to estimate the effects of monetary policy across the distribution of liquid assets. The CE has a rotating panel structure, households report information on consumption for at most four consecutive quarters, income information is collected in the first and last interviews, wealth information is collected in the last interview only.[1]

The measure of consumption expenditures follows the NIPA definition of nondurable and services expenditures. This measure aggregates the following expenditure categories: food, tobacco, domestic services, adult and child care, utilities, transportation, pet expenses, apparel, education, work-related and training, healthcare, insurance, furniture rental and small textiles, housing related expenditures excluding rent. In each interview the reference period for consumption flows covers the three month before the interview month. I assign an observation to the quarter in which the interview is taken. The wealth measure includes money owned to the household by individuals outside of the household, savings accounts, checking and brokerage accounts, the value of all securities held by the household, this includes government bonds, corporate bonds, stocks, and mutual funds. In the CE these values refer to the end of the last month before the interview. To compute beginning of period values I use information on the total change in these variables over the previous year. The reference period for the income flows covers the twelve months before the interview. To measure households' earnings I use earnings before taxes, and business income. However, in my analysis I use the information on households' earnings from the CE only for data cleaning purposes.

I use the assigned survey sample weights, designed to map the CE into the national population in all calculations. All variables are adjusted for inflation using the CPI to express all monetary variables in constant 2000 dollars. Demographic characteristics are defined relative to the household head. I restrict the sample to families with household's head between 22 and 64 years old. I exclude incomplete income reporters, households with negative earnings and with zero or negative consumption. In the baseline CE sample there are on average 4,518 households in each year and the sample period is 1991Q2-2016Q4. Over time the sample size increases moving from 3,290 households in 1992 to 4,910 households in 2000, 5,000 families in 2010. I use the microdata to construct consumption time series for different wealth groups.

[1] In particular, there is a preliminary interview followed by a maximum of four quarterly interviews. The second interview and the fith interview contain the relevant information for my analysis.

### A.5.2 Summary statistics

Table ?? reports summary statistics from the baseline CE sample. These are global statistics for the whole sample, that is they are constructed using family-year cells. As a comparison, the statistics are very much in line with those reported in Berger, Bocola, and Dovis (2023). I also compare the distribution of liquid assets in the CE with the same distribution from the SCF in 2004. The summary statistics show that there are significant differences in these distributions particularly at the top. The 90th wealth percentile in the SCF is more than 7 times the 90th percentile in the CE. These differences are due to the fact that the SCF oversamples households at the top of the wealth distribution, while the CE is not particularly designed to measure the wealth of these households. Despite this limitation, the CE includes households in all SCF percentiles and provides comprehensive quarterly consumption data that can be useful to learn about the cross-sectional effects of monetary policy.

Table A.1: Summary statistics.

| | Mean | Std. Deviation | 10th P. | Median | 90th P. |
|---|---|---|---|---|---|
| Age | 44 | 11 | 29 | 44 | 59 |
| Family size | 2.8 | 1.5 | 1 | 2 | 5 |
| | | | | | |
| Consumption | 22,306 | 14,842 | 8,623 | 19,198 | 38,811 |
| Cons. per person | 9,501 | 6,984 | 3,374 | 7,864 | 17,152 |
| Liquid assets | 27,956 | 154,484 | 0 | 1,234 | 46,479 |
| Earnings | 51,755 | 48,021 | 1,478 | 41,600 | 105,748 |
| Liquid assets (CE) | 34,081 | 184,548 | 0 | 1,323 | 53,791 |
| Liquid assets (SCF) | 172,313 | 1,044,840 | 23 | 14,931 | 353,976 |

Note: Summary statistics (weighted) for the overall sample in US dollars, 2000 prices. Data source: CE 1991-2016. See main text for variable definitions. The fraction of households with a college degree is 32 percent. Annual consumption shown. The last two rows report statistics for 2004 across surveys.

### A.5.3 Monetary Policy Shocks

To estimate the causal effects of monetary policy I need exogenous variations in the policy rate. The identification approach proposed by Romer and Romer (2004) is to regress changes in the policy rate on the central bank's forecasts of its macroeconomic targets and use the estimated residuals as a measure of monetary policy shocks. Alternatively, high-frequency changes in financial markets interest rates around policy announcements can be used as instruments for the exogenous component of the policy rate. Following this second approach, Jarociński and Karadi (2020) use a Bayesian Structural VAR with sign restrictions to further disentangle conventional monetary policy shocks from possible central bank information shocks. The identification relies on negative co-movements between the interest rate surprise and stock prices as stock prices are expected to rise after a policy rate cut.

In my empirical analysis I employ the monetary policy shocks from Jarociński and Karadi (2020) (JK) aggregated at the quarterly frequency. Figure **??** shows the time series of the monetary policy shocks. These are exogenous percentage changes in the short-term nominal interest rate used as low-frequency monetary policy indicator.[2] We observe monetary policy shocks also during the period when the federal funds rate is constrained by the zero lower bound. During this period interest rate changes capture the effects on the short-term interest rate of unconventional monetary policy measures. Overall, this time series contains sizable positive and negative changes over the entire CE sample period.

In my analysis I also employ the Romer and Romer (2004) (RR) time series of monetary policy shocks updated from Coibion, Gorodnichenko, Kueng, and Silvia (2017) that includes data until 2008Q4. The right panel in Figure **??** shows the estimated percentage changes in the federal funds rate. This time series features larger movements than the JK series and contains both positive and negative changes. I use these shocks as an additional robustness check for two reasons. First, the shorter sample period allows me to focus on conventional monetary policy interventions before the Great Recession. Second, the shocks are direct changes in the policy rate targeted by the Federal Reserve.

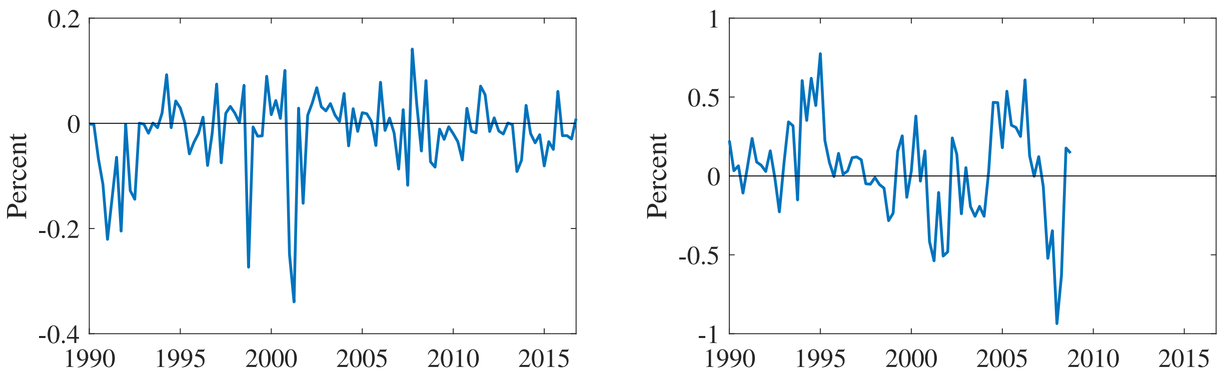


Figure A.6: Monetary policy shocks.

Note: The left panel plots the JK monetary policy shocks. The right panel plots the RR monetary policy shocks. Data at quarterly frequency.

Figure **??** shows that the JK and RR series mostly move in the same direction. This suggests a positive correlation between the two series. The only exception is in the first half of the 90s, when the JK series displays an expansionary shocks while RR features interest rate hikes.

[2]Specifically, the authors use the the monthly average of the one-year constant-maturity Treasury yield.

### A.5.4 Consumption responses

Figure **??** reports the impulse response functions of households' expenditure on nondurable goods and services for the different wealth groups. For comparison the peak response at the bottom 20% is around 0.15 percent and at the top 10% is close to 0.1 percent. We can observe that the magnitude of the consumption response across the wealth distribution is increasing in liquid wealth. However, the peak of these responses remains stable around 0.05 percent.

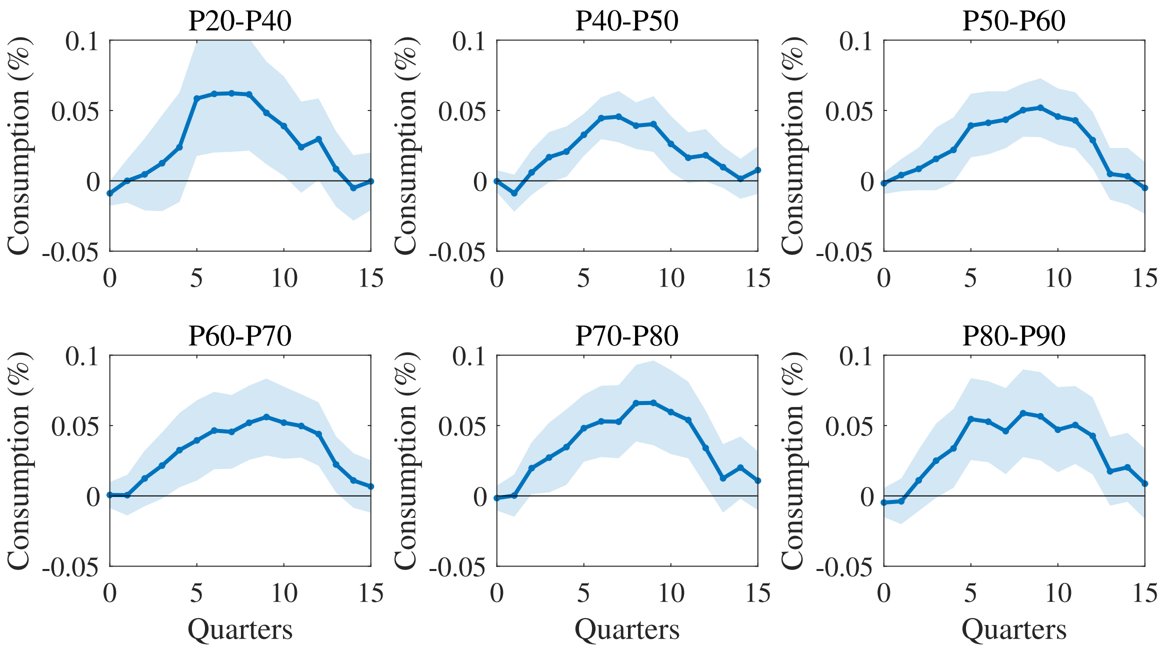


Figure A.7: Consumption responses.

Note: Responses to an interest rate cut of 100 basis points across the distribution of liquid wealth. Point estimates and 68% confidence bands shown.

### A.5.5 Robustness checks

In this section I report the results of a series of robustness checks for the main empirical analysis. I begin by changing the monetary policy shocks and the sample period. Specifically, I estimate the same model using the RR series from 1991Q3 until 2008Q4 before the Great Recession and the implementation of unconventional monetary policy measures. This is an important test because allows me to control for the identification assumptions, the variable used as policy rate, and the sample period. Since the scale of the shocks is different the estimates are an order of magnitude smaller than those obtained with the JK shocks. Changing the shocks has also implications for the dynamics. The consumption responses become more persistent. Figure **??** shows the consumption responses of different wealth groups over time. We can observe that consumption changes reach a peak after the second year and start declining only in the third year. However, also with the RR time series the consumption responses are sizable at both tails of the wealth distribution. The peak responses at the bottom 20% and top 10% tendo to be two times the peak responses of other wealth groups.

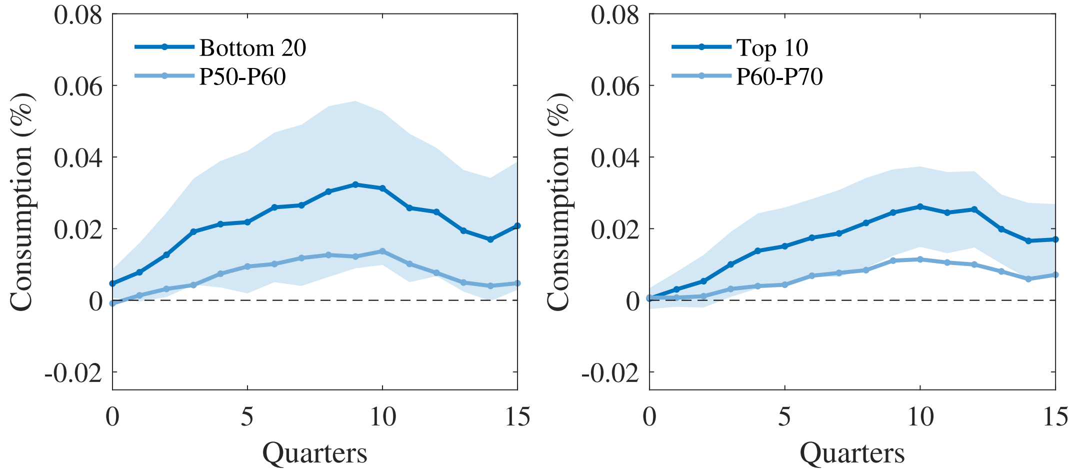


Figure A.8: Consumption responses with RR shocks.

Note: Responses to an interest rate cut of 100 basis points across the distribution of liquid wealth. Point estimates and 68% confidence bands shown.

Figure **??** plots the cross-sectional responses after two years and between two and three years from the monetary policy shock. This figure confirms the findings of the main empirical analysis. The consumption responses are decreasing in wealth for the bottom half of the distribution and increasing in wealth for the upper half.

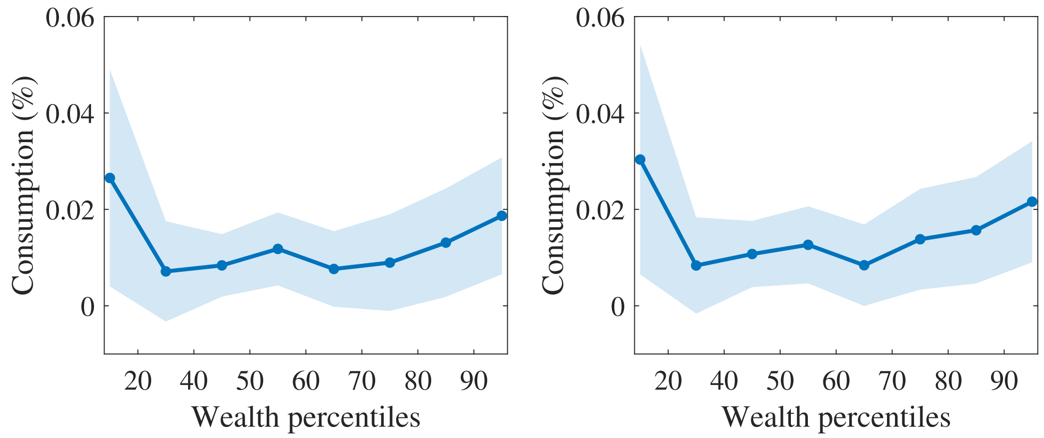


Figure A.9: Consumption responses with RR shocks.

Note: Responses to an interest rate cut of 100 basis points across the distribution of liquid wealth. Point estimates and 68% confidence bands shown. RR time series.

To further control for the sample period I estimate the model with the RR shock after removing the early years in the sample and the financial crisis. The local projections for the period 1993Q1-2008Q4 deliver very similar results. During the financial crisis in 2007-2008 the RR series displays large interest rate cuts. Removing these two years do not substiatially change the results and lead to a even more evident U-shaped effects. Increasing the estimation horizon and changing the number of lags included in the regressions also do not change the main results.

### A.5.6 Consumption shares

In this section I study the distribution of households' consumption by liquid wealth. Figure **??** plots the consumption shares of different wealth groups. The left panel shows the cross-sectional distribution in 2004 from CE data and PSID data. As expected low-wealth households and wealthy households account for a sizable share of aggregate consumption. Importantly, the CE features an high consumption share at the bottom 30% of the wealth distribution and understates the consumption share at the top 10% relative to the PSID. In both cases households at the top 10% have the largest consumption share than any other decile of the distribution.

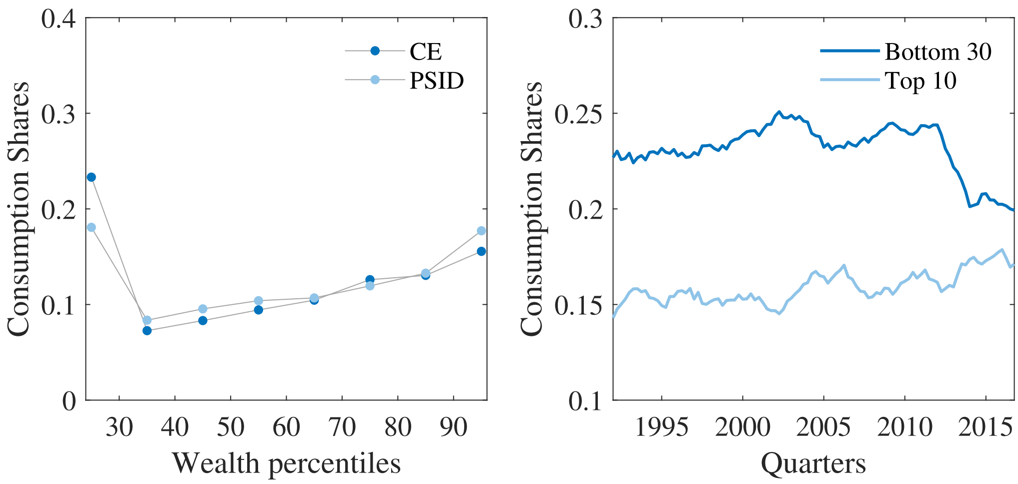


Figure A.10: Consumption shares in the microdata.

The CE allows me to compute these shares at quarterly frequency from the early 90s until 2016. The right panel in Figure **??** displays the evolution of the consumption shares at the bottom 30% and top 10% of the wealth distribution in the CE microdata. Overall, the consumption shares do not have a clear trend in the microdata. Since the early 2000s we can observe a slight increase in the consumption share of the top 10%. This share is 17 percent in 2016. On the other hand, immediately after the Great Recession, we observe a decline in the consumption shares of the bottom 30%.

# Appendix B

# Appendix

## B.1 Further details on the model

### B.1.1 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 $\mu_t$ 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.

### B.1.2 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 **??**, specifies the composition of household expenditure.[1] 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.

### B.1.3 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

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

[1] 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.

### B.1.4 Decomposing the aggregate consumption response

In this section I provide further details on the derivation and implementation of the decomposition in Section **??**, 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.2 Additional results

### B.2.1 Long-term energy shortages

In all the simulatons of Section **??** 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.[2] I begin using 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 **??** to build-in a dose of caution and at the same time acknowledge that the elasticity of substitution tend to be larger in the long run than the short run. Figure **??** contrasts the consumption response under this new scenario with the consumption response to the energy shock in Figure **??**. 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. However, the difference moslty reflects a larger decline in real wages relative to the baseline. The responses of the other variables are similar in both couterfactuals.

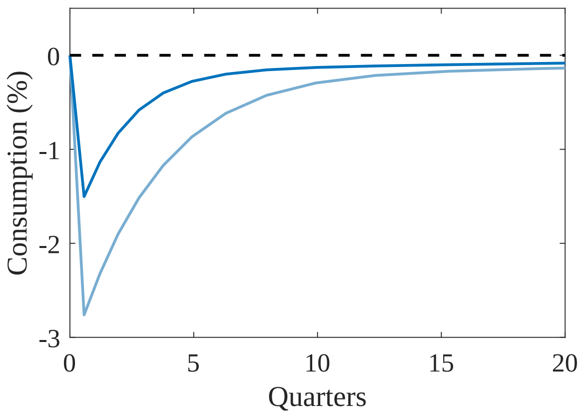


Figure B.1: Energy dynamics and aggregate consumption.

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 **??** with a fixed elasticity of 0.05.

[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.

Since the long term consequences of the shock can be substantial I further investigate these effects in the baseline model with energy consumption by firms and households. As before I consider a case in which the energy supply shortage lasts for 5 years and less than $60\%$ of the energy shortfall is absorbed within 1 year. Moreover, I also consider an intermediate case in which energy shortages last for 4 years. Throughout this experiment I use a low and fixed elasticity of substitution $\sigma = 0.1$. The analysis in this section is based on a sufficient statistic for the impact of an increase in the national energy expenditure from fossil fuels $B_t = p_{e,t}E_t$ on aggregate consumption. Specifically, I define the multiplier $M_t$ such that

$$dC_t = M_t dB_t.$$

To measure the magnitude of the shock I use the energy expenditure as it contains information on both energy price changes and energy supply changes. Figure **??** shows the response of consumption and energy expenditure share when the shock lasts respectively 3 years, 4 years, and 5 years. The energy expenditure share is defined with respect to annual GNI before the shock. In the baseline calibration the energy expenditure share increases to $9\%$ of national income, a very large increase in the total energy bill of the economy. It is important to highlight that while energy consumption is complementary for the consumption of other goods, households can partly substitute energy use. These effects offset the impact of a large increase in the total energy bill on income. If the shock lasts for 5 years the expenditure share rises to $8\%$ of national income and remains above the steady state level for 3 years leading to a consumption loss of $2\%$. In the baseline case the cumulative consumption loss over the first year is $2.3\%$ while if energy shortages last for 5 years the cumulative loss over the first year is $5.3\%$. Figure **??** shows that most of the consumption loss occurs in the first year after the shock. Moreover, the elasticity of substitution increases over time. For these reasons in my analysis I focus on the first year after the shock. There are two main reasons why the consumption loss is larger with fully flexible wages and energy consumption only by firms. First, with energy consumption by households the economic burden no longer falls only on firms and a substantial fraction of households are well-insured against income losses. Second, with nominal price and wage rigidities the drop of the real wages is more contained leading to a less severe reduction in households' earnings than in the economy with fully flexible wages.

To summarize the dynamic properties of the structural impulse response functions I use the cumulative multiplier given by

$$M_T = \int_0^T M_t dt.$$

Note that the multipliers in absolute value can be obtained from Figure **??** using a simple back-of-the-envelope calculation, for example to compute the impact multiplier in the baseline case in which the energy shock lasts for 3 years one can use $(0.01/0.05) = 4M_0$ where $M_0$ is 0.05 and 4 is due to the fact that to compute the response of the energy share I use annual consumption.

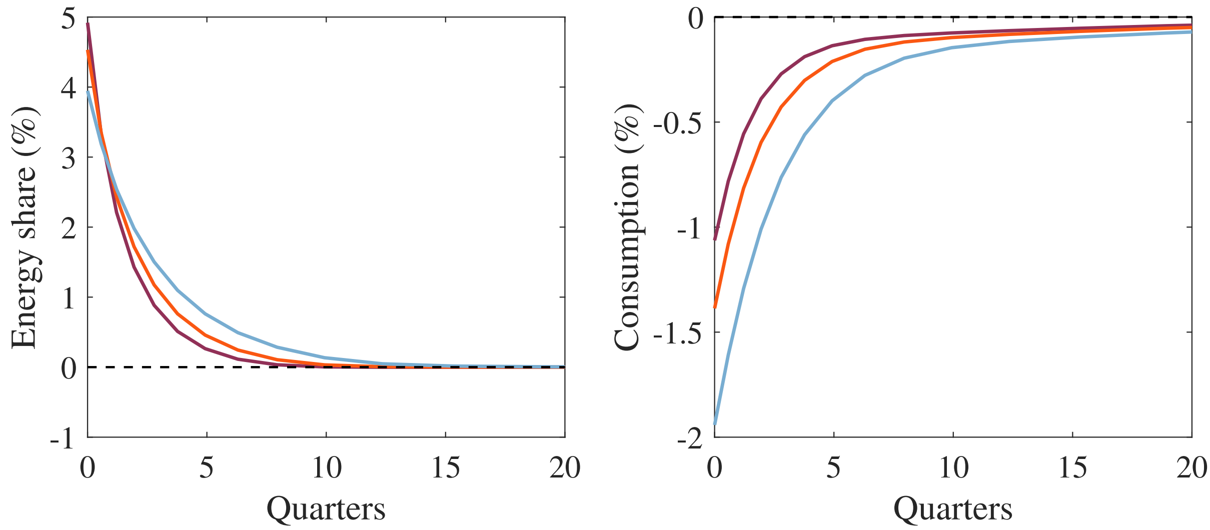


Figure B.2: Energy dynamics and the consumption multiplier.

Note: The figure shows the response of consumption and energy expenditure share when the shock lasts for 3 years (purple), 4 years (orange), and 5 years (light blue).

Table B.1: Structural multipliers

| Shock Persistence | 3 Years | 4 Years | 5 Years |
|---|---|---|---|
| Impact multiplier | 0.05 | 0.08 | 0.12 |
| 1 Year multiplier | 0.3 | 0.4 | 0.6 |

Note: The columns of the table report the multipliers when the energy shortages last for 3 years, 4 years, and 5 years. Multipliers shown in absolute value.

Table **??** reports the impact multiplier and the cumulative multiplier over the first year and shows how these multipliers vary with the persistence of the energy shock. The cumulative multiplier is an order of magnitude higher than the impact multiplier and can be large if energy shortages last for 5 years. Moreover, the impact multiplier also increases with the persistence of the shock as households and firms anticipate today the long lasting effects of the shock. Overall, these computations quantitatively illustrate the dynamic implications of the aggregate demand effects for the output loss from an energy supply shock. I find that for a very persistent shock the dynamic amplification effects can be substantial. Moreover, these results suggest that the uncertainty regarding long lasting effects can amplify the economic losses. However, I find that even the cumulative multipliers are substantially below one.

### B.2.2 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 **??**. The model generates large MPCs, yet these MPCs are at the lower bound of empirical estimates, as I discuss in Section **??**. 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.

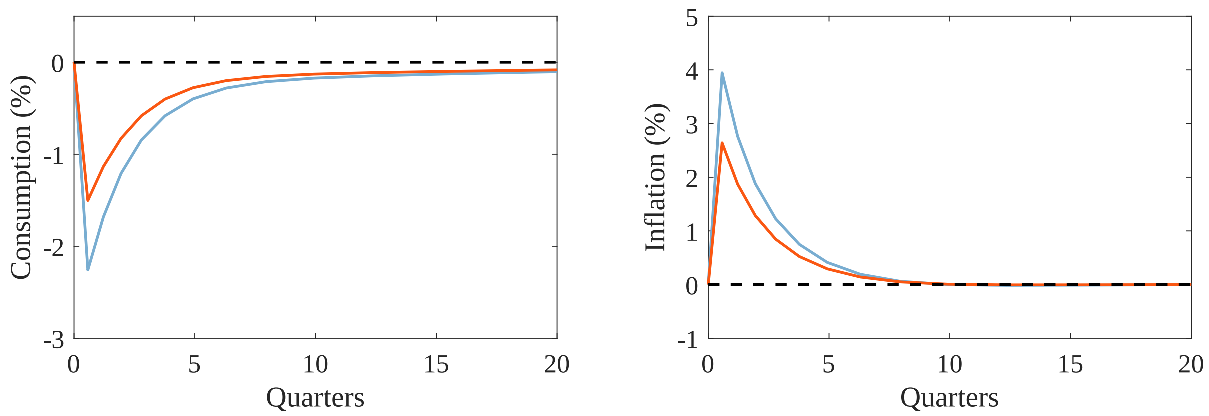


Figure B.3: MPC and aggregate consumption.

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 **??** 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 **??** are likely to be robust.

### B.2.3 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 **??** 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.

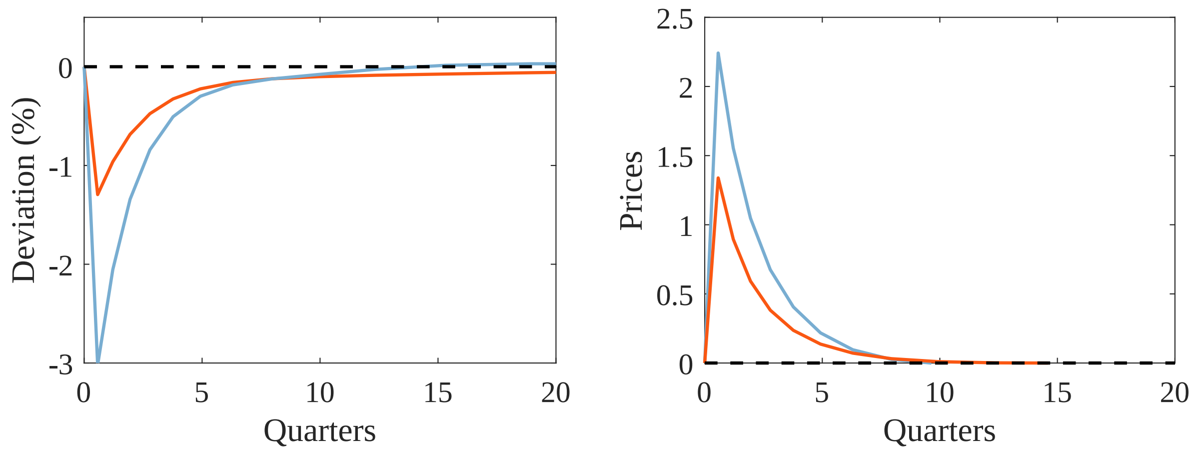


Figure B.4: Frisch elasticity and aggregate dynamics.

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.

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