Energy Inflation and Consumption Inequality

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Abstract

Recent research unveiled the heterogeneous effects of rising energy prices for low-income and high-income European households, as they tend to purchase distinct consumption baskets. We explore the effects of energy inflation on consumption inequality in a Two-Agent New Keynesian (TANK) model with an exogenous energy sector, and look for the optimal monetary policy response to an energy price shock. We find that rising energy prices widen consumption inequality through the expansions of inflation and income gaps. The effects of a maximizing welfare monetary policy are partially approximated by a core inflation targeting Taylor rule.

JEL-Classification: E21, E23, E31, E52, I14, Q43.

Keywords: TANK models, energy, monetary policy.

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1 Introduction

2021 is the year that marked the return of inflation in Europe. After a long period of stability consumer prices have resumed to grow again, so that at the end of 2022 the annual European Harmonised Index of Consumer Prices[1] (HICP) inflation, as reported by Eurostat data, exceeded 10% and proved to be persistent even in 2023. Gonçalves et al. (2022) studied the role of demand and supply factors in each component of the euro area HICPX inflation, that is the HICP inflation excluding energy and food, finding that its surge in the third quarter of 2021 was initially mostly driven by the supply side of the economy, and later also fueled by demand factors. Menyhert et al. (2022) suggest that in the EU, which is a net energy importer, the growth of inflation appears to have been mainly driven by the rise in energy prices—including gas, electricity, fuel and other energy products. Already manifested in 2021 the increase in energy prices exploded the following year, when exceeded 40% on an annual basis in the euro area, largely due to the consequences of the Russian invasion of Ukraine. Furthermore, energy inflation has in turn influenced increases in the prices of non-energy goods. Indeed, energy price shocks tend to be passed on to the prices of other goods and services; to the extent that firms have the market power to pass these costs on to final consumers, large inflationary pressures will arise (Kilian and Zhou (2022)).
Anyway, while a change in energy prices can have several origins, an individual household will perceive it as an exogenous shock to its real disposable income, as it takes energy prices as given when making decisions on consumption and savings (Battistini et al. (2022)). Inflation has reduced the real income of European households, impacting low-income families more significantly. Ari et al. (2022) estimated that in 2022 the growth in fossil fuel prices increased the cost of living of European households by close to 7% of consumption on average, affecting them in most cases in a regressive form. This is not surprising: according to Erosa and Ventura (2002) inflation has important distributional effects, as it is effectively a regressive consumption tax. Corsello and Riggi (2023) highlight that the inflationary wave started in 2021, largely driven by energy and food prices, has exacerbated the regressive nature of inflation, as the most vulnerable households consume a much larger share of these primary goods compared to the more affluent ones. The principle according to which the effects of price growth can be very heterogeneous for different types of households has already been investigated in several studies (e.g. Bach and Ando (1957); Gürer and Weichenrieder (2020); Ha et al. (2021)). Seminal works in this sense are those by Michael (1979) and Hagemann (1982), according to which the exposure to higher inflation varies greatly across individual families in the United States, as low-income households devote a relatively larger share of their income to the purchase of basic necessities, and are therefore more affected by the increase in prices of these types of goods and

[1]The European Central Bank's (ECB) main task is to maintain price stability in the euro area and the indicator it uses for monitoring inflation is the Harmonised Index of Consumer Prices (HICP). Inflation is measured by the means of a consumer price index to compare current and past prices of goods and services. The HICP is calculated by Eurostat, the statistical office of the European Union, on the basis of a consumption bundle made up by goods and services that people typically purchase. For further information see https://www.euro-area-statistics.org/.

services. A work by Charalampakis et al. (2022) shows that it is the case for European families too; the effects of recent hikes in euro area HICP inflation differ significantly for low- and high-income households, mainly for two reasons. The first lies in what they call the inflation gap, that is the gap between the effective inflation rates experienced by low-income and high-income households, determined by their different spending patterns. As a matter of fact, they have different consumption baskets: the former allocate a greater fraction of their consumption expenditure on basic necessities, including food, electricity, gas and heating, while they spend a smaller share of their overall consumption in everything else, such as transportation, recreation, restaurants, and more. The authors exploit the Eurostat Household Budget Survey[2] (EU-HBS) to estimate the specific consumption basket of each income quintile group, discovering that the difference between the effective inflation rates experienced by households in the lowest and highest income quintiles has recently increased dramatically, from 0.1% in September 2021 to 1.9% in September 2022. The second is the ability to amortize increments in the cost of living through savings. Low-income households tend, more often than high-income households, to consume a larger share of their income, save less, and face liquidity constraints. Usually they are unable to spread their consumption over time, for example by the means of financial markets, hence they have a reduced capacity to absorb inflation-driven increases in the cost of living. Also Battistini et al. (2022) and Battistini et al. (2023) agree that the different exposure of households to energy costs and their different incomes imply a relatively higher impact of energy inflation for low-income households. They observe that the share of households' monthly income that goes on utilities and transport services, i.e. the energy-intensive consumption, that is an approximate indicator of their exposure to an energy price change, differs widely across income groups, standing at almost 35% for the lowest quintile of the income distribution, but less than 10% for the top quintile. Finally, the analysis by Menyhert et al. (2022), based on the EU-HBS reveals that, on average, European families devote the 25.4% and 13% of their consumption expenditure to food and energy, respectively.

This paper studies the distributional effects of energy inflation across households' consumption, and look for the optimal monetary policy response to an energy price shock. We focus on energy inflation as it seems to be one of the fundamental drivers of recent enlargements in European consumer prices, and on consumption inequality, as consumption data better reflect the impact of inflation on households' heterogeneous consumption bundles. A novel empirical investigation by Bettarelli et al. (2023) unveils that energy inflation increases several measures of consumption inequality for a large panel of 129 economies during the period 1970-2013. We conduct a theoretical analysis employing a stylized model of the European economy, characterized by the presence of two types of consumer and an exogenous energy sector. In other words, we introduce energy in an otherwise standard Two-Agent New Keynesian (TANK) model, as Blanchard and Galí (2010) do for oil, introducing

[2]The Household Budget Survey by Eurostat is a national survey that focuses on households' expenditure on goods and services and gives a picture of living conditions in the EU. It is carried out by each EU country and the results are used to make key macroeconomic indicators. For further information see https://ec.europa.eu/eurostat/web/household-budget-surveys.

energy both as a production input and as a consumption good, assuming that the country is an net energy importer and that the real price of energy follows an exogenous process. There are two types of consumer: savers and Hand-to-Mouth. The former can rely on differentiated sources of income and smooth consumption over time, as they receive dividends deriving from the ownership of firms and have full access to financial markets. The latter have a higher marginal propensity to consume (MPC), as they only have got labor income, consume what they earn in each period and do not have access to financial markets. Moreover, the households purchase two distinct consumption baskets in order to capture the European families' features suggested by the data. Thus, similar to Corsello and Riggi (2023), the two baskets will consist of a household-specific combination of energy and non-energy goods, where the share of expenditure on energy is higher for Hand-to-Mouth than for savers. Consequently, the former will consume a larger fraction of their income on energy goods.
Our work is twofold. First, we explore the effects of an energy price shock on households' consumption inequality. Second, we look for the most suitable monetary policy measure to face an energy price shock. Our main contribution consists in extending the theoretical framework by Corsello and Riggi (2023) to the analysis of optimal monetary policy with a focus on the euro area, operationally following Chan et al. (2022). The increase in the real price of energy leads to a rise in the general price level. In response, the central bank significantly raises the monetary policy rate, thereby exacerbating the contractionary effects of the price shock. Firms sharply cut production and manage to maintain positive profits, partly due to a reduction in wages. Energy inflation directly enters the households' consumption basket, affecting the HtM more severely due to the composition of their basket. In addition to the inflation gap effect, there is also an increase in the income gap resulting from the distribution of profits to savers in the form of dividends, amplifying the rise in the consumption gap between the two consumer types. At the aggregate level, we observe a response to a negative supply shock: output decreases, as does consumption and employment. Analyzing the maximizing welfare monetary policy reveals that the monetary authority can adopt a different strategy in response to the imported good price shock. If the central bank responds by adjusting the policy rate more moderately consumption inequality among households substantially decreases, along with production, consumption, and employment losses. Approaching the outcome obtained in this exercise may be achieved by modifying the baseline model and substituting the monetary policy target with core inflation, the measure associated with price dispersion and, consequently, proving relevant from a welfare perspective.

Related Literature This paper is related to various strands of the literature. One of them is the extensive branch concerning the study of the effects of energy prices surge on the economy, which has evolved since the oil crises of the 1970s and whose foundations are laid in the articles by Bruno and Sachs (1985), Hamilton (1983) and Hamilton (1996), Hooker (1996), and Rotemberg and Woodford (1996), among others. There is a long tradition of papers employing New Keynesian models to explore this relationship. One of the pioneering contributions is that of Blanchard and Galí (2010), who modify a standard Dynamic Stochastic General Equilibrium (DSGE) model to explain the underlying causes of the different macroeconomic effects of variations in oil prices over time. First, they introduce oil both as an input in production and as a consumption good, assuming that the country is an oil importer, and that the real price of oil, in terms of domestic goods, follows an exogenous process; second, they allow for real wage rigidities along the lines of Blanchard and Galí (2007). They conclude that the effects of oil price shocks must have coincided in time with large shocks of different natures, and that they have changed over time for three possible reasons: a decrease in real wage rigidities, an increased credibility of monetary policy, and the decrease in the share of oil in consumption and in production. In their wake, Blanchard and Riggi (2013) estimate a modified version of the model for the United States (US) economy, while Vásconez et al. (2015) broaden it with capital accumulation. The former find that two major changes have taken place in the US economy since the 1970s: a large decrease of real wage rigidities and a substantial increase in the credibility of monetary policy and the anchoring of inflation expectations. The latter observe that an increase in energy efficiency significantly attenuates the effects of an oil shock, and that oil consumption and energy efficiency have been two major engines for US growth from the 1990s to the 2010s. We contribute to this branch of the literature investigating the implications of energy price shocks on households' consumption inequality. In particular, we draw inspiration from their oil modelling approach and apply it to the broader category of energy goods, within a framework featuring a tractable form of household heterogeneity à la Bilbiie (2008).

We also make our contribution to the domaine of the literature on inflation and inequality, focusing on the effect of energy inflation on consumption inequality, rather than income inequality. A number of works confirm that higher inflation raises income inequality (see, among others, Amble and Stewart (1994); Bulir and Gulde (1995); Garner et al. (1996)). However, according to Bettarelli et al. (2023), consumption data better reflects the impact of rising prices on the consumption basket of households and different dynamics in the relative prices of goods consumed by rich and poor. They use a large panel of 129 advanced and developing economies during the period 1970-2013, showing that higher energy prices increase various measures of consumption inequality, including the Gini index of consumption inequality and the top/bottom ratios for the 10th and 20th income percentiles. They realize that higher energy prices reduce (increase) the share of consumption for households in the lower (higher) income deciles. We narrow the scope of analysis to Europe and leverage the empirical evidence to construct a theoretical model that can provide us with policy implications.

Another related segment of the literature is the one about the involvements of household heterogeneity for macroeconomic dynamics. Indeed, we use specific features of models based on the concept of Limited Asset Market Participation (LAMP), as put forth by Campbell and Mankiw (1989), and subsequently employed in various articles, including Galí et al. (2007), Bilbiie (2008), Colciago (2011), and Albonico et al. (2019). We enhance this setting with an exogenous energy sector and seek the optimal monetary policy response to maximize the welfare of consumers populating the economy.

Finally, we contribute to the literature that look into the consequences of diverse monetary policy reactions to energy price shocks. Auclert et al. (2023) study the macroeconomic effects of energy price shocks in energy-importing economies using an open-economy Heterogeneous-Agent New Keynesian (HANK) model. They notice that when MPCs are realistically large and the elasticity between energy and domestic goods is realistically low, energy inflation reduces real incomes and induces a recession, even if the central banks does not tighten monetary policy. Moreover, monetary tightening has limited effect on imported inflation when dose in isolation, but can be powerful when done in coordination with other energy importers by lowering world energy demand. Fiscal policy, especially energy price subsidies, can isolate individual energy importers from the shock, but raises world energy demand and prices, imposing large negative externalities on other economies. Gnocato (2023) studies the optimal conduct of monetary policy in a tractable HANK model with Search and Matching (S&M) frictions in the labor market and non-homotethic household preferences. He notes that rising energy prices induce a drag on aggregate demand and employment. The price shock acts endogenously as a cost-push term: it implies that the monetary authority optimally accommodates some core inflation so as to contain the rise in unemployment, and hence avoid households to become more exposed to the shock. Chan et al. (2022) build an open-economy TANK model, with labor and imported energy as complementary inputs in production, to analyze the demand side effects of an energy price shock. They conclude that, assuming production inputs are sufficiently difficult to substitute, or that prices are sufficiently flexible, an energy price shock has a negative impact on aggregate demand, i.e. the supply shock has a self-correcting effect, since the reduction in aggregate demand mitigates inflationary pressures. Furthermore, they look for the optimal response of monetary policy to an energy price shock: optimal monetary policy is contractionary in the baseline scenario, but can be expansionsary when the share of financially constrained families rises. We conduct a similar analysis: we study the effect of an energy price shock on consumption inequality and calculate the desirable monetary policy response, assuming, however, that the two types of households have two different consumption baskets. The closest to our model is the one in Corsello and Riggi (2023), who construct and estimate a closed-economy TANK model with imported energy for the Italian economy, concluding that the impact of the shock worsens when monetary policy responds aggressively to inflation. Similarly, we assume that each type of household derives utility from a basket of goods composed of a combination of energy and non-energy goods, where the former are imported, and the latter are domestically produced. Furthermore, in our model too, inspired by data on European households, the share of expenditure for energy is higher for low-income families, which in their case are represented by low-efficiency households. We extend the study to the European case and derive the optimal monetary policy response to an energy price shock.

The remainder of the article is organized as follows. Section 2 illustrates the model. The effects of energy inflation on consumption inequality, both analytically and numerically, are presented in section 3. Section 4 is devoted to optimal monetary policy and Section 5 concludes.

2 Model

The model builds on the framework of Blanchard and Galí (2010) and Bilbiie (2008). Time is discrete and the horizon is infinite. It consists of a cashless closed economy populated by households, unions, firms, government, and a monetary policy authority. As Blanchard and Galí (2010) for oil, here energy is introduced both as a consumption good and as an input in production, assuming that the country is an energy importer, and that the real price of energy follows an exogenous process. Energy is imported from abroad at an exogenous world price and energy imports are paid for with exports of output, with trade being balanced at every date, an assumption that allows us to consider the economic system as a closed economy. As in Bilbiie (2008) there are two types of household: savers and Hand-to-Mouth (HtM). Savers are forward-looking optimizing agents, who smooth consumption, since they are able to trade in all markets for state-contingent securities. They invest in government bonds and own firms, thus they receive dividends too[3]. Since markets are complete savers can perfectly insurance themselves. HtM are optimizing agents who consume each period their disposable income which comes from labor, and have no access to financial markets, hence they cannot smooth consumption over time. There are two types of consumption good, energy and non-energy goods, combined in a different consumption basket depending on the consumer type. Savers and HtM consume two different baskets of goods, where the share of expenditure on energy goods is relatively higher for HtM, while the share of expenditure on non-energy goods is relatively greater for savers. In summary, savers purchase a bundle of energy and non-energy goods, hold government bonds and firms shares, and supply labor to firms. HtM purchase another bundle of energy and non-energy goods, and supply labor to firms. Firms are distinguished in a continuum of monopolistically competitive intermediate goods firms and a perfectly competitive firm. The former hire labor, purchase energy, and produce differentiated intermediate goods, the latter packages a final good which is sold to households. We deviate from the assumption of a perfectly competitive labor market, introducing the presence of a continuum of unions (see, among others, Galí et al. (2007)), in order to avoid type-dependent labor supply implications for consumption inequality. As for standard New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models staggered price setting à la Calvo (1983) is introduced in the goods market. Finally, the central bank is in charge of monetary policy, setting the short-term nominal interest rate.

2.1 Energy

We follow the approach by Blanchard and Galí (2010) for oil, introducing energy both as consumption good and as an input in production, assuming that the country is an energy importer and that the real price of energy, in terms of domestic final good, follows an exogenous process. Energy is imported from abroad at an exogenous world price $P_{E,t}$ and energy imports are paid for with exports of output, with trade being balanced at every date. $P_{Q,t}$ represents the price of non-energy goods, i.e. the final

[3]We do not model the equity market explicitly as in Bilbiie and Straub (2004), among others.

domestic goods, while the real price of energy in terms of domestic final good is given by

$$S_{E,t} = \frac{P_{E,t}}{P_{Q,t}} \tag{1}$$

The real price of energy follows an AR(1) process

$$\ln S_{E,t} = \rho_{se} \; lnS_{E,t-1} + e_{se,t} \tag{2}$$

where $\rho_{se} \in (0,1)$, and $e_{se,t} \sim \mathcal{N}(0, \sigma^2_{se})$ is an *i.i.d.* energy price shock with zero mean and constant variance σ^2_{se}.

2.2 Households

The economy is populated by a continuum of infinitely-lived households of measure 1, all having the same utility function. A $1-\lambda$ time-invariant share of households is forward-looking and is able to smooth consumption, trading in all complete markets for state-contingent securities. From now on they will be referred to as Savers. The λ remaining share of consumers, henceforth Hand-to-Mouth, have no access to financial markets: they cannot smooth consumption and entirely consume their disposable income which comes from labor.

2.2.1 Savers

Savers want to maximize their expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C^s_t N^s_t)$$

where E_0 is the expectation operator conditional on time $t = 0$, $\beta \in (0,1)$ is the savers' subjective discount factor, N^s_t represents the savers' hours of labor, and C^s_t their composite consumption index[4] defined by

$$C^s_t \equiv \left[(1-\chi_s)^{\frac{1}{\eta}} (C^s_{Q,t})^{\frac{\eta-1}{\eta}} + (\chi_s)^{\frac{1}{\eta}} (C^s_{E,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

$C^s_{Q,t}$ is an index of savers' non-energy goods consumption given by the Constant Elasticity of Substitution (CES) Dixit and Stiglitz (1977) aggregator

$$C^s_{Q,t} \equiv \left(\int_0^1 C^s_{Q,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}$$

where $j \in [0,1]$ denotes the generic non-energy variety, and $C^s_{E,t}$ the savers' consumption of imported energy. Note that η measures the elasticity of substitution between non-energy and energy goods, ϵ

[4] When $\eta = 1$ the composite consumption index becomes $C^s_t = \frac{1}{(1-\chi_s)^{(1-\chi_s)} \chi_s^{\chi_s}} {C^s_{Q,t}}^{1-\chi_s} {C^s_{E,t}}^{\chi_s}$.

the elasticity of substitution among non-energy varieties, and $\chi_s \in [0,1]$ captures the relative weight of energy in the savers' consumption baskets.

To maximize their expected lifetime utility savers are subject to a sequence of flow budget constraints of the form

$$\int_0^1 P_{Q,t}(j)C^s_{Q,t}(j)dj + P_{E,t}C^s_{E,t} + B_t \leq W_t N^s_t + R_{t-1}B_{t-1} + P^s_{C,t}D^s_t$$

for $t = 0, 1, 2...$ Where $P_{Q,t}(j)$ is the price of non-energy variety j, $P_{E,t}(j)$ the price of the energy good in terms of domestic currency, B_t is the quantity of nominally riskless one-period bonds purchased in period t offering a nominal gross return R_t in period $t+1$, W_t is the nominal wage, and $P^s_{C,t}D_t$ are nominal dividends from the ownership of firms. Furthermore, Savers must satisfy the following solvency condition for all t

$$\lim_{T\to\infty} E_t\{B_T\} \geq 0$$

The saver's problem can be divided into three steps. First, he has to allocate his consumption expenditures among different non-energy good varieties. This means that he must maximize $C^s_{Q,t}$ for any given level of expenditures $\int_0^1 P_{Q,t}(j)C^s_{Q,t}(j)dj$. The solution to this problem yields the Saver's demand schedule for the generic non-energy variety j

$$C^s_{Q,t}(j) = \left(\frac{P_{Q,t}(j)}{P_{Q,t}}\right)^{-\epsilon} C^s_{Q,t}$$

for all $j \in [0,1]$, where

$$P_{Q,t} = \left(\int_0^1 P_{Q,t}(j)^{1-\epsilon}dj\right)^{\frac{1}{1-\epsilon}}$$

is the price index of non-energy goods, as we are going to see further on.

Second, savers must allocate their consumption expenditures between energy and non-energy goods. Therefore they maximize their composite consumption basket C^s_t subject to the their consumption expenditures constraint, given by $P^s_t C^s_t = P_{Q,t}C^s_{Q,t} + P_{E,t}C^s_{E,t}$. Solving this problem yields the savers' demand schedules for non-energy and energy goods, respectively given by

$$C^s_{Q,t} = (1-\chi_s)\left(\frac{P_{Q,t}}{P^s_{C,t}}\right)^{-\eta} C^s_t \tag{3}$$

and

$$C^s_{E,t} = (\chi_s)\left(\frac{P_{E,t}}{P^s_{C,t}}\right)^{-\eta} C^s_t \tag{4}$$

where

$$P^s_{C,t} \equiv \left[(1-\chi_s)(P_{Q,t})^{1-\eta} + \chi_s(P_{E,t})^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{5}$$

is the saver's Consumer Price Index[5] (CPI^s). Hence saver's total consumption expenditures are given by

$$P_{C,t}^s C_t^s = P_{Q,t} C_{Q,t}^s + P_{E,t} C_{E,t}^s$$

and its period budget constrain can be rewritten as

$$P_{C,t}^s C_t^s + B_t \leq W_t N_t^s + R_{t-1} B_{t-1} + P_{C,t}^s D_t^s$$

for $t = 0, 1, 2...$

Third, savers must decide how much to consume, to work, and invest in government one-period bonds. Solving the following maximization problem allows us to find the saver's remaining optimality conditions. The intratemporal condition, i.e. its labor supply, is given by

$$-\frac{U_{ns,t}}{U_{cs,t}} = \frac{W_t}{P_{C,t}^s}$$

where $U_{ns,t}$ is saver's marginal utility of labor, and $U_{cs,t}$ its marginal utility of consumption. The intertemporal condition, i.e. the Consumption Euler equation, by

$$\frac{1}{R_t} = \beta E_t \left\{ \frac{U_{cs,t+1}}{U_{cs,t}} \frac{P_{C,t}^s}{P_{C,t+1}^s} \right\}$$

for $t = 0, 1, 2, ...$

Under the assumption of a Constant Relative Risk Aversion (CRRA) period utility function separable in consumption and hours worked in the form

$$U(C_t^s, N_t^s) = \frac{{C_t^s}^{1-\sigma}}{1-\sigma} - \frac{{N_t^s}^{1+\varphi}}{1+\varphi}$$

the saver's labor supply and Euler equation can be rewritten respectively as

$${C_t^s}^{\sigma} {N_t^s}^{\varphi} = \frac{W_t}{P_{C,t}^s}$$

and

$$\frac{1}{R_t} = \beta E_t \left\{ \left(\frac{C_{t+1}^s}{C_t^s} \right)^{-\sigma} \frac{P_{C,t}^s}{P_{C,t+1}^s} \right\} \tag{6}$$

where σ measures relative risk aversion and φ is the inverse of Frisch labor supply elasticity. The intratemporal optimality condition is substituted by a wage schedule due to the presence of an economy-wide union. One can determine the stochastic discount factor for nominal payoffs from t

[5]In the particular case of $\eta = 1$, CPI^s becomes $P_{C,t}^s = {P_{Q,t}^s}^{1-\chi_s} {P_{E,t}^s}^{\chi_s}$.

to $t+1$ as

$$\Theta_{t,t+1} = \beta \frac{\Theta_{t+1}}{\Theta_t} = \beta \frac{U_{cs,t+1}}{U_{cs,t}} \frac{P^s_{C,t}}{P^s_{C,t+1}}$$

i.e.

$$\frac{1}{R_t} = E_t(\Theta_{t,t+1})$$

Consequently, the stochastic discount factor for nominal payoffs from t to $t+k$ is equal to

$$\Theta_{t,t+k} = \beta^k \frac{\Theta_{t+k}}{\Theta_t} = \beta^k \frac{U_{cs,t+k}}{U_{cs,t}} \frac{P^s_{C,t}}{P^s_{C,t+k}}$$

2.2.2 Hand-to-Mouth

The Hand-to-Mouth are the consumers who simply consume their disposable income and do not participate to asset markets because of their constraints or myopic behavior[6]. The HtM maximizes its period utility function $U(C^h_t, N^h_t)$, where N^h_t represents its hours worked, C^h_t its composite consumption index[7] defined by

$$C^h_t \equiv \left[(1-\chi_h)^{\frac{1}{\eta}} (C^h_{Q,t})^{\frac{\eta-1}{\eta}} + (\chi_h)^{\frac{1}{\eta}} (C^h_{E,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

where $C^h_{Q,t}$ is an index of HtM's consumption of non-energy goods given by the CES function

$$C^h_{Q,t} \equiv \left(\int_0^1 C^h_{Q,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}$$

where $j \in [0,1]$ denotes the generic non-energy variety, and $C^h_{E,t}$ HtM's consumption of energy goods. Note that $\chi_h \in [0,1]$ represents the share of energy in the HtM's consumption basket. The period utility function is subject to the following period budget constraint

$$\int_0^1 P_{Q,t}(j) C^h_{Q,t}(j) dj + P_{E,t} C^h_{E,t} \leq W_t N^h_t$$

for $t = 0, 1, 2...$ As the saver does the HtM must allocate its consumption expenditures among different non-energy good varieties, and between energy and non-energy goods. Problems are analogous to the saver's case and yield the aggregate HtM's consumption expenditures for non-energy goods

$$P_{Q,t} C^h_{Q,t} = \int_0^1 P_{Q,t}(j) C^h_{Q,t}(j) dj$$

[6] They are often referred to as Non-Ricardian, Constrained or Rule-of-Thumb consumers.

[7] When $\eta = 1$ the composite consumption index becomes $C^h_t = \frac{1}{(1-\chi_h)^{(1-\chi_h)} \chi_h^{\chi_h}} {C^h_{Q,t}}^{1-\chi_h} {C^h_{E,t}}^{\chi_h}$.

the HtM's demand schedule for the generic non-energy variety

$$C^h_{Q,t}(j) = \left(\frac{P_{Q,t}(j)}{P_{Q,t}}\right)^{-\epsilon}$$

for all $j \in [0,1]$; and the HtM's optimal conditions related to the allocation of consumption between energy and non-energy goods

$$C^h_{E,t} = \chi_h \left(\frac{P_E, t}{P^h_{C,t}}\right)^{-\eta} C^h_t \tag{7}$$

$$C^h_{Q,t} = (1-\chi_h)\left(\frac{P_Q, t}{P^h_{C,t}}\right)^{-\eta} C^h_t \tag{8}$$

where

$$P^h_{C,t} \equiv \left[(1-\chi_h)(P_{Q,t})^{1-\eta} + \chi_h (P_{E,t})^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{9}$$

is the Consumer Price Index for Hand-to-Mouth[8] (CPI^h). The HtM's total consumption expenditures are given by

$$P^h_{C,t}C^h_t = P_{Q,t}C^h_{Q,t} + P_{E,t}C^h_{E,t}$$

and its period budget constraint can be rewritten as

$$P^h_{C,t}C^h_t = W_t N^h_t \tag{10}$$

for $t = 0, 1, 2, ...$ HtM's remaining optimality conditions can be computed maximizing its period utility function subject to (10). The solution to this problem yields the HtM's optimal condition

$$-\frac{U_{nh,t}}{U_{ch,t}} = \frac{W_t}{P^h_{C,t}}$$

Assuming the same period utility function adopted for savers in the CRRA form

$$U(C^h_t, N^h_t) = \frac{{C^h_t}^{1-\sigma}}{1-\sigma} - \frac{{N^h_t}^{1+\varphi}}{1+\varphi}$$

yields the hand-to-mouth labor supply

$${C^h_t}^{\sigma}{N^h_t}^{\varphi} = \frac{W_t}{P^h_{C,t}}$$

substituted by the employment chosen by firms for both savers and HtM in the system of equilibrium conditions, due to the introduction of unionized wages.

[8]When $\eta = 1$ CPI^h becomes: $P^h_{C,t} = {P^h_{Q,t}}^{1-\chi_h}{P^h_{E,t}}^{\chi_h}$.

2.2.3 Aggregation

Aggregate consumption in the economy is given by

$$P_{C,t}C_t = (1-\lambda)P^s_{C,t}C^s_t + \lambda P^h_{C,t}C^h_t \tag{11}$$

Aggregate hours worked are equal to

$$N_t = (1-\lambda)N^s_t + \lambda N^h_t \tag{12}$$

Finally, the aggregate Consumer Price Index (CPI) is

$$P_{C,t} = (1-\lambda)P^s_{C,t} + \lambda P^h_{C,t} \tag{13}$$

2.2.4 Unions

Following Galí et al. (2007) a monopolistically competitive labor market structure is considered. An economy-wide union sets the wages according to a centralized fashion, and firms instead of households determine the hours worked, taking the wage as given. Assuming wages always higher than families' marginal rate of substitutions yields that labor demand from firms is always met. Firms allocate labor demand uniformly across different workers, independently of their household type. As a consequence the union chooses an equal amount of hours worked for both Savers and HtM

$$N^s_t = N^h_t = N_t \tag{14}$$

for all t. The wage schedule is then given by

$$\left(\frac{1-\lambda}{C^{s\,\sigma}_t N^\varphi_t} + \frac{\lambda}{C^{h\,\sigma}_t N^\varphi_t}\right)\frac{W_t}{P_{C,t}} = \frac{\epsilon_w}{\epsilon_w - 1}$$

where ϵ_w is the elasticity of substitution across different types of household. In real terms the result can be restated as

$$\left(\frac{1-\lambda}{C^{s\,\sigma}_t N^\varphi_t} + \frac{\lambda}{C^{h\,\sigma}_t N^\varphi_t}\right)\frac{W^r_t P_{Q,t}}{P_{C,t}} = \frac{\epsilon_w}{\epsilon_w - 1} \tag{15}$$

where the real wage is defined as

$$W^r_t \equiv \frac{W_t}{P_{Q,t}}$$

The equilibrium conditions (14) and (15) replace the saver's and HtM's labor supply schedules. This labor market assumption allows to avoid type-dependent labor supply implications for inequality[9].

[9]See for instance, among others, Neri et al. (2023)

2.3 Firms

There is a continuum of monopolistically competitive firms indexed by $i \in [0,1]$ producing differentiate intermediate goods. The latter are used as input by a perfectly competitive firm producing a homogeneous final domestic good.

2.3.1 Final Good Firm

The representative and perfectly competitive final good firm produces the final non-energy good with a CES production function given by

$$Q_t = \left(\int_0^1 Q_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}$$

where $Q_t(i)$ is the quantity of the intermediate non-energy good i used as an input, ϵ is the constant elasticity of substitution across intermediate non-energy goods. For simplicity no energy is needed to produce the final non-energy good. The final good firm chooses $Q_t(i)$ and Q_t in order to maximize profits, taking $P_{Q,t}(i)$ and $P_{Q,t}$ as given. The solution to its problem provides us the final good firm's demand schedule for the non-energy intermediate good i

$$Q_t(i) = \left(\frac{P_{Q,t}(i)}{P_{Q,t}} \right)^{-\epsilon} Q_t$$

where

$$P_{Q,t} = \left(\int_0^1 P_{Q,t}(i)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}$$

as at the equilibrium final good firm's profits must be equal to zero.

2.3.2 Intermediate Goods Firms

There is a continuum of intermediate goods firms indexed by $i \in [0,1]$. Each of them hires a homogeneous type of labor and energy, and produces a differentiated good, exploiting the same technology represented by the following production function

$$Q_t(i) = \begin{cases} A_t E_t(i)^{\alpha} N_t(i)^{1-\alpha} - Fix, & A_t E_t(i)^{\alpha} N_t(i)^{1-\alpha} > Fix \\ 0, & otherwise \end{cases}$$

where $Q_t(i)$ is the quantity of non-energy variety produced by the generic firm i; A_t denotes the level of technology common to all firms, that evolves exogenously over time according to the following rule

$$\ln A_t = \rho_a \ln A_{t-1} + e_{a,t} \tag{16}$$

with $\rho_a \in (0,1)$, and $e_{a,t} \sim \mathcal{N}(0, \sigma_a^2)$ is an *i.i.d.* technology shock with zero mean and constant variance σ_a^2; $E_t(i)$ and $N_t(i)$ are the quantities of energy and labor used by the generic firm i as input in production, respectively; Fix is a fixed cost common to all intermediate good firms. Note that α and $1-\alpha$ respectively represent the output elasticities to energy and hours worked. Each firm pays the same wage because labor is homogeneous. Intermediate good firms solve a two-stage problem: first, they take input prices as given and rent labor and energy in perfectly competitive factor markets to minimize costs; second, they set their price with the aim of maximizing their expected real profits.

Cost Minimization The intermediate goods firms take prices of energy $P_{E,t}$ and labor W_t as given, since they are price-takers with respect to both inputs in production. Then they choose the quantity of energy and labor in order to minimize their costs subject to their production technology, with cost function $Cost_t(i)$ represented by

$$Cost_t(i) = P_{E,t}E_t(i) + W_t N_t(i)$$

The problem's first-order conditions are

$$P_{E,t} = \Psi_t(i)\alpha A_t E_t(i)^{\alpha-1} N_t(i)^{1-\alpha} = \Psi_t(i)\alpha \frac{Q_t(i)}{E_t(i)}$$

and

$$W_t = \Psi_t(i)(1-\alpha) A_t E_t(i)^{\alpha} N_t(i)^{-\alpha} = \Psi_t(i)(1-\alpha)\frac{Q_t(i)}{N_t(i)}$$

where $\Psi_t(i)$ is the problem's Lagrange multiplier that represents the firm's i nominal marginal cost, since it measures the increase in the cost function as output $Q_t(i)$ marginally increases. Combining the first-order conditions yields

$$\frac{P_{E,t}E_t(i)}{\alpha} = \frac{W_t N_t(i)}{1-\alpha}$$

Moreover, solving first-order conditions respectively for $E_t(i)$ and $N_t(i)$ allows to rewrite the production function as

$$Q_t(i) = A_t \left(\frac{\alpha \Psi_t(i) Q_t(i)}{P_{E,t}} \right)^{\alpha} \left(\frac{(1-\alpha)\Psi_t(i) Q_t(i)}{W_t} \right)^{1-\alpha}$$

Solving for Ψ_t

$$\Psi_t(i) = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)} \frac{P_{E,t}^{\alpha} W_t^{1-\alpha}}{A_t}$$

Noting that all intermediate firms face the same input prices and have access to the same production technology, it follows that the nominal marginal costs $\Psi_t(i)$ are identical across firms

$$\Psi_t(i) = \Psi_t$$

Defining the real marginal cost as

$$MC_t \equiv \frac{\Psi_t}{P_{Q,t}}$$

the former can be expressed as follows

$$MC_t = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}\frac{S_{E,t}^{\alpha}{W_t^r}^{1-\alpha}}{A_t} \tag{17}$$

and firm's i cost function can be restated as

$$Cost_t(Q_t(i)) = \Psi_t Q_t(i)$$

Profit Maximization Under Flexible Prices Under flexible prices the intermediate goods firms choose $P_{Q,t}(i)$, $Q_t(i)$, $N_t(i)$, and $E_t(i)$ in order to maximize their profits subject to the final good firm's demand schedule. The problem's first-orders condition is given by

$$P_{Q,t}(i) = \frac{\epsilon}{\epsilon - 1}\Psi_t = P^*_{Q,t}(i)$$

for all $i \in [0,1]$ where $\frac{\epsilon}{\epsilon-1}$ is the constant markup under flexible prices or frictionless or desired markup. Each intermediate goods firm chooses the optimal price $P^*_{Q,t}(i)$ for its differentiated non-energy variety as a constant markup over the nominal marginal cost Ψ_t. However, both the frictionless markup and the nominal marginal cost do not depend on i, since they are identical across firms. For this reason firm's i optimal price $P^*_{Q,t}(i)$ is equal to $P^*_{Q,t}$, that is the optimal price for each firm i.

Optimal Price Setting As mentioned above, intermediate good firms have to set the price $P_{Q,t}(i)$ in order to maximize their profits. Prices are set à la Calvo (1983), hence each intermediate goods firm may readjust its price with probability $1-\theta$ with $\theta \in [0,1]$ in any period t, independent of time passed from the last adjustment. This means that in any period a share of $1-\theta$ of intermediate goods firms change their prices, while the remaining portion of measure θ keeps their price unchanged, since θ is constant and the law of large numbers holds. In the staggered price setting introduced by Calvo random price duration occurs, and the parameter θ can be thought as an index of price stickiness. All intermediate good firms readjusting their price are in front of the same optimization problem, therefore they are going to go for the same price $P^*_{Q,t}(i) = P^*_{Q,t}$ for all $i \in [0,1]$ and $t = 0, 1, 2, ...$ Similarly, all remaining intermediate good firms, who are not readjusting their price, are going to maintain the same price of the period before. This means that one can write the following aggregate price level equation:

$$P_{Q,t} = \left[(1-\theta)(P^*_{Q,t})^{1-\epsilon} + \theta(P_{Q,t-1})^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}} \tag{18}$$

since the distribution of prices among firms not adjusting in period t corresponds to the distribution of effective prices in period $t-1$ with total mass reduced to θ. In other words, because the adjusting firms were selected randomly in any previous period, the average price of non-adjusting firms is just the average price of all firms that prevailed in period $t-1$ adjusted by a proportionality factor θ.

The representative intermediate goods firm i that has the opportunity of readjusting its price at time t, i.e. the reoptimizing firm, is going to choose the price $P^*_{Q,t}$, as the problem does not depend on i, that maximizes the sum of expected future real profits subject to the final good firm demand schedule. The first-order condition for $P^*_{Q,t}$ is

$$E_t \sum_{k=0}^{\infty} (\theta\beta)^k \vartheta_{t+k} Q_{t+k} \Big[P^*_{Q,t} P^{\epsilon-1}_{Q,t+k} - \frac{\epsilon}{\epsilon-1} MC_{t+k} P^{\epsilon}_{Q,t+k} \Big] = 0$$

for all $k \geq 0$, where θ^k is the probability that the newly set price at time t is still in place at time $t+k$; $\vartheta_{t+k} = (C^s_{t+k})^{-\sigma}$, implicitly given by $\vartheta_{t,t+k}$, the stochastic discount factor from t to $t+k$ for real payoffs, defined as $\vartheta_{t,t+k} = \beta^k \frac{\vartheta_{t+k}}{\vartheta_t} = \beta^k \frac{U_{cs,t+k}}{U_{cs,t}} = \beta^k \left(\frac{C^s_{t+k}}{C^s_t} \right)^{-\sigma}$; Q_{t+k} denotes non-energy production for intermediate firms at period $t+k$, and $MC_{t+k} = \frac{\Psi_{t+k}}{P_{Q,t+k}} = \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)} \frac{P^{\alpha}_{E,t+k} W^{1-\alpha}_{t+k}}{P_{Q,t+k} A_{t+k}}$ is the real marginal cost at time $t+k$. Solving the optimal condition for $P^*_{Q,t}$

$$P^*_{Q,t} = \frac{\epsilon}{\epsilon-1} \frac{E_t \sum_{k=0}^{\infty} (\theta\beta)^k (C^s_{t+k})^{-\sigma} MC_{t+k} P^{\epsilon}_{Q,t+k} Q_{t+k}}{E_t \sum_{k=0}^{\infty} (\theta\beta)^k (C^s_{t+k})^{-\sigma} P^{\epsilon-1}_{Q,t+k} Q_{t+k}}$$

or

$$P^*_{Q,t} = \frac{\epsilon}{\epsilon-1} \frac{Z_{N,t}}{Z_{D,t}} \tag{19}$$

where $Z_{N,t}$ and $Z_{D,t}$ are auxiliary variables we use to rewrite recursively the optimal price setting condition, which are respectively defined as

$$Z_{N,t} = E_t \sum_{k=0}^{\infty} (\theta\beta)^k (C^s_{t+k})^{-\sigma} MC_{t+k} P^{\epsilon}_{Q,t+k} Q_{t+k} = (C^s_t)^{-\sigma} MC_t P^{\epsilon}_{Q,t} Q_t + \theta\beta E_t Z_{N,t+1} \tag{20}$$

and

$$Z_{D,t} = E_t \sum_{k=0}^{\infty} (\theta\beta)^k (C^s_{t+k})^{-\sigma} P^{\epsilon-1}_{Q,t+k} Q_{t+k} = (C^s_t)^{-\sigma} P^{\epsilon-1}_{Q,t} Q_t + \theta\beta E_t Z_{D,t+1} \tag{21}$$

Hence, intermediate goods reoptimizing firms choose an optimal non-energy good price that represents their optimal desired markup over a weighted average of current and expected future marginal costs.

2.4 GDP and GDP Deflator

Nominal value added or Gross Domestic Product (GDP) is defined as domestic non-energy or gross production minus energy imports

$$P_{Y,t}Y_t \equiv P_{Q,t}Q_t - P_{E,t}E_t \tag{22}$$

where Y_t is real GDP and $P_{Y,t}$ the GDP deflator, implicitly defined by

$$P_{Q,t} \equiv (P_{Y,t})^{1-\alpha}(P_{E,t})^{\alpha} \tag{23}$$

2.5 Monetary Policy

The Central Bank sets the nominal short-term interest rate by responding to deviations of inflation and output from their steady state values, according to the following interest rate rule

$$\frac{R_t}{R} = \left(\frac{\Pi_{C,t}}{\Pi_C}\right)^{\phi_\pi}\left(\frac{Y_t}{Y}\right)^{\phi_y}\upsilon_t \tag{24}$$

where

$$\Pi_{C,t} \equiv \frac{P_{C,t}}{P_{C,t-1}} \tag{25}$$

is the aggregate (gross) CPI inflation between $t-1$ and t, and Π_C is its steady state level i.e. the monetary authority's inflation target; Y is the steady state level of GDP; ϕ_π and ϕ_y are respectively the non-negative inflation- and output-response coefficients set by the monetary authority; and υ_t is an exogenous monetary policy shock that evolves according to the following AR(1) process

$$\ln \upsilon_t = \rho_\upsilon \ln \upsilon_{t-1} + e_{\upsilon,t} \tag{26}$$

with $\rho_\upsilon \in (0,1)$, and $e_{\upsilon,t} \sim \mathcal{N}(0, \sigma_\upsilon^2)$ is an *i.i.d.* monetary policy shock with zero mean and constant variance σ_υ^2.

2.6 Equilibrium

2.6.1 Market Clearing

At the equilibrium all economic agents solve their optimization problems and all markets clear. The non-energy goods market clearing condition is provided by the aggregate level of non-energy production, equal to

$$Q_t = \left(\int_0^1 Q_t(i)^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}$$

Similarly, the energy goods and labor market clearing conditions are respectively given by

$$E_t = \int_0^1 E_t(i)di$$

and

$$N_t = \int_0^1 N_t(i)di$$

Moreover, at the equilibrium the intermediate good firms' nominal profits are

$$P_{Q,t}O_t = \int_0^1 P_{Q,t}(i)O_t(i)di$$

where they are equally rebated to savers under the form of dividends

$$P_{Q,t}O_t = (1-\lambda)P^s_{C,t}D^s_t$$

Since markets are complete and consumers who have access to financial markets are identical, government bonds are always in zero net supply

$$B_t = 0$$

for each $t = 0, 1, 2, ...$ Finally, the economy resource constraint is given by

$$P_{C,t}C_t = P_{Y,t}Y_t \tag{27}$$

2.6.2 Aggregation

An aggregate formulation for the intermediate firms' cost minimization condition in real terms is provided by

$$\frac{S_{E,t}E_t}{\alpha} = \frac{W^r_t N_t}{1-\alpha} \tag{28}$$

An expression for the intermediate firms' aggregate production function is given by

$$Q_t = \frac{A_t E^\alpha_t N^{1-\alpha}_t - F}{\zeta_t} \tag{29}$$

where

$$\zeta_t = \int_0^1 \left(\frac{P_{Q,t}(i)}{P_{Q,t}}\right)^{-\epsilon} di$$

is the price dispersion term, measuring the inefficiency due to the staggered price setting. As we mentioned above, in each period, a share of intermediate firms of measure θ keeps its price unchanged, while the remaining fraction $1-\theta$ changes its price. It follows that the price dispersion term can be rewritten as

$$\zeta_t = \int_0^{1-\theta} \left(\frac{P^*_{Q,t}}{P_{Q,t}} \right)^{-\epsilon} di + \int_{1-\theta}^{1} \left(\frac{P_{Q,t-1}(i)}{P_{Q,t}} \right)^{-\epsilon} di$$

or, recursively

$$\zeta_t = (1-\theta) \left(\frac{P^*_{Q,t}}{P_{Q,t}} \right)^{-\epsilon} + \theta \zeta_{t-1} \tag{30}$$

2.6.3 Equilibrium Conditions

The competitive equilibrium is given by a set of processes for the following 30 variables $\big[C^s_{Q,t}, C^s_{E,t}, C^s_t, C^h_{Q,t}, C^h_{E,t}, C^h_t, C_t, N^s_t, N^h_t, N_t, P_{Q,t}, P^*_{Q,t}, P_{E,t}, P^s_{C,t}, P^h_{C,t}, P_{C,t}, P_{Y,t}, S_{E,t}, \Pi_{C,t}, MC_t, R_t, Q_t, E_t, W^r_t, \zeta_t, Y_t, A_t, \upsilon_t, Z^*_{N,t}, Z^*_{D,t}\big]$ that satisfy the system of non-linear equilibrium conditions including the equations from (1) to (30). In addition, there are the following 17 parameters $\big[\beta, \lambda, \chi_s, \eta, \epsilon, \sigma, \varphi, \chi_h, \theta, \alpha, F, \mathcal{M}, \phi_\pi, \phi_y, \rho_{se}, \rho_\upsilon, \rho_a\big]$. Then, we rewrite the equilibrium conditions only in terms of relative prices and inflation, getting rid of price levels. We introduce four new variables core inflation $\Pi_{Q,t}$ defined as

$$\Pi_{Q,t} \equiv \frac{P_{Q,t}}{P_{Q,t-1}} \tag{31}$$

optimal core inflation

$$\Pi^*_{Q,t} \equiv \frac{P^*_{Q,t}}{P^*_{Q,t-1}} \tag{32}$$

relative aggregate CPI and relative GDP deflator in terms of price of the domestic good given by, respectively

$$P_{CQ,t} \equiv \frac{P_{C,t}}{P_{Q,t}} \tag{33}$$

and

$$P_{YQ,t} \equiv \frac{P_{Y,t}}{P_{Q,t}} \tag{34}$$

Finally, we express the auxiliary variables $Z_{N,t}$ and $Z_{D,t}$ in terms of core inflation respectively as

$$Z^*_{N,t} = (C^s_t)^{-\sigma} MC_t Q_t + \theta \beta E_t \Pi^{\epsilon}_{Q,t+1} Z^*_{N,t+1} \tag{35}$$

and

$$Z^*_{D,t} = (C^s_t)^{-\sigma} Q_t + \theta \beta E_t \Pi^{\epsilon-1}_{Q,t+1} Z^*_{D,t+1} \tag{36}$$

We end up with a new competitive equilibrium given by a set of processes for the following 27 variables $\big[C^s_{Q,t}, C^s_{E,t}, C^s_t, C^h_{Q,t}, C^h_{E,t}, C^h_t, C_t, N^s_t, N^h_t, N_t, \Pi_{Q,t}, \Pi^*_{Q,t}, P_{CQ,t}, P_{YQ,t}, S_{E,t}, \Pi_t, MC_t, R_t, Q_t, E_t, W^r_t, \zeta_t, Y_t, A_t, \upsilon_t, Z^*_{N,t}, Z^*_{D,t}\big]$ that satisfy a system of 27 non-linear equilibrium conditions[10].

[10] The system of non-linear equilibrium conditions is rewritten in terms of inflation measures and relative prices.

2.7 Steady State

The deterministic steady state is found evaluating the equilibrium conditions assuming all variable are constant and in the absence of shocks. Thus, we assume $S_E = A = \upsilon = 1$, where steady state variables are denoted by the same letters as before, but without the subscript t. We assume that inflation is zero at the steady state, hence gross CPI inflation is equal to one $\Pi_C = 1$. From the definition of aggregate CPI inflation and the aggregate core inflation dynamics equation, evaluated at the steady state, follows respectively that $\Pi_Q = \Pi_Q^* = 1$. Price dispersion converges to one too $\zeta = 1$. At the zero inflation steady state the Saver's Euler equation collapses to

$$\frac{1}{R} = \beta$$

Combining the new auxiliary variables and the optimal core inflation ratio at the steady state we get that the real marginal cost, at the steady state, is constant and equal to the inverse of the frictionless markup

$$MC = \frac{1}{\mathcal{M}}$$

Combining the steady state expressions for the real marginal cost and the optimal core inflation ratio yields

$$W^r = \left[\alpha^\alpha (1-\alpha)^{(1-\alpha)} \mathcal{M}^{-1}\right]^{\frac{1}{1-\alpha}}$$

Zero profits in the long-run are assumed, hence intermediate firms' fixed cost are set in order to get zero profits at the steady state. Thus, there is perfect insurance in consumption for the two types of households

$$C^s = C^h = C$$

From labor supply and aggregate labor schedules it follows that

$$N^s = N^h = N$$

Through the wage schedule and the HtM's budget constraint we find his steady state hours worked N^h and consumption C^h. Substituting the results into the steady state conditions we found for the families we get the optimal demands for energy and non-energy goods for both types of them. Moreover, energy and non-energy are given respectively by

$$E = \frac{\alpha W^r N}{1-\alpha}$$

and

$$Q = C + E$$

Real value added is equal to

$$Y = C$$

Finally, fixed cost F are given by

$$F = E^{\alpha} N^{1-\alpha} - Q$$

3 Energy Inflation and Consumption Inequality

The effects of the increase in the real price of energy on an index of average consumption gap are now investigated, in order to delve into the channels through which energy inflation contributes to household consumption inequality in the model economy.

3.1 The Consumption Gap

The index of average consumption gap between savers and HtM following is defined as

$$C_{gap,t} \equiv \frac{C_t^s}{C_t^h}$$

It captures the consumption heterogeneity between the two types of households; the greater the consumption inequality, the greater $C_{gap,t}$. At the steady state perfect consumption insurance between families holds, ensuring $C^s = C^h$, hence $C_{gap} = 1$.
Consider the saver's and the HtM's budget constraints given respectively by

$$P_{C,t}^s C_t^s + B_t = W_t N_t^s + R_{t-1} B_{t-1} + P_{C,t}^s D_t^s$$

and

$$P_{C,t}^h C_t^h = W_t N_t^h$$

Solving them respectively for C_t^s and C_t^h, and noting that in equilibrium government bonds are in zero net supply, allows to re-express the index of consumption gap as follows

$$C_{gap,t} = \frac{W_t N_t^s + P_{C,t}^s D_t}{P_{C,t}^s} \frac{P_{C,t}^h}{W_t N_t^h}$$

We define the price gap between the two types of consumer as the ratio between the HtM's and the saver's price indexes

$$P_{gap,t} \equiv \frac{P_{C,t}^h}{P_{C,t}^s}$$

and the income gap between the two types as

$$Inc_{gap,t} \equiv \frac{W_t N_t^s + P_{C,t}^s D_t^s}{W_t N_t^h}$$

thus, the index of average consumption gap can be rewritten as

$$C_{gap,t} = P_{gap,t} Inc_{gap,t}$$

or, in log-linear terms

$$c_{gap,t} = p_{gap,t} + inc_{gap,t}$$

In the present setting, the effect of an energy price shock on consumption inequality is determined by movements in the the price gap and the income gap. The higher the price gap, the higher the index of consumption gap, and the same relationship holds for the income gap. Let's take an in-depth look at these two channels.

The Price Gap Log-linearizing $P_{gap,t}$ around the zero inflation steady state up to first-order approximation yields:

$$p_{gap,t} = (\chi_h - \chi_s) s_{e,t}$$

where $s_{e,t}$ is the log-linearised real price of energy in terms of domestic non-energy good. An energy price shock that raises the real price of energy $s_{e,t}$ induces an expansion of the price gap $p_{gap,t}$, as we assume that the HtM consume a larger share of energy goods than savers ($\chi_h > \chi_s$), generating a growth in the index consumption gap $c_{gap,t}$, hence increasing consumption inequality. The larger the real price of energy, the larger the differential between the consumption baskets prices, thus the larger the impact on the differential between saver's and HtM's consumption. Assuming identical consumption baskets for the two types of consumers shuts off this channel of consumption heterogeneity; indeed, if $\chi_h = \chi_s = \chi$ it follows that $p_{gap,t} = 0$ for each $t = 0, 1, 2, ...$ As a consequence, the index of consumption gap becomes coincident with the income gap.

The Income Gap Since $N_t^s = N_t^h = N_t$ the income gap becomes

$$INC_{gap,t} = 1 + \frac{P_{C,t}^s D_t^s}{W_t N_t}$$

Since nominal profits $P_{Q,t} O_t$ are entirely rebated from intermediate good firms to savers, it must be true that

$$P_{Q,t} O_t = (1 - \lambda) P_{C,t}^s D_t^s$$

where

$$P_{Q,t} O_t = P_{Q,t} Q_t - W_t N_t - P_{E,t} E_t = \zeta_t (1 - MC_t) Q_t$$

Hence, the ratio between nominal dividends and aggregate labor income can be rewritten as

$$\frac{P_{C,t}^s D_t}{W_t N_t} = \frac{\zeta_t (1 - MC_t) Q_t}{(1 - \lambda) \zeta_t (1 - \alpha) MC_t Q_t} = \frac{1}{(1 - \lambda)(1 - \alpha)} \frac{1 - MC_t}{MC_t}$$

Defining the firms' average markup weighted by firms' input shares as the inverse of the real marginal cost as $\mathcal{M}_t \equiv MC_t^{-1}$ the income gap can be rewritten as follows:

$$INC_{gap,t} = 1 + \frac{\mathcal{M}_t - 1}{(1-\lambda)(1-\alpha)}$$

where

$$W_t N_t = \zeta_t (1-\alpha) MC_t Q_t$$

There is a positive relationship between the firms' average markup and the income gap. Notice that, denoting firm i's gross markup as $\mathcal{M}_t(i) = \frac{P_{Q,t}(i)}{\Psi_t(i)}$, and employing the intermediate firms' cost minimization conditions, we can write

$$S_{E,t}\mathcal{M}_t(i)E_t(i) = \alpha Q_t(i)\frac{P_{Q,t}(i)}{P_{Q,t}}$$

Since aggregate non-energy production is given by $Q_t = \left(\int_0^1 Q_t(i)^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}$, and the demand schedule facing firm i is $Q_t(i) = \left(\frac{P_{Q,t}(i)}{P_{Q,t}}\right)^{-\epsilon} Q_t$ it follows that

$$E_t = \frac{\alpha Q_t}{\mathcal{M}_t S_{E,t}}$$

Log-linearizing the result around the zero inflation steady state up to first order and ignoring constant yields

$$e_t = q_t - \mu_t - s_{e,t}$$

There is a negative relationship between firms' average markup, hence profits' share, and real energy price, ceteris paribus. This means that in front of an increase in the real price of energy, for the firms' average markup to growth, and simultaneously for the gross product to decrease, a drastic reduction in real energy imports is necessary.

3.2 Calibration

The model is calibrated quarterly. Calibration is standard and summarised in Table 1, with some specific parameter to tailor the model to the euro area economic context. The saver's subjective discount factor β is 0.99, consistent with an annualized real interest rate of about 4%. The utility function of both types of consumers is assumed logarithmic on consumption, i.e. risk aversion coefficient σ is set to 1. The same is true for the Frisch labor supply elasticity, therefore also φ is equal to 1. The last two values are commonly used in the reference literature, providing a standard basis for straightforward comparison with our results. This reasoning also applies for the Calvo parameter θ, and the elasticity of substitution among differentiated non-energy varieties ϵ, and across different types of households ϵ_w, respectively fixed to 0.75, 6, and 6. θ is consistent with an average period of one year for price adjustments, ϵ and ϵ_w with frictionless price and wage markup both equal to 20% (hence $\mathcal{M} = 1.2$). In line with Auclert et al. (2023), which calibrate their model to capture a large European energy-importing country, we choose a low elasticity of substitution between energy and non-energy goods η of 0.1. Moreover, as they do, we assume a high energy shock persistence ρ_{se} equal to 0.96, and a share of energy in domestic production α equal to 4%. The Total Factor Productivity (TFP) shock has persistence ρ_a of 0.9, following Chan et al. (2022), among others; and the persistence of monetary policy shock ρ_v is 0.5 (Galí (2007)). The response to inflation ϕ_π and GDP ϕ_y in the Taylor rule are standard and respectively equal to 1.5 and 0.125. The shares of energy consumption for savers χ_s and HtM χ_h, that are the key parameters of the model, are parameterized on the basis of the EU-HBS data, and following the analysis by Corsello and Riggi (2023) and Battistini et al. (2022) for the euro area. The latter observe that the households' energy-intensive consumption, that is the share of their monthly income devoted on utilities and transport services, stands at around 35% for the lowest (i.e. poorest) and at 10% for the highest (i.e. richest) income quintiles. It follows that we set $\chi_s = 0.10$ and $\chi_h = 0.35$. As a consequence, the share of HtM households λ is calibrated to 0.20, matching the share of people at risk of poverty and social exclusion in EU in 2022 too. Corsello and Riggi (2023) notice that aggregate headline CPI inflation for Italy closely tracks the price dynamics faced by the households in the fourth income quintile. So, as they do, we alternatively calibrated the saver's share of energy in consumption to match the households in the fourth income quintile, getting similar results, but less pronounced.

Table 1: Baseline Calibration

Parameter	**Value**	**Description**
β	0.99	Subjective Discount Factor
λ	0.2	Share of HtM
χ_s	0.1	Share of Energy in Saver's Basket
χ_h	0.35	Share of Energy in HtM's Basket
η	0.1	Energy and Non-Energy Elasticity of Substitution
ϵ	6	Non-Energy Goods Elasticity of Substitution
ϵ_w	6	Households Elasticity of Substitution
σ	1	Risk Aversion Coefficient
φ	1	Inverse of Frisch Elasticity
θ	0.75	Calvo Parameter
α	0.04	Share of Energy in Production
F	0.158	Fixed Cost
$\mathcal{M}$	1.200	Steady State Intermediate Firms' Gross Markup
ϕ_π	1.5	Inflation Feedback Coefficient

Table 1 – Continued

Parameter	Value	Description
ϕ_y	0.125	GDP Feedback Coefficient
ρ_a	0.9	Autoregressive Coefficient for Technology
ρ_v	0.5	Autoregressive Coefficient for Monetary Policy
ρ_s	0.96	Autoregressive Coefficient for Energy

3.3 Impulse Response Functions

In figures 1, 2, and 3 the economy's dynamic response to a 25 standard deviation shock to the real price of energy is illustrated. The blue dash-dotted line describes the response of the baseline model, where the consumption baskets of the two types of household are heterogeneous. The baseline model is compared to two alternative specifications; a homogeneous baskets model, featuring a single consumption basket for both types of consumer, and a representative agent model, whose reactions are respectively outlined with a red dashed and a green dotted line. On the supply side an unexpected increase in the real price of energy results in a reduction in the demand for the energy good by intermediate goods firms. Consequently, there is a sharp decrease in imported energy, and firms reduce domestic production, also referred to as non-energy production or gross output. The latter also leads to a firms' decrease in the demand for labor, resulting in a subsequent decline in employment. The decline in gross output is significant enough to outweigh the reduction in energy imports, causing a contraction in the GDP of the economy. The decrease in labor demand due to the reduction in production creates downward pressure on wages. The negative effect on wages is so substantial that it more than compensates for the increase in production costs due to the rise in the real price of energy, pushing down the real marginal cost of firms. As a consequence, the intermediate goods firms' average markup and profits, later distributed to savers in the form of dividends, increase, widening the income inequality between the two types of consumers, measured by the income gap. On the demand side, as both wages and hours worked decrease, an increase in the real price of energy leads to a contraction in aggregate demand. Both savers and HtM, who face higher consumer price indexes, cut their units consumed leading to a fall in aggregate consumption. The effect of the shock on aggregate demand propagates both through the supply side and directly through price increases, as energy is used both as a production input and a consumer good. The growth of CPI inflation prompts the central bank to implement a restrictive monetary policy intervention, as evidenced by the sharp rise in the nominal interest rate, leading to an increase in the real interest rate and consequently contracting the economic activity, exacerbating the recessionary effect of the shock. Notice that the aggregate economic variables response to an energy price shock is identical

Figure 1: Dynamic Responses to an Energy Price Shock

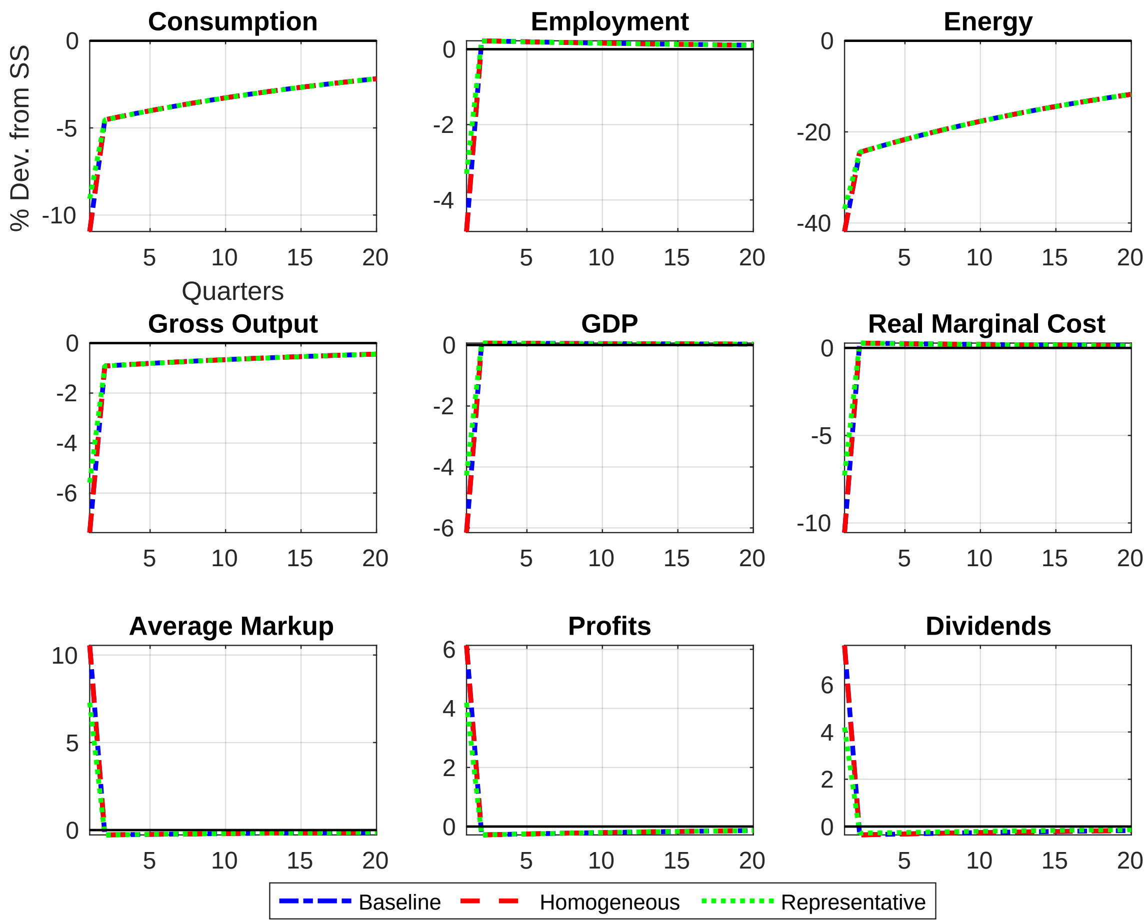
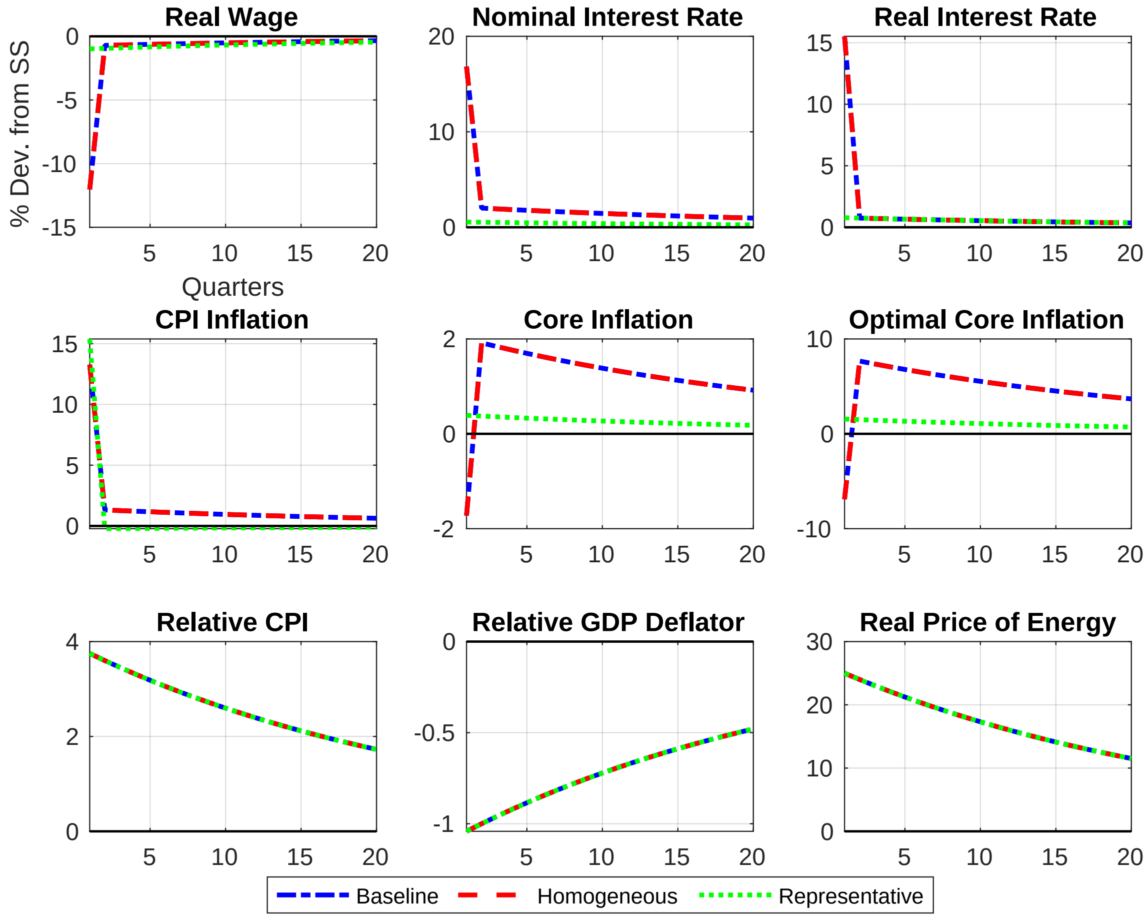


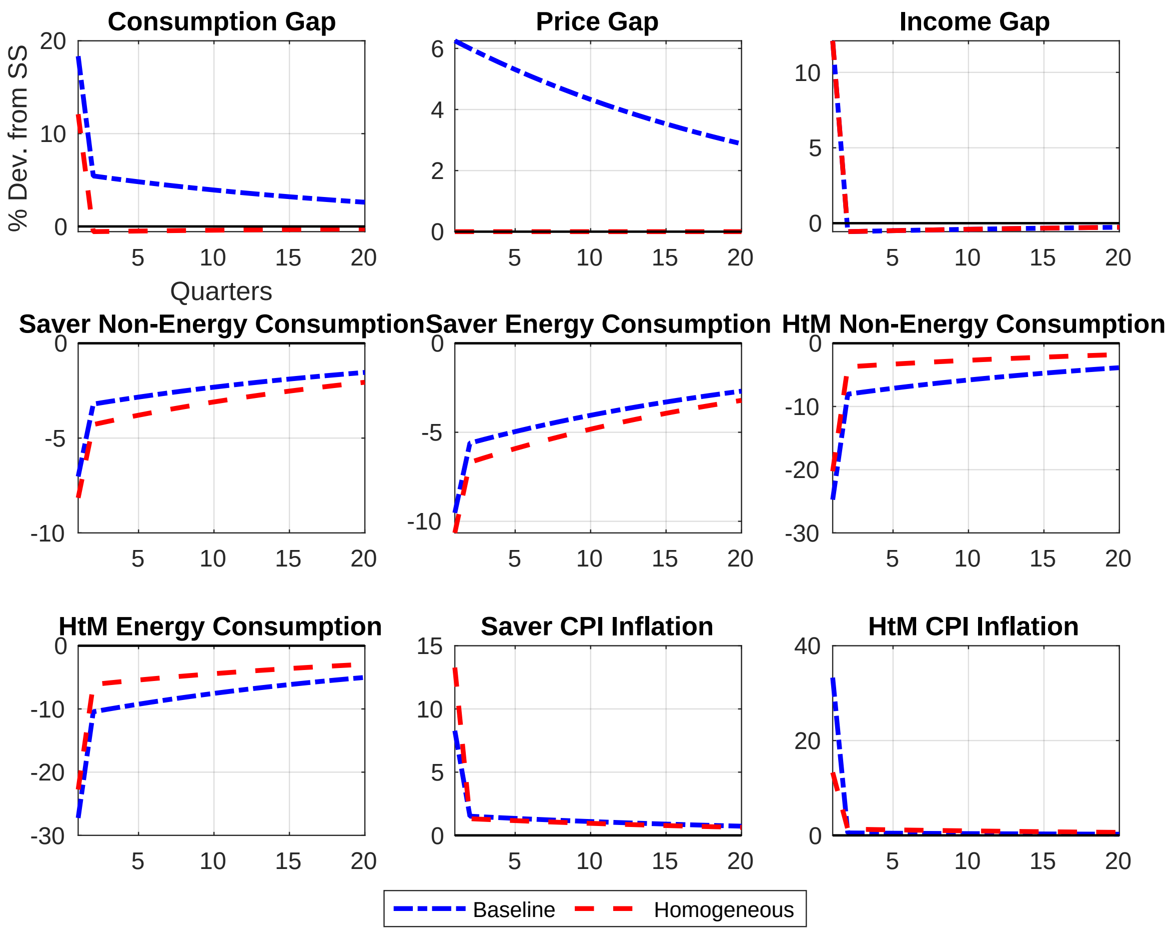
Figure 2: Dynamic Responses to an Energy Price Shock



in the baseline and in the homogeneous baskets models. Hence, in this setting the assumption of heterogeneous baskets doesn't affect the response of aggregates to an energy price shock. Thing are different in the representative agent economy, where the impact of the shock is less significant, thanks to the ability of each agent to smooth consumption over time, while the negative effect on the aggregate demand is almost entirely caused by restrictive monetary policy.

In figure 3 the consumption inequality reaction to the energy price shock in the two specifications with two types of consumer is depicted. As mentioned above aggregate consumption falls. However, it doesn't go down equally for both families, but it shrinks to a greater extent for HtM, because the expansion in the real price of energy has a greater impact on them. This is due to the combination of two effects that occur when the shock happens. The first is the increment in the price gap, as the HtM basket contains a higher percentage of the energy good compared to that of savers. In other words, the two consumer types perceive heterogeneous effective inflation, with HtM experiencing a harsher impact. The second is the enhancement in the income gap, as profit growth translates into augmented dividends distributed among savers who, unlike HtM, can partially offset the downturn in labor income through greater capital income. In the homogeneous basket model both types allocate 13% of their total consumption expenditure on energy goods, which is the weighted average of the energy consumption shares they purchase in the baseline model. The rise in the real price of energy equally affects the consumer price indexes of savers and HtM, thus they both face the same inflation rate and the price gap channel is turned off. Shutting down the price gap channel restricts the consumption gap among household types, making it equivalent to the income gap which remains positive mirroring the baseline model.

Figure 3: Dynamic Responses to an Energy Price Shock



4 Optimal Monetary Policy

We look for the optimal monetary policy response to an energy price shock, assuming a Ramsey planner set the maximizing welfare monetary policy in a centralized fashion. In particular, in line with Bilbiie (2008), a convex combination of households' utilities weighted by the mass of consumers of each type is maximized, subject to the non-linear equilibrium conditions of the economy's private sector. A fiscal authority provides an optimal subsidy[11] that makes the steady state efficient and equitable, meaning that at the steady state the consumption gap is equal to zero. This is true because the fiscal instrument, financed by lump-sum taxes on firms, induces marginal cost pricing at the steady state making steady state profits—hence dividends—equal to zero, and ensuring perfect consumption insurance between savers and HtM. Figures 4, 5, and 6 plot the Ramsey economy's response (red dashed line) to a 25 standard deviation increase in the real price of energy, in comparison with the baseline model (blue dashed dotted line) and a decentralized economy's response (green dotted line), where core inflation targeting is achieved by the monetary authority. Each specification features two types of family purchasing a heterogeneous basket of goods, hence both the aforementioned consumption inequality channels—price gap and income gap—are in action. Let's first compare the response of the maximizing welfare and the baseline model, where the latter is characterized by a decentralized economy with headline CPI inflation targeted by the central bank. The Ramsey economy's reaction is a moderated version of the baseline model's one, where energy inflation leads to a reduction in energy imports and hours worked, causing a decrease in domestic production and GDP, albeit to a lesser extent than in the decentralized economy. The same dynamics are observed for real wages and marginal cost, and consequently for profits and dividends. As in the baseline model, the energy price shock reduces aggregate demand and thus consumption, which decreases more for the HtM, once again amplifying the index of consumption gap. However, it is worth noting the different magnitude of the impact: in the baseline model there is an increase of almost 20% in the index of consumption gap, compared to an expansion of about 5% in the Ramsey model, where we hence observe a lower impact of energy inflation on consumption inequality. Maximizing welfare monetary policy response reduces the impact of energy inflation on consumption inequality. This is because in the Ramsey specification the monetary authority answers to the shock with a negligible augmentation in the annualized nominal interest rate, in contrast with the a strong response in the baseline model. In the latter indeed the instrument rule targets headline CPI inflation, amplifying the recessionary effect of the energy price hike. This effect is absent in the Ramsey model, where the income gap channel is turned off and the negative impact on aggregate consumption and GDP is significantly reduced. What emerges from the response of a decentralized economy where the target of monetary policy changes is interesting. In fact, when the central bank responds to variations in domestic or core inflation instead of headline CPI inflation, the result is much closer to what is observed in the Ramsey economy. Responding to an underlying inflation measure proves to be a better choice both in terms of containing consumption inequality and the

[11]see, among others, Woodford (2003) and Galí (2007).

overall response of the economy. The result confirms the perspective endorsed by a segment of the literature, according to which in this context core inflation represents the welfare-relevant measure of inflation given its association with price dispersion. According to Corsello and Riggi (2023) this modeling choice appears consistent with the ECB's medium-term orientation of monetary policy, which allows disregarding temporary shocks, such as exogenous energy shocks, thus avoiding unnecessary volatility in interest rates and economic activity. From this analysis we conclude that the optimal monetary policy response to an increase in the real price of energy is better approximated by achieving a medium-term core inflation targeting policy, rather than one that looks at headline inflation. In general, taking less into account temporary shocks seems to be desirable for the central bank. The latter could be the best strategy to be combined with fiscal policy interventions by the government to allow for better absorption of the shock by the economy. The role of fiscal policy and its combination with monetary policy to counteract an energy price shock is a question we leave for future research developments.

Figure 4: Dynamic Responses to an Energy Price Shock

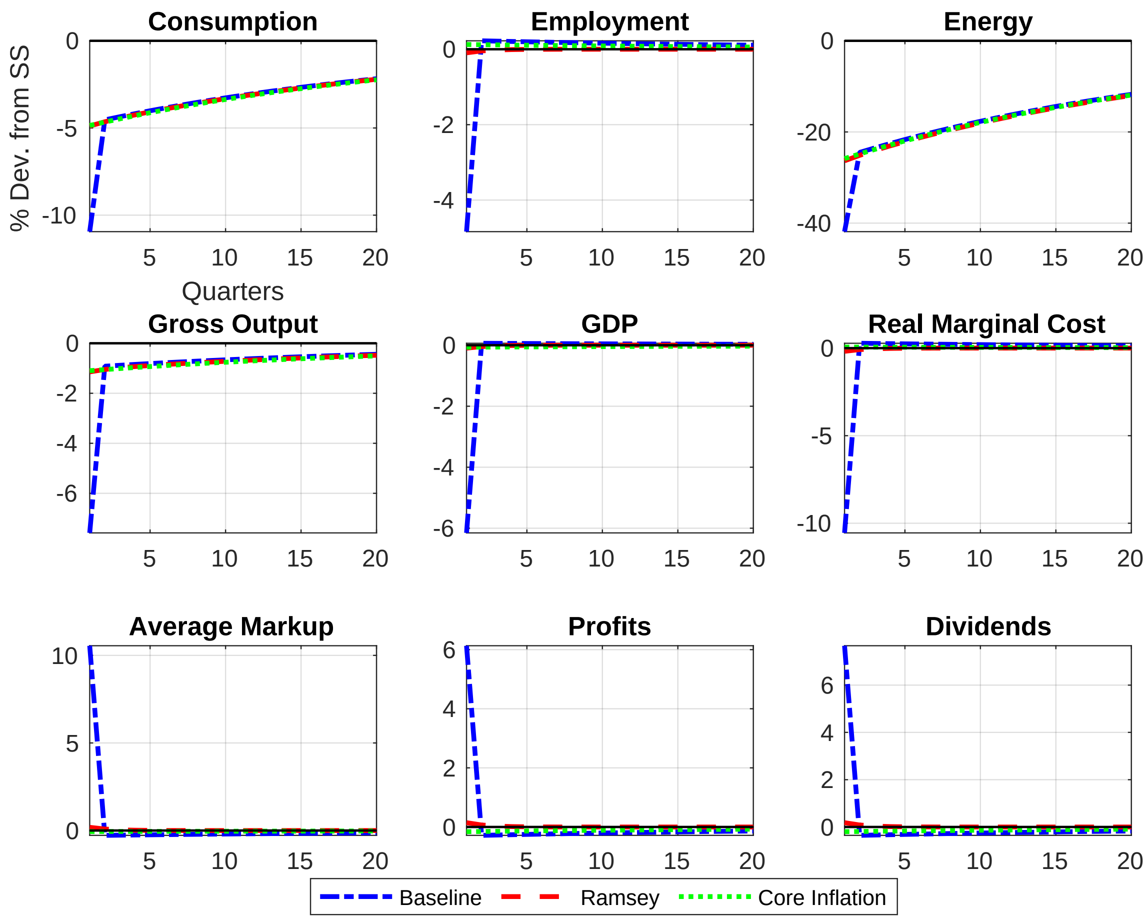


Figure 5: Dynamic Responses to an Energy Price Shock

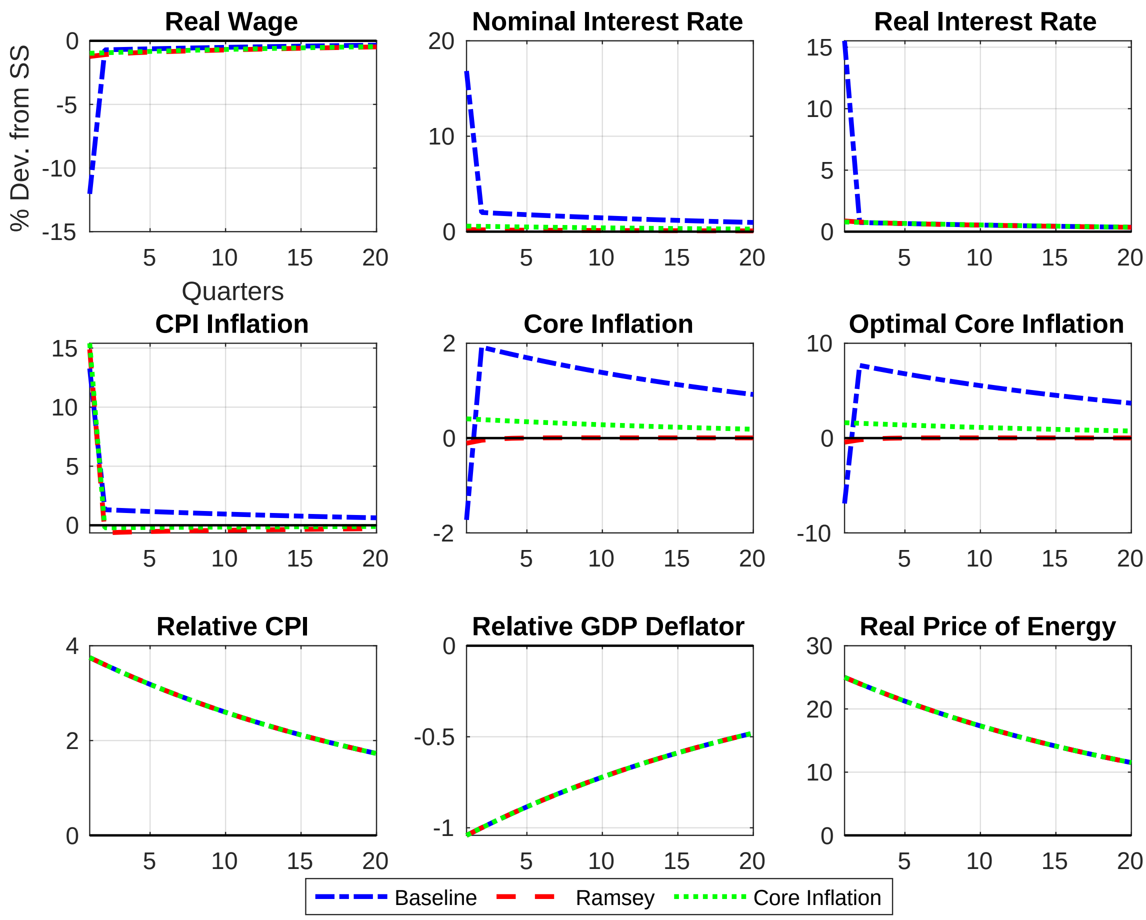
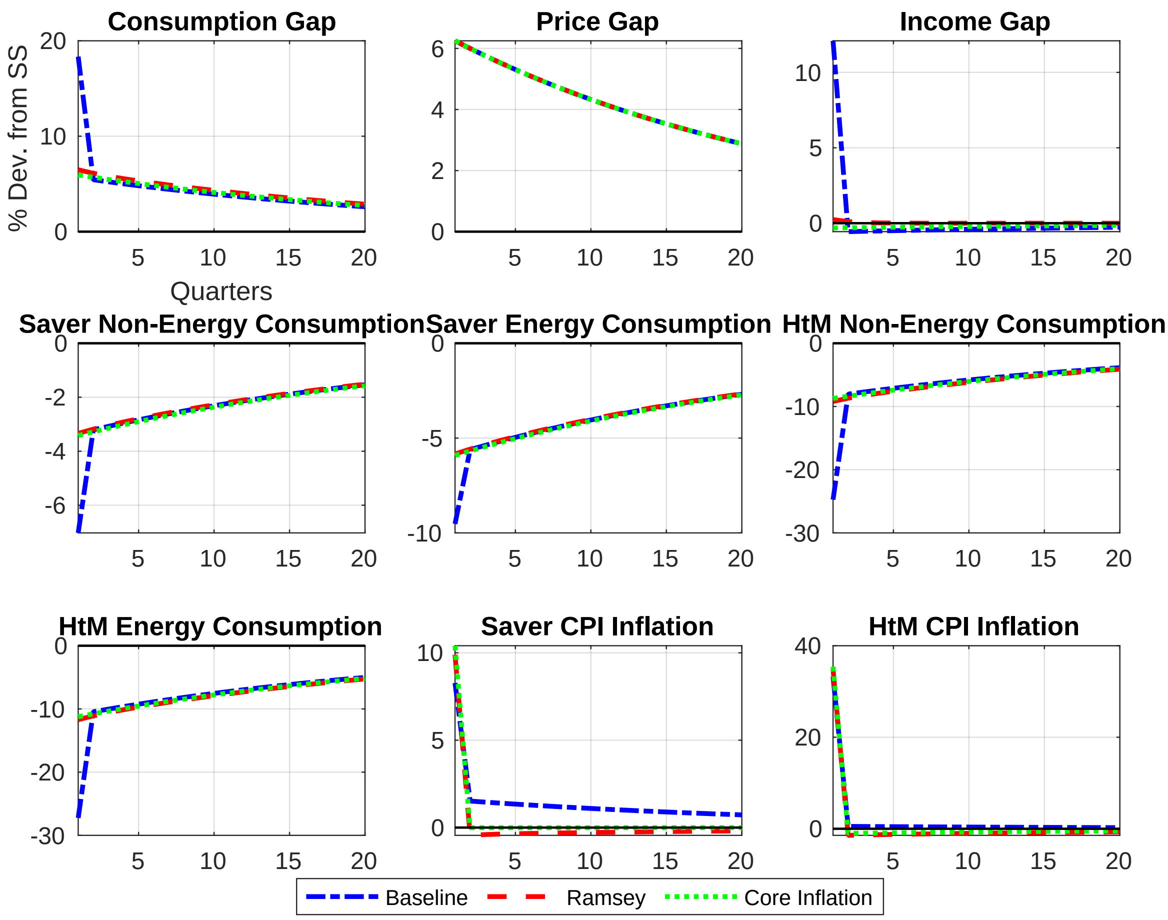


Figure 6: Dynamic Responses to an Energy Price Shock



5 Conclusions

Recent research unveiled that the return of inflation, mainly driven by spikes in energy prices, had a heterogeneous impact on low-income and high-income European households, as they tend to purchase distinct consumption baskets, differ for income levels and consequently exhibit diverse abilities to smooth consumption over time. We explore the effects of energy inflation on consumption inequality in a TANK model with an exogenous energy sector and look for the optimal monetary policy response to an energy price shock. The increase in the real price of energy leads to a rise in the general price level. In response, the central bank significantly raises the monetary policy rate, thereby exacerbating the contractionary effects of the price shock. Firms sharply cut production and manage to maintain positive profits, partly due to a reduction in wages. Energy inflation directly enters the households' consumption basket, affecting the HtM more severely due to the composition of their basket. In addition to the inflation gap effect, there is also an increase in the income gap resulting from the distribution of profits to savers in the form of dividends, amplifying the rise in the consumption gap between the two consumer types. At the aggregate level, we observe a response to a negative supply shock: output decreases, as does consumption and employment. Analyzing the maximizing welfare monetary policy reveals that the monetary authority can adopt a different strategy in response to the imported good price shock. If the central bank responds by adjusting the policy rate more moderately, consumption inequality among households substantially decreases, along with production, consumption, and employment losses. Approaching the outcome obtained in this exercise may be achieved by modifying the baseline model and substituting the monetary policy target with core inflation, a measure of underlying inflation associated with price dispersion and, consequently, proving relevant from a welfare perspective.

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