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

A Heterogeneous Agent Model of Energy Consumption and Energy Conservation

Volha Audzei and Ivan Sutóris *

Abstract

In this paper, we investigate whether inflation-targeting monetary policy affects households' incentives to build resilience against energy price shocks. We utilize a stylized heterogeneous agent New Keynesian model with search and matching frictions in the labor market and nominal asset holdings. We modify the model to include energy in consumption and production, and energy conservation capital, so that energy price fluctuations affect both the supply and demand side of the economy. In such a framework, we study the responses of energy conservation to monetary policy, rising energy prices, and their interaction. We find that monetary policy influences energy intensity of consumption through both the intertemporal elasticity of substitution and labor market allocations. Our model predicts that a weaker policy response to rising energy prices is beneficial in terms of welfare to firm owners, borrowers and workers despite higher consumer price inflation. Such a policy stimulates energy conservation, and results in lower energy intensity and higher resilience against energy price fluctuations. We further find that a policy of looking through energy prices does not yield welfare benefits as it underreacts to consumer prices initially, but overreacts in later periods. Ramsey optimal policy predicts a strong immediate rise in the policy rate with a decline afterwards.

JEL Codes: E12, E24, E52, Q43, Q50.
Keywords: Distributional aspects of monetary policy, energy intensity of consumption, energy prices, heterogeneous agent New Keynesian models.

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Abstrakt

V tomto článku zkoumáme, zda měnová politika v režimu cílování inflace ovlivňuje motivaci domácností k budování odolnosti vůči šokům do cen energií. Využíváme stylizovaný model nové keynesiánské ekonomie s heterogenními ekonomickými subjekty, s frikcemi v oblasti hledání a párování na trhu práce a s nominální držbou aktiv. Model upravujeme tak, aby zahrnoval energie ve spotřebě a výrobě a kapitál pro úsporu energií a aby tak kolísání cen energií ovlivňovalo stranu nabídky i poptávky v ekonomice. V tomto rámci zkoumáme reakce úspor energií na měnovou politiku, rostoucí ceny energií a jejich vzájemné působení. Zjišujeme, že měnová politika ovlivňuje intenzitu spotřeby energie prostřednictvím jak intertemporální elasticity substituce, tak alokace na trhu práce. Náš model předpovídá, že slabší reakce měnové politiky na rostoucí ceny energií je prospěšná pro vlastníky firem, dlužníky a pracovníky, protože navzdory vyšší spotřebitelské inflaci stimuluje zaměstnanost. Navíc slabší reakce měnové politiky podporuje úspory energií a vede k nižší energetické náročnosti a vyšší odolnosti vůči kolísání cen energií. Dále zjišujeme, že politika odhlížení od cen energií nezvyšuje blahobyt, protože zpočátku na spotřebitelské ceny reaguje nedostatečně, ale v pozdějších obdobích naopak přehnaně. Ramsey optimální politika předpokládá strnulý narůst sazeb a jejich následný pokles.

1. Introduction

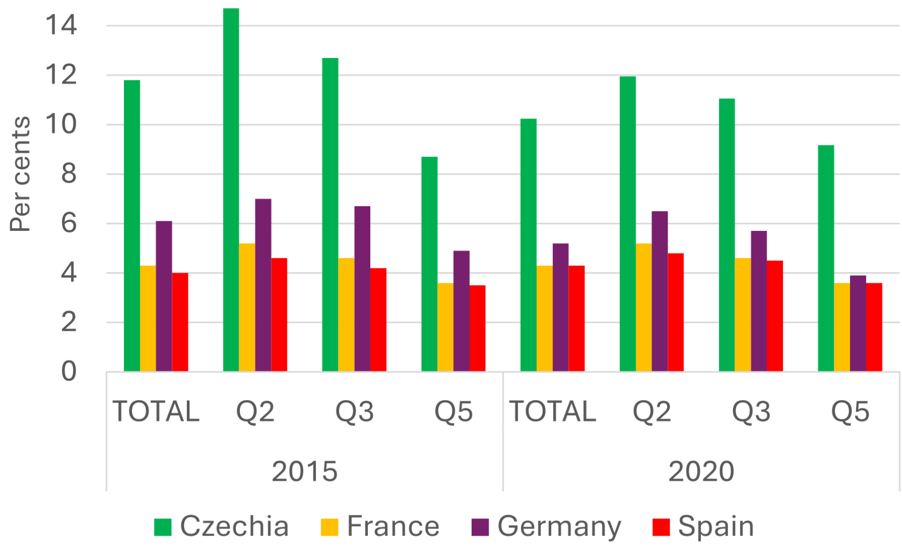
Elevated energy prices and energy conservation are a major current macroeconomic challenge, and there is a debate on the role of central banks in addressing these issues. Monetary policy affects agents' consumption and investment decisions. The monetary policy response to rising energy prices can amplify or dampen the effects of energy price shocks on different economic agents, stimulating or dampening their incentives to invest in energy conservation and build resilience to energy price fluctuations.

In this paper, we contribute to the literature by investigating how inflation-targeting monetary policy interacts with energy conservation decisions. It has been shown in the literature that monetary policy has distributional effects,[1] while the data suggests that energy price shocks have a heterogeneous impact on households. Moreover, households, which can afford it, are able to insulate themselves from energy price shocks by investing in energy saving or abatement capital. Such an investment insulates these households from energy price fluctuations. The heterogeneous shares of energy expenditure in final consumption expenditure, as shown in Figure 1 for selected OECD countries, imply that poor households have a larger share of energy expenditure in total expenditure and are more vulnerable to energy price shocks.[2]

In our model, we consider how the possibility of abatement and the heterogeneous effects of both energy price fluctuations and monetary policy change monetary policy propagation in response to energy price shocks. We further consider alternative monetary policy reaction functions in response to energy price shocks. While central banks' mandate focuses on inflation, we believe it is important to understand the various consequences of monetary policy decisions to be able to communicate them to the relevant policy institutions. In our analysis, we only consider inactive fiscal policy.

[1] For an analysis of the distributional effects of monetary policy in the euro area, see Slacalek et al. (2020), Ampudia et al. (2018) or Colciago et al. (2019). For surveys, see Coibion et al. (2017) for the US, and Junicke et al. (2023) for the Czech Republic as an example of a small open economy.
[2] More evidence can be found in, for example, Battistini et al. (2022) and Pieroni (2023).

Figure 1: Energy Share in Household Consumption Expenditure by Income Quantiles



Note: Households are grouped by quantiles depending on their after-tax income. The top quantile of income distribution – the highest 20 % of income earners – has the lowest share of energy expenditure in their final consumption expenditure, while the households in the lower income quantiles have the largest energy expenditure shares. We choose to report on the second quantile instead of the first, as some of the poorest households dropped their energy consumption in 2020 due to energy poverty, resulting in a lower than average energy share in their final expenditure.
Source: Eurostat.

We add energy in consumption and production, and households' energy conservation capital to a stylized heterogeneous agent New Keynesian (HANK) model with search and matching as in Ravn and Sterk (2021) and Challe et al. (2017). We consider a model with endogenous labor market tightness and nominal asset holdings, as studies (e.g. Slacalek et al. 2020) have found these channels to be important monetary policy channels. We employ two assumptions to make the HANK model – which includes both nominal assets and abatement capital – tractable. The first assumption from Challe et al. (2017) is perfect risk-sharing among employed workers. Challe et al. (2017) have shown that this assumption preserves workers' motives for precautionary savings, while resulting in a finite number of agent types. We employ a similar assumption for abatement capital, with employed and unemployed workers living in separate places of residence differentiated by abatement capital levels, with workers moving between places of residence when their labor market status changes. As such, workers' investment and consumption decisions do not depend on their individual employment history, but rather on their current employment status and the asset positions of their labor market pool.

In our model, monetary policy affects labor market tightness, returns on nominal savings, firm ownership, and investment in capital and energy abatement capital. As such, through consumption and abatement decisions, monetary policy affects energy intensity of consumption. Energy prices in the model affect both aggregate supply and aggregate demand through the firms' marginal costs and households' consumption and investment decisions respectively. Changes in energy prices have direct effects on households by increasing their expenditure on the energy component of consumption, as well as indirect effects through changes in firms' pricing and hiring decisions. In such a framework, calibrated to match households' income distribution and energy consumption, we study the individual and aggregate responses of energy conservation and energy consumption to monetary policy, rising energy prices and their interaction. The developed intuition regarding energy conservation decisions within our model framework can be extended to fuel consumption or investment in renewable energy. For the calibration, we focus on the Czech case: as a small open economy, the Czech Republic is sensitive to changes in the external environment, but even more sensitive to energy price fluctuations, as it has a high share of energy in household consumption expenditure, see Figure 1. Most of the Czech statistics used in the model are in line with the euro area estimates, except for the share of energy expenditure in household budgets. As such, the qualitative conclusions can be easily extended to other European small open economies. For calibration we use the Household Finance and Consumption Network (2023) for the euro area, and for the Czech Republic when available.

Our results show that a restrictive monetary policy shock leads to a decrease in energy conservation capital and an increase in the energy intensity of consumption. It increases the share of unemployed workers with limited investing possibilities and decreases the incentives of employed workers to invest in abatement capital when the returns on savings are larger and precautionary motives are stronger. We further consider several types of monetary policy reactions to rising energy prices. In a standard monetary policy reaction function, we vary the coefficients of response to inflation and output. We also consider a policy of "looking through" energy price shocks, where the central bank reacts to core inflation, ignoring the energy price component of CPI inflation.[3] We find that even when energy price increases are large and persistent, policies which have a stronger response to inflation suppress output and investment in abatement capital and result in larger energy intensity of consumption relative to policies which have a weaker response to inflation, while more restrictive policies result in lower inflation. We further calculate households welfare for each type of policy as a discounted infinite stream of consumption. After the energy price shock, the decline in welfare is smaller for all household groups under more accommodative policies. In the case of accommodative policies, borrowers benefit from low interest rates, employed and unemployed workers benefit from a higher job-finding rate, while unemployment benefits are indexed by core inflation. More importantly, accommodative policies result in larger holdings of abatement capital and households' consumption is affected less by energy price shocks. The looking-through policy is more accommodative in the initial periods after the energy price shock, when energy prices are growing, but becomes more restrictive in the later periods, when energy price inflation is falling short of core inflation. Thus, within our framework, where central banks do not change their policy rules, we do not find the looking-through policy beneficial. We further calculate Ramsey policy which minimizes the volatility of aggregate utility with individual utilities weighted by the time-varying shares of different agents. Ramsey policy predicts a strong immediate hike in the policy rate with a quick decline afterwards. It results in larger abatement capital holdings and lower energy intensity, thus smaller household exposure to energy price shocks. We provide alternative simulations with unemployment benefits fixed in nominal terms, with more flexible wages or larger steady state nominal savings. While the policy trade-off in terms of aggregate welfare are narrower under the first two simulations, and somewhat wider under the latter, the welfare ranking of the policies remains similar.

In this paper, we build upon models with endogenous labor market tightness and precautionary savings as in Challe et al. (2017) and Ravn and Sterk (2021). We draw from the empirical work based on the Household Finance and Consumption Network (HFCS) by Slacalek et al. (2020). The paper is related to the debate on the monetary policy response to rising energy prices and energy price shocks in a heterogeneous framework, in particular, to Auclert et al. (2023) and Chan et al.

[3] The motivation for ignoring energy price fluctuations comes from their volatility and short life (see Schnabel 2022).

(2024), who study fiscal and/or monetary policy responses to energy price shocks but without the possibility of abatement. Our framework builds upon HANK models, with seminal contributions by Kaplan et al. (2018), Violante (2021), and Pappa et al. (2023). Battistini et al. (2022) and Celasun et al. (2022) provide empirical evidence on the heterogeneity of households' responses to surging energy prices. When modelling energy consumption and abatement, we draw extensively from general equilibrium models of energy consumption and emissions: Varga et al. (2022), Campiglio et al. (2022), and Kiuila and Rutherford (2013).[4] While these models focus on reducing carbon emissions, we adopt a general formulation of abatement capital and energy consumption. Our work is somewhat related to the literature on the macroeconomic impact of a change in energy prices, Forni et al. (2015), Kilian (2008), and the monetary policy response to surging energy prices, Natal (2012) and Kormilitsina (2011). We contribute to this literature by considering abatement and monetary policy transmission in a heterogeneous framework.

The paper is structured as follows. We first describe the model and the underlying assumptions. We then simulate the model response to monetary and energy price shocks to illustrate the mechanism behind the model's reaction. We then move to the analysis of different types of monetary policy rules and show the implications for the aggregate economy and different groups of households. Finally, we consider how different policy responses affect households welfare and energy conservation decisions.

2. The Model

The underlying model is an extension of the models with imperfect insurance against unemployment risks and endogenous labor market tightness, as in Challe et al. (2017). In this model, we incorporate energy into the consumption bundle and the production function. Within each household, an energy service is made from raw energy using the household's "abatement" capital. A straightforward illustration of the energy service is heat generated within the house using abatement capital (installed heating system and house insulation), while paying bills for raw energy (electricity, gas, etc.). Clearly, investing in better insulation or more efficient heating systems lowers raw energy usage. The investment decisions depend on the households income and precautionary motives. Such an investment is unaffordable for the poor hand-to-mouth (HtM) households, as documented by vast empirical research.[5]

2.1 Households

There is a unit mass of households, indexed by h. Each household consumes a composite good, $\mathbb{C}_t(h)$, and holds positions in nominal bonds, $B(h)$. Following the literature, we consider a share ξ of the households to be firm owners, who are unproductive when employed. These households, whom we call capitalists, do not participate in the labor market and own all the firms and production capital in this economy. The rest of the households, whom we call workers, supply a unit of labor inelastically if employed. Employment is stochastic, where the share of $N_t \in (0, 1-\xi)$ of households are employed, and $U_t = 1 - N_t - \xi$ are unemployed in each period. The job destruction rate ω is exogenous; the job-finding rate η_t is determined endogenously. The period in the model is one quarter.

[4] We also consult with integrated assessment models, i.e. Benmir et al. (2020) or Heutel (2012) for the abatement function formulation.

[5] Examples incude Ameli and Brandt (2015), Dato (2018) for OECD countries; or Umit et al. (2019) for European countries; survey for the U.S. Zhao et al. (2012) indicates that low income household do not participate in incentives programs for energy efficiency due to unaffordability of investment costs.

Each household maximizes the infinite sum of expected utility over the composite consumption good $\mathbb{C}_t(h)$ taking into account expected employment status and discount factor $\beta(h)$, which is different for capitalists and workers:

$$U_t(h) \equiv E_t \sum_{j=0}^{\infty} \beta^j(h) \frac{\mathbb{C}_{t+j}(h)^{1-\mu}}{1-\mu}, \tag{1}$$

where μ is the degree of relative risk aversion. The composite consumption good consists of energy services, E_t^s, and a non-energy consumption good, C_t, combined in a constant elasticity of substitution index:

$$\mathbb{C}_t(h) = \left[(1-\phi_e)^{\frac{1}{\lambda_e}} C_t(h)^{\frac{\lambda_e-1}{\lambda_e}} + \phi_e^{\frac{1}{\lambda_e}} E_t^s(h)^{\frac{\lambda_e-1}{\lambda_e}} \right]^{\frac{\lambda_e}{\lambda_e-1}}, \tag{2}$$

where parameters ϕ_e and λ_e reflect the equilibrium share of energy in household consumption and the limited substitution between the energy and non-energy goods in the short to medium term. A constant elasticity of substitution index between non-energy and energy goods is widely used in the literature when studying energy consumption (de Walque et al. 2017, and Auclert et al. 2023).

We differ from the literature by making energy service a function of abatement capital. Households obtain energy services $E_t^s(h)$ from raw energy $E_t^r(h)$ using their abatement capital $K_{t-1}^e(h)$, installed in the previous period:

$$E_t^s(h) = f(K_{t-1}^e(h))E_t^r(h), \tag{3}$$

where the abatement function, defined as a reduction in raw energy consumption $E_t^r(h)$ for a given amount of energy services $E_t^s(h)$, $1/f$ is decreasing and convex in the abatement capital $K_{h,t-1}^e$: $(1/f)' < 0$ and $(1/f)'' > 0$.

In particular, we assume the following functional form $f(K_{t-1}^e) = \phi_{1,e}(K_{t-1}^e)^{\phi_{2,e}}$. For the functional form, we take inspiration from the models of abating emissions, see Benmir et al. (2020) or Nordhaus (2008). We assume a quadratic functional form with $\phi_{2,e} = 2$ and calibrate $\phi_{1,e}$ to match the distribution of energy shares in household final consumption.

The abatement capital has a positive depreciation rate δ_e, and can be changed by non-negative investment I_t^e:

$$K_{t+1}^e(h) = (1-\delta_e)K_t^e(h) + I_t^e(h). \tag{4}$$

While the preferences in (2) are homothetic in energy and non-energy goods, unlike in, for example, Pieroni (2023), the heterogeneity in abatement capital holdings results in heterogeneity of consumption patterns among the households.

All the types of agent maximize utility in (1), but have different budget constraints. We start by characterizing the unconstrained, employed agents. Employed workers receive a nominal wage $P_t W_t(h)$ and pay income tax τ_t. They can choose to hold positions in nominal bonds $B_t(h)$ and pay portfolio adjustment costs when changing the position relative to their steady-state level. The nominal return on bonds is the risk-free rate R_{t-1} set by the central bank. They spend on non-energy goods $C_t(h)$ and on raw energy $E_t^r(h)$, and invest in abatement capital $I_t^e(h)$. Investment is subject to adjustment costs. All investment and adjustment costs are paid in units of domestic final goods at the price P_t. The energy price P_t^e follows an exogenous process and raw energy is in unlimited supply from the rest of the world.

$$P_t C_t(h) + P_t^e E_t^r(h) + B_t(h) + \frac{\psi_b}{2}\left(\frac{B_t(h)}{\bar{B}(h)} - 1\right)^2 B_t(h) + P_t I_t^e(h) + P_t \frac{\psi_i}{2}\left(\frac{I_t^e(h)}{I_{t-1}^e(h)} - 1\right)^2 +$$
$$\leq P_t W_t(h)(1-\tau_t) + R_{t-1}B_{t-1}(h). \tag{5}$$

Unemployed workers receive nominal benefits $P_t W_{\mu,t}(h)$ fixed in real terms. Later in the paper we study the role of benefits indexation. We further assume that workers who are unemployed for the first period receive only 75% of the unemployment benefits $P_t W_{\mu,t}(h) = P_t(0.75W_\mu)$[6], while workers unemployed for longer than one period receive $P_t W_{\mu,t}(h) = P_t W_\mu$. Workers who are unemployed for the first period enjoy their precautionary savings. We assume borrowing limits for unemployed workers $\underline{b}^u$, discussed in details below.

$$P_t C_t(h) + P_t^e E_t^r(h) + B_t(h) + \frac{\psi_b}{2}\left(\frac{B_t(h)}{\bar{B}(h)} - 1\right)^2 B_t(h) + P_t I_t^e(h) + P_t \frac{\psi_i}{2}\left(\frac{I_t^e(h)}{I_{t-1}^e(h)} - 1\right)^2 +$$
$$\leq P_t W_{\mu,t}(h) + R_{t-1}B_{t-1}(h), \tag{6}$$
$$\text{s.t. } B_t(h) \geq \underline{b}^u. \tag{7}$$

Capitalists own firms and capital in this economy. They receive firms dividends div_t, net of capital investment and tax τ_t^c. Besides investing in abatement capital, capitalists invest in productive capital I_t, paying the same adjustment costs in units of domestic final goods at the price P_t. We further assume a borrowing limit for capitalists, $\bar{b}^c$, discussed in details below.

$$P_t C_t(h) + P_t^e E_t^r(h) + B_t(h) + \frac{\psi_b}{2}\left(\frac{B_t(h)}{\bar{B}(h)} - 1\right)^2 B_t(h) + P_t I_t^e(h) +$$
$$P_t \frac{\psi_i}{2}\left(\frac{I_t^e(h)}{I_{t-1}^e(h)} - 1\right)^2 + P_t I_t(h) + P_t \frac{\psi_i}{2}\left(\frac{I_t(h)}{I_{t-1}(h)} - 1\right)^2 \leq (div_t)(1-\tau_t^c) + R_{t-1}B_{t-1}(h), \tag{8}$$
$$\text{s.t. } B_t(h) \geq \bar{b}^c. \tag{9}$$

To have a tractable solution for a model with heterogeneous holdings of two assets, we employ a convenient assumption from Challe et al. (2017) that all households are grouped in identical "families" of the same size. As the probability of changing employment status is the same across families, all the families have the same share of employed and unemployed workers, but with different unemployment durations. Within the families, there is a distribution of agents with different histories of asset holdings. As in Challe et al. (2017), we allow for risk-sharing among employed family members, that is, all the bonds are averaged among the currently employed households. That is, after the labor market status of the workers is realized, those who are employed share their nominal assets invested in the previous period $B_{t-1}(h)$. When making their asset holdings decisions workers take this redistribution into account. Such an assumption simplifies the model solution, while generating endogenous precautionary savings.

[6] This may be due to the time frictions involved in applying for and getting the benefits approved. This assumption is also helpful in achieving low intertemporal elasticity of substitution for first-period unemployed workers.

We further assume that workers move between employed and unemployed places of residence when their employment status changes, and they cannot take their abatement capital with them. When they move, their stock of abatement capital is absorbed by the government, which provides every newcomer to the residence with the same level of abatement capital as the other residents. That is, when formerly unemployed workers enter the employed pool, they enjoy the same level of abatement capital as the rest of the employed workers. Employed workers, when investing in abatement capital, take into account the probability of becoming unemployed and leaving their employed residence. Thus abatement capital does not play the role of a precautionary asset. This assumption simplifies the model solution while preserving heterogeneity of energy intensity through different levels of abatement capital.

The consumption and asset holdings problem is solved in Appendix A, where we show that only employed workers choose to save in nominal bonds with their intertemporal marginal rate of substitution (IMRS) times interest rate equal to unity, while other agents, including the first-period unemployed, do not choose to save with their IMRS x R < 1. That is, first-period unemployed workers prefer to consume all their precautionary savings during a single period. We further set the borrowing limit for unemployed workers to zero $\underline{b}^u = 0$. As shown in Appendix A, both types of unemployed workers choose not to invest in abatement capital, choose not to save, and do not have nominal debt by assumption on zero borrowing limit. We further assume that abatement capital for the unemployed workers is maintained at its steady-state level $\bar{K}^u$ from their unemployment benefits. Employed workers are non-constrained households who have nominal savings and invest in abatement capital. As unemployed workers have zero savings and zero debt, the employed workers' averaged nominal bonds holdings are $B'_{t-1}(h) = (1-\omega(1-\eta))B_{t-1}(h)\frac{N_t}{N_{t-1}}$. Every employed worker has the same amount of nominal savings $B'_{t-1} \geq 0$ and abatement capital $K^e_{e,t-1} > 0$. As will be shown below, they receive identical wages. They make the same consumption and investment decisions. Workers, who became unemployed in the first period enjoy the same amount of precautionary savings $B_{e,t-1} > 0$, as all employed workers made identical saving decisions in the previous period. As unemployed workers neither save nor borrow, those who stay unemployed for more than one period have no income apart from unemployment benefits, which are identical. This is why unemployed workers with an unemployment spell of longer than one period behave identically.

Capitalists invest in abatement and productive capital. They do not have precautionary motives and the equilibrium interest rate on nominal credit is attractive for them. Therefore, they become rich borrowers who absorb households' nominal savings in the steady state. Outside the steady state, we set the borrowing limit for the capitalists $\bar{b}^c$ equal to their steady state borrowing level. Outside the steady state, when workers savings do not match capitalists' borrowings, we let excessive real borrowings or savings be absorbed by the global traders.[7]

The presence of the global traders' real credit outside of the steady state requires additional assumptions in order to close the model. We use the results from Schmitt-Grohe and Uribe (2003) and incorporate portfolio adjustment costs for employed workers, defined above, and an endogenous discount factor for capitalists. Under the assumption of an endogenous discount factor, capitalists become more patient when the current level of aggregate capital K_{t-1} falls short of its steady-state

[7] In this paper we focus on the effects of external energy price shock on a small open economy and abstract from other open economy dimensions. We analyze a model in proximity to the steady state so that the capitalists have preferences to be borrowers. If we allow the capitalists' credit to move with households' savings, while capitalists prefer to borrow, the model responses are counter-intuitive. E.g. there is a rise in investment after a monetary policy shock due to larger credit availability for the capitalists. Preserving capitalists as rich HtM is preferable for analyzing distributional effects as their presence was found important in many studies: Slacalek et al. (2020) or Kaplan et al. (2018).

Table 1: Agent Types and Asset Holdings

Agent	Subscript	Income	Nominal Assets	Abatement Capital Other Assets
employed	e	wages	$B'_{e,t-1} > 0$	$K^e_{e,t-1}$
1st per. unemployed	eu	0.75 of un. benefits	$B_{e,t-1} > 0$	$\bar{K}^e_u$
long-term unemployed	u	unempl. benefits	$\underline{b}^u = 0$	$\bar{K}^e_u$
capitalists	c	firms' dividends	$\bar{b}^c < 0$	$K^e_{c,t-1}$, K_{t-1}, firms

value, and less patient when the current capital rises above it steady-state level:

$$\exp(\beta^c_t) = \exp(\beta^c)\left(\frac{K_{t-1}}{\bar{K}}\right)^{-\psi_k \beta}, \tag{10}$$

where β is the constant discount factor for workers and ψ_k is the parameter governing the elasticity of capitalists discount factor with respect to the aggregate level of capital. The capitalists do not internalize the effect their capital investment has on their discount factor.

Together with the assumptions on insurance among employed workers, sharing abatement capital within the places of residence, borrowing limits help us to reduce the distribution of agents into four groups: employed, newly unemployed, long-term unemployed, and capitalists. While preserving the labor market, nominal asset channels of monetary policy and heterogeneous energy intensity among the agents. We summarize the types of agents in Table 1. We view HtM agents as in line with Kaplan et al. (2018) as agents who are highly sensitive to income shocks but do not respond to interest rate changes as predicted by the Euler equation.[8] In our economy there are poor HtM - both types of unemployed workers, and we call rich HtM the wealthy agents who have large level of debt - capitalists.

The timeline for the model is in Figure 2. At the beginning of the period, the exogenous state is realized and the matches between the firms and the workers are exogenously destroyed. The labor market opens and the firms decide how many workers to hire. The workers from the recently separated matches participate in the labor market and new matches take place. With the new employment status, there is a redistribution of nominal assets among employed workers, and abatement capital levels among the corresponding residencies. Production takes place and income is paid. Afterwards, households make their investment and consumption decisions. Consumption takes place at the end of the period.

2.2 Good Producers

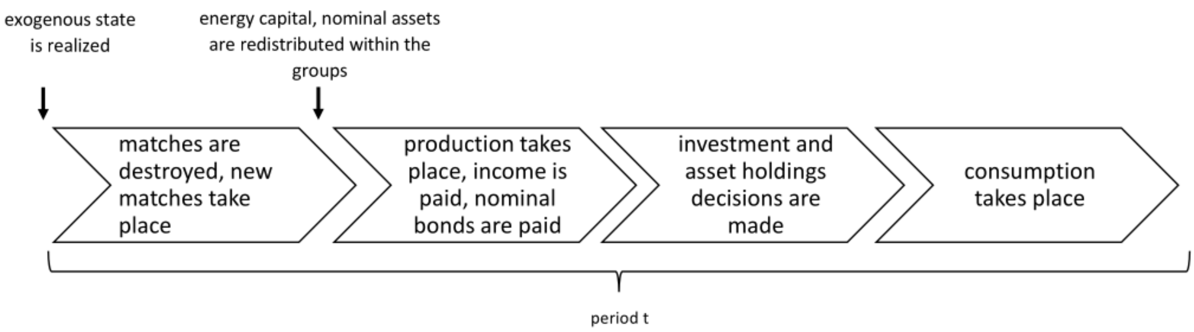
There are competitive, identical final goods producers who take all prices as given and aggregate differentiated intermediate goods i into the final good. Their production function and first-order conditions are:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\gamma-1}{\gamma}} di\right)^{\frac{\gamma}{\gamma-1}}, \tag{11}$$

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\gamma} Y_t, \tag{12}$$

[8] Due to the presence of two assets, we have simplified our model significantly relative to Kaplan et al. (2018), so that our HtM agents do not receive labor income but unemployment benefits or firms' dividends.

Figure 2: Timeline



where γ is the elasticity of substitution between the intermediate good varieties. Final goods producers earn zero profits. They sell final goods to households.

The differentiated intermediate goods are produced by monopolistic intermediate goods producers indexed by (i). In the production function, producers use domestic capital K_{t-1}, domestic labor N_t and raw energy input E_t^{rp}. In this paper, we abstract from producers' incentives for energy conservation and fix the share of energy used in production at ρ_o. This assumption can be further motivated by the limited possibilities of producers to adjust their energy usage within the monetary policy horizon.[9] We formulate the production function using Leontief technology in energy inputs:

$$Y_t(i) \quad = \quad min\left[\frac{1}{1-\rho_o}A_t N_t^{1-\gamma_k}(i)K_{t-1}^{\gamma_k}(i), \frac{1}{\rho_o}E_t^{rp}(i)\right], \tag{13}$$

where A_t is an aggregate productivity process.

The producers price their output in the Rotemberg pricing tradition with the pricing cost parameter ϕ in units of final goods. The producers pay vacancy costs κ in units of final goods and the number of vacancies opened is $v_t \geq 0$. The firms' problem in any period s can be stated as follows:

$$\max_{N_t(i),P_t(i)} E_t \sum_{t=s}^{\infty} \left(\beta_{c,t}^{t-s} E_t \Lambda_{s,t} \frac{P_t(i)}{P_t} Y_t(i) - W_t(i)N_t(i) - \kappa v_t(i) - \phi \left[\frac{P_t(i)}{P_{t-1}(i)} - 1\right]^2 Y_t \right), \tag{14}$$

$$s.t. \qquad Y_t(i) = \frac{1}{\rho_o}E_t^{rp}(i), \tag{15}$$

$$v_t(i) \geq 0, \tag{16}$$

where $\beta_{c,t}E_t\Lambda_{t,t+1} = E_t\left(\frac{\mathbb{C}_{c,t+1}}{\mathbb{C}_{c,t}}\right)^{-\mu}$ is capitalists' discount factor. $\Pi_t(i) = P_t(i)/P_{t-1}(i)$ is the producer's (i) price inflation. The producers face demand from the final goods aggregators in (12).

The producers face identical labor costs and demand functions. As a result, they make identical decisions on pricing and inputs, and they offer identical wages to the households. In what follows we drop the firms' indices.

[9] Hassler et al. (2021) find the elasticity of the US to be rather low at 0.02. Some scarce evidence for the euro area is found in Alpino et al. (2023) for Italy, which suggests low elasticity of firms energy expenditure to rising energy prices.

With the marginal product of labor, MPL_t, the real marginal costs, MC_t, reflect firms' current and future labor costs and energy expenditures. The probability of filling the vacancy q_t is endogenously determined by the producers labor demand. The firms are assumed to be sufficiently large, so that a fraction of $1/q_t$ of their vacancies is filled every period:

$$MC_t = \frac{1-\rho_o}{MPL_t}\left(W_t + \kappa/q_t - (1-\omega)\beta_{c,t}E_t\Lambda_{t,t+1}\frac{\kappa}{q_{t+1}}\right) + \rho_o P_t^e. \quad (17)$$

As a result of Rotemberg pricing, the marginal costs are equalized to current and expected inflation taking into account the cost of price adjustments ϕ and elasticity of substitution between the goods γ:

$$\gamma MC_t = \phi(\Pi_t - 1)\Pi_t - \phi\beta_{c,t}E_t\left(\frac{C_{c,t}}{C_{c,t+1}}\right)^{-\mu}(\Pi_{t+1}-1)\Pi_{t+1}\frac{Y_{t+1}}{Y_t} + \gamma - 1. \quad (18)$$

In each period, intermediate goods producers send their profits as dividends to the capitalists:

$$div_t = P_tY_t(1-\kappa q_t - \rho_o P_e - (\phi/2)(\Pi_t - 1)^2) - P_tW_tN_t. \quad (19)$$

2.3 Labour Market and Wages

The firms post $v_t \geq 0$ vacancies. For unemployed workers, the probability of finding a job is η_t. For employed workers, the probability of becoming unemployed equals the exogenous rate ω multiplied by the probability of not finding a match during the same labor market period: $\omega(1-\eta_t)$. The probability of staying employed equals the probability of not becoming unemployed: $1-\omega(1-\eta_t)$. Firms and workers take the probabilities of finding a match as a given. Following the literature, we assume the Cobb-Douglas matching function:

$$m_t = e_t^{\alpha}v_t^{1-\alpha}, \quad (20)$$

where e_t is a measure of job seekers, and v_t is a measure of all vacancies; $\alpha \in (0,1)$ is the matching function elasticity with respect to the measure of job seekers. The job-finding rate η_t is then defined as $\eta_t = \frac{m_t}{e_t}$, and the probability of filling a vacancy is $q_t = \frac{m_t}{v_t}$. It is straightforward to express both probabilities as a function of labor market tightness $\theta_t = \frac{v_t}{e_t}$:

$$\eta_t = \theta_t^{1-\alpha}, \quad (21)$$
$$q_t = \theta_t^{-\alpha}, \quad (22)$$
$$q_t = \eta_t^{\frac{\alpha}{\alpha-1}}. \quad (23)$$

Following Challe et al. (2017) in the spirit of Hall (2005), we assume rigidity in nominal wages, such that nominal wages are persistent and move around their steady-state value $\bar{P}\bar{W}$ in response to deviations in the job-finding rate η_t from the steady state. We explore the role of wage rigidity for the policy trade off later in the text. In real terms, the process for real wages is modeled as in Challe et al. (2017):

$$W_t = \left(\frac{W_{t-1}}{\Pi_t}\right)^{\gamma_w}\left(\bar{W}\left[\frac{\eta_t}{\bar{\eta}}\right]^{\chi}\right)^{1-\gamma_w}, \quad (24)$$

where $\bar{W}$ is the steady-state real wage as defined in Appendix B. γ_w reflects the persistence of nominal wages and χ characterizes the degree to which wages react to labor market parameters.

For W_t to be in the bargaining set, the surplus of the match for both workers and firms must be non-negative. Workers' surplus S_w is the difference between earning a wage and receiving unemployment benefits: $W_t - W_\mu$. The firm's surplus of a match is the cost of opening another vacancy $\kappa/q_t = \kappa\eta_t^{\frac{\alpha}{\alpha-1}} \geq 0$ as job-finding rate vacancy costs are non-negative by construction. In Figure A2 in Appendix A, we show that the workers' surplus is positive in the simulations we consider.

As the firms and labor market parameters are homogeneous, all the matches result in the same wage W_t.

2.4 Aggregation and Monetary Policy

With N_t being the number of employed individuals and U_t the number of unemployed individuals, the dynamics of aggregate employment are driven by the job-finding rate η_t :

$$N_t = N_{t-1}(1-\omega(1-\eta_t)) + (U_{t-1} - \xi)\eta_t, \tag{25}$$

$$U_t = 1 - N_t - \xi. \tag{26}$$

Output in each economy is used for consumption, payment for raw energy from abroad, investment into capital and abatement capital including adjustment costs, payments for vacancy costs, costs of price adjustment and employed workers nominal asset portfolio adjustment costs. In our model, trade balance with the rest of the world is zero in the steady state, as well as net foreign asset positions are zero in the steady state. For convenience, we denote energy prices and wages relative to non-energy good as $\tilde{P^e} \equiv \frac{P^e}{P}$ and $\tilde{W} \equiv \frac{W}{P}$, and real bonds as $\tilde{B} \equiv \frac{B}{P}$. Denoting the variables aggregated among agents in bold capital letters where aggregate investment includes adjustment costs, we write the resource constraint in real terms:

$$Y_t = \mathbf{C}_t + \tilde{P}_t^e(\mathbf{E}_t^r + E_t^{rp}) + \mathbf{I}_t + \mathbf{I}_t^e + \left(\kappa\eta_t^{\frac{\alpha}{1-\alpha}} + \phi(\Pi_t - 1)^2\right)Y_t + \frac{\psi_b}{2}\left(\frac{\tilde{B}_{e,t}}{\bar{B}} - 1\right)^2 \tilde{B}_{e,t}N_t. \tag{27}$$

Note that the investment in abatement capital is formulated in terms of final goods, similarly to Benmir et al. (2020) or Heutel (2012). That is, larger investment increases demand for final goods and can be stimulative. Only employed workers change their portfolio, and as they all behave identically, the aggregate portfolio adjustment costs are costs per employed worker $\frac{\psi_b}{2}\left(\frac{\tilde{B}_{e,t}}{\bar{B}} - 1\right)^2 \tilde{B}_{e,t}$ times the number of employed workers N_t.

The unemployment benefits are financed by future tax collection. The tax is collected from employed workers and capitalists' dividends.

$$\tau_{t+1} = \frac{W_\mu(U_t - \xi)}{W_t N_t + div_t \xi}. \tag{28}$$

There is a central bank that sets the nominal interest rate using the following baseline rule:

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_r}\left[\left(\frac{E_t\Pi_t^{CPI}}{\bar{\Pi}}\right)^{\phi_\pi}\left(\frac{Y_t}{\bar{Y}}\right)^{\phi_y}\right]^{1-\rho_r}\varepsilon_t^r. \tag{29}$$

In the above rule, the central bank adjusts the policy rate relative to its steady-state value, $\bar{R}$, responding to the deviations of CPI inflation Π_t^{CPI} from the target $\bar{\Pi}$ and to the deviations of output Y_t from its steady-state level $\bar{Y}$. The strength of the response is governed by parameters ϕ_π and ϕ_y. In the rule, there is a stochastic AR(1) process, ε_t^r, with i.i.d. shock μ_t^r and persistence ρ_r.

CPI inflation is the weighted average of non-energy consumer good inflation and energy price inflation:

$$\Pi_t^{CPI} = \Pi_t^{core} \left(\frac{\tilde{P}_t^e}{\tilde{P}_{t-1}^e} \right)^{\phi_e}, \tag{30}$$

where $\tilde{P}_t^e$ is the price of raw energy normalized by the price of the non-energy good P_t and $\Pi_t^{core} = \Pi = P_t/P_{t-1}$ is non-energy consumer good inflation, which in our model stands for the core inflation. CPI inflation reflects the composition of the consumption bundle in (2) by using the share of the energy service in the consumption bundle ϕ_e as a weight on energy price inflation.

The equilibrium is defined in Appendix A, the steady-state of the model is characterized in Appendix B.

3. Calibration

We calibrate the model with a period of one quarter. We take some of the standard parameters from the literature (e.g Ravn and Sterk 2021 and Coenen et al. (2018)) and discuss them in Appendix C. We use the data for the Czech Republic to calibrate the country-specific parameters as it is an example of a small open economy with large exposure to energy price shocks. Most of the calibrated parameters in Table 2 are close to their euro area counterpart, except for the share of household energy expenditure and share of households' savings. The parameters specific to our model include energy-related ϕ_e, λ_e, δ_e. We set $\phi_e = 0.1$ to match the average 10% share of energy consumption in final consumption expenditure. We calibrate the share of energy in the production function $\rho_o = 5\%$.[10] The abatement capital depreciation rate $\delta_e = 0.01$ is set to match 4% depreciation per year.[11] We set the elasticity of substitution between energy and non-energy consumption goods λ_e to 0.3 in accordance with the literature (de Walque et al. 2017 and Natal 2012).

Labor market specific parameters – the steady-state job-finding rate, $\bar{\eta} = 0.15$ – is set to match the share of poor HtM consumers of 9%; and the share of capitalists ξ is set to 12% to match the shares of poor and wealthy HtM households respectively as reported by Slacalek et al. (2020) for the euro area. With these ratios and workers discount rate β, we match the steady-state interest rate and households saving rate in Table 3. We calculate ratios of workers' savings to their income using the Household Finance and Consumption Survey.[12] While the value for $\beta = 0.95$ is somewhat lower than in the literature, it can be explained in our model by the presence of additional assets and limited financial market participation for capitalists and unemployed workers. For adjustment

[10] This number was chosen to reflect the energy intensity of production and consumption in the Czech Republic, while the estimates for Germany are very close for production, see the references in Chan et al. (2024). For consumption, the estimates for Germany as reported by Pieroni (2023) are between 6 and 12%.

[11] As our abatement capital is a housing-specific product, we set the full depreciation period to 25 years, similar to housing products and heating systems.

[12] The survey is from Household Finance and Consumption Network. The shares are calculated using the following series: the financial assets of the 40-60 % income group divided by their median wealth. This estimate varies across countries: it is around 9% in France and 35% in Germany.

costs, we choose very small numbers which guarantee the convergence of the model. To ensure the convergence of the capital stock, we set the parameter for elasticity of capitalists' discount factor to capital fluctuations to 0.13. We further use Table 3 to compare the resulting steady-state

Table 2: Calibrated Parameters

Name	Symbol	Value
Energy consumption:		
Share of energy in CES aggregator	ϕ_e	0.1
Elasticity of substitution	λ_e	0.3
abatement capital depreciation	δ_e	0.01
Energy share in output	ρ_o	0.05
Labour market:		
Steady-state job-finding rate	$\bar{\eta}$	0.15
Share of firm owners	ξ	0.12
Financial variables:		
Borrowing limits for unemployed workers	$\bar{b}_e$	0
Adjustment costs:		
Portfolio adjustment costs	ψ_b	10^{-5}
Capitalists' discount factor adjustment	ψ_k	0.13
Abatement capital and capital adjustment costs	ψ	$9x10^{-3}$
Abatement and preferences:		
Abatement parameter	$1/\psi_{ab}$	1/29
Workers discount rate	β	0.95
Capitalists discount rate	β	0.98
Other parameters		
Steady state tax rate	τ	0.0395

values with the data. We calculate energy shares for 2020 using the average energy share as an indicator for employed workers; for unemployed workers, we use the second lowest quantile of income distribution.

Table 3: Matched Steady-State Ratios and the Data

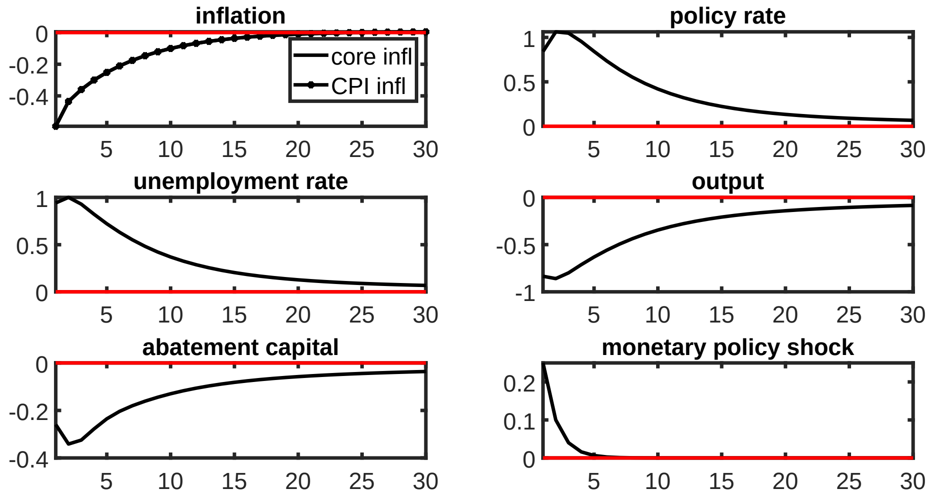
Name	Symbol	Value	
		Model	Data
Workers' savings to wealth ratio	$\bar{B}_t/Net\,wealth$	0.0684	0.068
Share of workers energy expenditure	$\bar{E}^r_n/(\bar{E}^r_n+\bar{C}_n)$	0.111	0.11
Share of poor HtM households energy expenditure	$\bar{E}^r_u/(\bar{E}^r_u+\bar{C}_u)$	0.125	0.12
Share of capitalists' energy expenditure	$\bar{E}^r_c/(\bar{E}^r_c+\bar{C}_c)$	0.071	0.09
Total share of energy expenditure	$\bar{E}^r/(\bar{E}^r+\bar{C})$	0.1019	0.102
Annualized interest rate	$\bar{R}$	1.034	1.03

4. Simulations

In this section, we simulate the model, linearized around a non-stochastic steady state, to demonstrate how the shocks propagate through the model with a closer analysis of the distributional effects of monetary policy and energy price shocks. For every shock, we check in Figure A1, Appendix A that the conditions implying that the capitalists and unemployed workers choose not to save, and that unemployed workers choose not to invest in abatement capital, are satisfied in every period.

Figure 3 shows the impulse responses of the aggregate variables to an unexpected monetary policy shock. The rising policy rate suppresses inflation and output, leading to an increase in unemployment.[13] The shock results in a decline in the holdings of abatement capital.

Figure 3: Impulse Responses to a 0.25% Positive Monetary Policy Shock



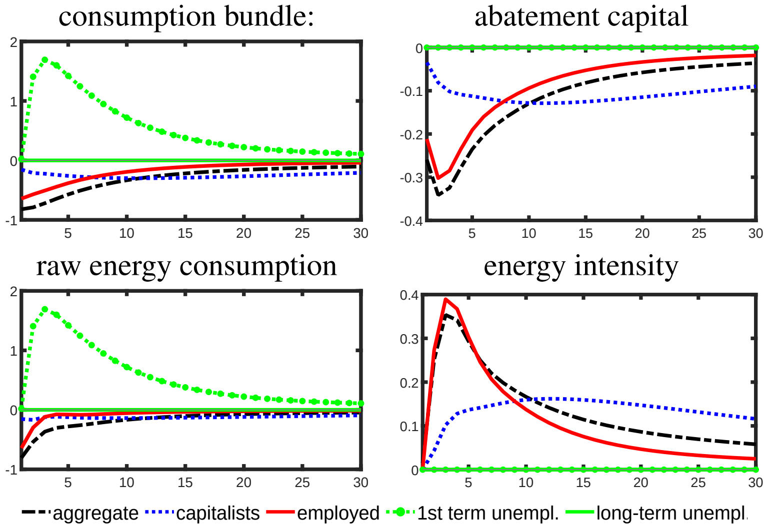
Note: All responses are reported as percentage deviations from the steady state, except for the responses of inflation and interest rates, which are annualized percentage-point deviations from the steady state; unemployment is reported as percentage-point deviations from the steady state.

We study the distributional effects of energy usage in Figure 4, where we show the responses for different groups of households and for aggregate variables. We introduce a measure of energy intensity of consumption as the ratio of raw energy used for a unit of final consumption $E^r/\mathbb{C}$. Note that final consumption $\mathbb{C}$ includes energy services as a function of abatement capital. That is, energy intensity of consumption reflects both how effectively raw energy is used in consuming energy services and the limited substitution between energy and non-energy goods. A rise in energy intensity indicates that energy is used less efficiently as the agents use more raw energy for a consumption unit. A fall in this index indicates more efficient energy usage by households.

Looking at the dynamics of the consumption bundle in the upper left chart of Figure 4, note that employed workers are the only agents in the economy that follow the binding consumption Euler equation (A4) and have a working intertemporal elasticity of substitution channel. As the interest rate increases, they reduce their consumption to save more. A rising unemployment rate further

[13] The strength of annualized inflation response to monetary policy shock is roughly in line with other studies, e.g. Coenen et al. (2018) for 0.25 percentage point rise in euro area interest rate estimated 0.10-0.15 fall in consumption deflator, which correspods to 0.4-0.6 fall for 1 percentage point increase in interest rate; in Brazdik et al. (2020) for the Czech economy 0.7 percentage points rise resulted in 0.6 percentage points fall in inflation, all in annualized terms.

Figure 4: Effects of Heterogeneity, 0.25% Positive Monetary Policy Shock



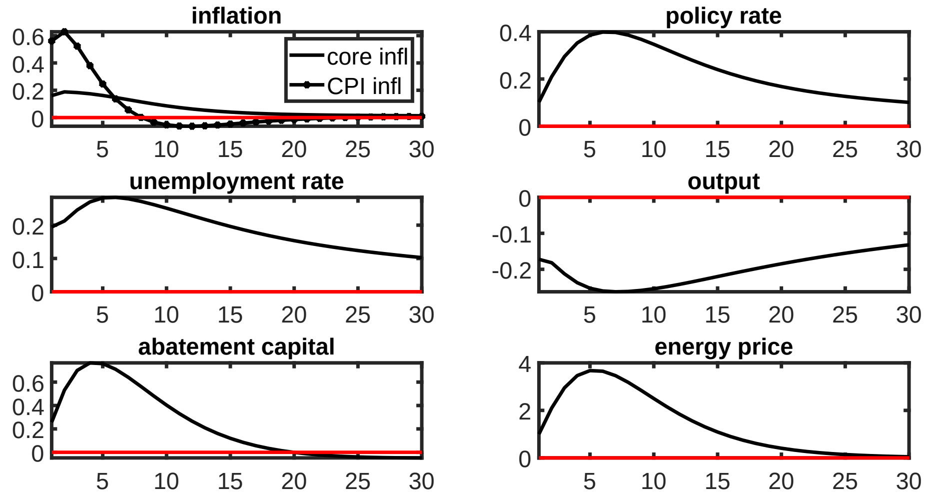
Note: All responses are reported as percentage deviations from the steady state.

intensifies their incentive for precautionary savings. Long-term unemployed workers have their benefits fixed in real terms and do not change their consumption pattern in response to a monetary policy shock. First-term unemployed workers enjoy a larger return on their precautionary savings. Capitalists, who have large debt, suffer as a result of an increase in interest rates, and, as firm owners, from lower aggregate demand, thus reducing their consumption. The aggregate variables are the weighted averages for all the groups and not only reflect the choices of each group, but also the size of the groups. As the pool of unemployed workers increases, the aggregate variables reflect unemployed workers' choices more. In the case of a monetary policy shock, when the consumption of long-term unemployed workers remains at its steady-state level, the fall in aggregate consumption reflects that there are more workers with a lower consumption level. That is why the fall in aggregate consumption exceeds that of employed workers and capitalists.

When it comes to abatement capital, (see the upper right chart of Figure 4) unemployed workers choose not to adjust it. Employed workers reduce their abatement capital holdings as a rising policy rate makes savings more attractive. Capitalists decrease their abatement capital holdings as their debt service becomes more expensive. The aggregate fall in abatement capital is large as there are more unemployed workers with low abatement capital holdings. Raw energy consumption (see the bottom left chart) falls for all the groups apart from unemployed workers, reflecting the changes in both the consumption bundle and abatement capital. First-period unemployed workers enjoy higher consumption and energy expenditure due to larger returns on their precautionary savings. Long-term unemployed workers are unaffected by monetary policy shocks. To disentangle the effects of changes in consumption and abatement capital, we plot energy intensity of consumption. Energy intensity rises for workers and capitalists, and in the aggregate.

We further consider impulse responses to an energy price shock in Figure 5. In period 1, energy prices rise unexpectedly, but are expected to grow further, peaking in five quarters. As we want to study monetary policy trade-offs, we choose this process for the energy price shock, which would cause an increase in CPI inflation and monetary authority would have to react to it. As energy is part of the production function, a rise in the marginal costs of production pushes core inflation up and the policy rate reflects both rising energy and producers' prices. Producers expecting rising production costs further reduce their hiring and increase domestic prices once the shock arrives. There is an increase in unemployment and a fall in output accompanied by the higher policy rate. There are stronger incentives for employed workers and capitalists to invest in abatement capital. As abatement capital is produced with domestic final goods, stronger demand for abatement capital somewhat stimulates domestic output and employment.[14]

Figure 5: Impulse Responses to a 1% Energy Price Shock



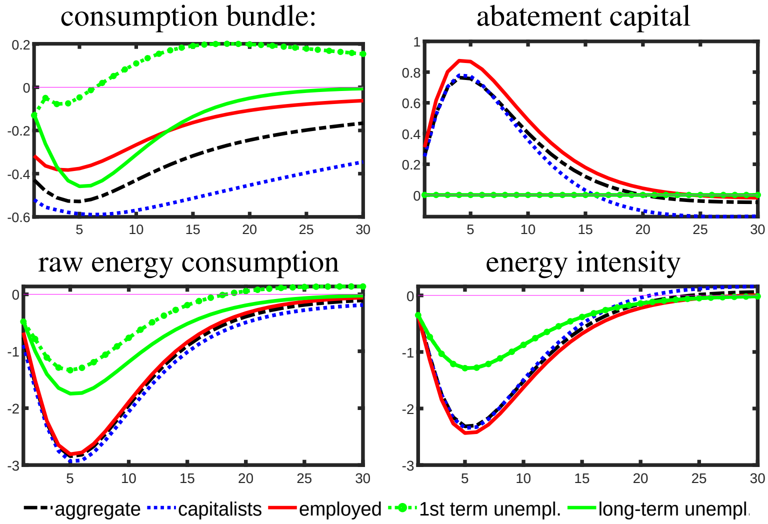
Note: All responses are reported as percentage deviations from the steady state, except for the responses of inflation and interest rates, which are annualized percentage-point deviations from the steady state; unemployment is reported as percentage-point deviations from the steady state.

The distributional effects of rising energy prices in Figure 6 depend on the agents' ability to adjust their raw energy consumption by investing in abatement capital. Unemployed workers decrease their consumption, and decrease their consumption of expensive raw energy even more, while the substitution between energy and non-energy goods is limited. First-period unemployed workers do not have the opportunity to invest in abatement capital, but they benefit from rising interest rates. That is why the initial fall in their consumption is smaller and they experience a rise afterwards. Employed workers and capitalists lower their consumption of raw energy and increase their abatement capital. Raw energy consumption and energy intensity falls for all groups, with the fall being larger for capitalists and workers. The smaller fall of the energy intensity is for unemployed workers, who can only save energy by consuming it less. The importance of the distributional effects of the energy price shock on aggregate variables depends on the size of the groups and their choices. Rising share of unemployed workers results in lower aggregate abatement capital than would have implied by the employed workers and capitalists choices alone due to the presence of poor HtM households.

To sum up, our simulations show that monetary policy shocks can result in an increase in energy intensity, and heterogeneity plays a role in their propagation. We also show how movements in policy rate influence the propagation of energy price shocks. Energy price shocks result in decrease in raw energy consumption and energy intensity, but this effect is muted by the presence of constrained unemployed workers. In the next section, we consider the different types of policy rules and analyze their role in the economy and in energy conservation decisions in the presence of energy price shocks.

[14] Note that the somewhat unconventional shape of the energy price shock and the stimulative effects of abatement investment slows down the economy's convergence to the steady state.

Figure 6: Effects of Heterogeneity, 1% Energy Price Shock



Note: All responses are reported as percentage deviations from the steady state.

5. Monetary Policy and Energy Price Shocks

In this section we consider the effects of different policy responses to rising energy prices. In particular, we are interested in the response of the aggregate energy intensity of consumption. When energy prices rise, it is expected that agents will invest more in abatement capital. The question we are interested in is whether different policy rules can fuel or mitigate this incentive through the distribution channels of monetary policy, in particular, the labor market channel and through the agents' nominal asset holdings.

The persistence of the energy price shocks and how strongly these shocks propagate to core inflation change both the economic outlook and monetary policy implications. If a shock is not expected to have a prolonged and significant impact on CPI inflation,[15] it is reasonable for a central bank not to react to it. In the opposite case, it can be desirable for a monetary authority to increase policy rates in response to rising inflation. However, a policy trade-off arises between suppressing inflation and stimulating employment. This is why we consider a persistent and hump-shaped energy price shock which results in stronger energy price propagation to the economy, see Figure 5.

To highlight the monetary policy effects, we consider several scenarios in which monetary policy reacts to CPI inflation and output with varying strength as described in Table 4. In other words, we consider rules with different parameters in central bank policy rules (29), such that these parameters are constant over time and agents have full-information rational expectations about both the parameters and future economic variables. We first add "output support" to the baseline policy rule, so that the central bank reacts to declining output in the Taylor rule. Furthermore, we consider a case of "looking through" the energy price policy, which is the policy of reacting to *core inflation* instead of CPI inflation, i.e. ignoring energy price movements.

[15] For example, if the energy shock is short-lived.

Table 4: Policy Simulations Overview

	ϕ_π	ϕ_y	inflation measure
baseline	2	0	$E_t\Pi_t^{CPI}$
baseline+output	2	0.5	$E_t\Pi_t^{CPI}$
weak reaction to infl.	1.1	0	$E_t\Pi_t^{CPI}$
looking-through	2	0	$E_t\Pi_t^{core}$
Ramsey policy	-	-	-

In addition, we calculate "Ramsey policy"[16] which sets interest rate R_t to minimize the volatility of the expected social utility in response to the energy price shock as in Figure 5 at time t:

$$\sum_{j=0}^{\infty} \beta_R^j w_{t+j}(h) \frac{\mathbf{C}(h)_{t+j}^{1-\mu}}{1-\mu}, \tag{31}$$

where weights $w(h)$ are time varying shares of agents‘ types in population. As the economy features agents with different discount factors, we choose a discount factor for Ramsey problem $\beta_R = 0.99$ so that the steady state interest rate coincides with the interest rate in the Taylor-rule based model. While Ramsey policy is rather unachievable for a central bank, one can treat it as an aspiration.

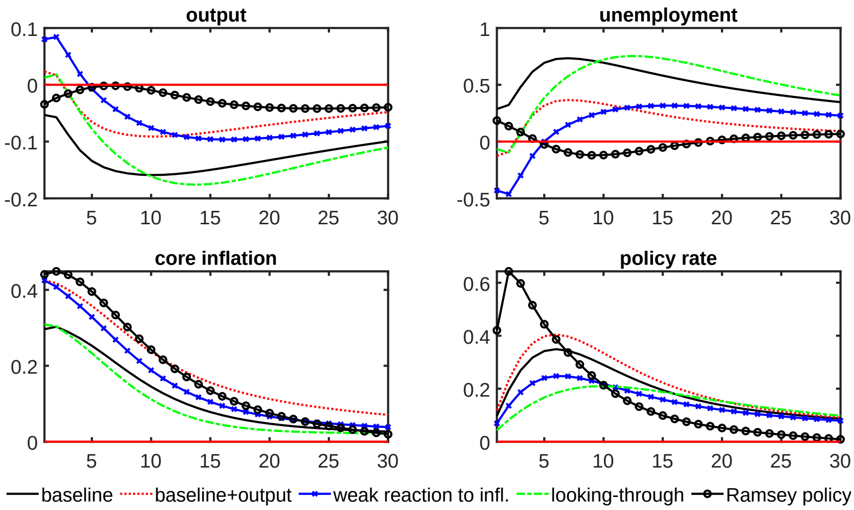
In Figure 7 we report the responses under different policies. Policies that react more weakly to inflation than the baseline and support output result in a smaller recession in terms of output and unemployment. The most supportive policies increase the stimulative effects of higher demand for abatement capital. At the same time, accommodative policy rates result in higher inflation. The policy "baseline + output" support results in larger both interest rates and inflation. The policy of "looking through" energy prices is more accommodative relative to the baseline in periods when energy prices are rising; that is, when CPI inflation, which includes energy price growth, is higher than core inflation. Once energy prices start falling, CPI inflation returns to its steady state faster, while core inflation is still above the target as shown in Figure 5. That is why, the looking-through policy supports output and employment more in the short term after the shock, but starts to suppress them later in the monetary policy horizon.[17] "Ramsey policy" predicts sharper immediate increase policy rate peaking *before* the peak of the energy price shock, and sharper fall of interest rates afterwards. After the peak of the shock, Ramsey policy rate is smaller than under the baseline Taylor rule.

To zoom in the policy effects on abatement capital and energy efficiency, in Figure 8 we further show the responses of energy intensity of consumption and abatement capital in differences relative to the baseline policy rule. The policy rule with a weaker policy response and greater output support results in smaller energy intensity and larger abatement capital holdings. The looking-through policy supports energy efficiency initially, but the effect is reversed once it starts to be relatively more restrictive. Note, that " Ramsey policy" also results in the smallest energy intensity of consumption

[16] We use Dynare *Ramsey policy* tool, see Adjemian et al. (2024) for description. First, first order conditions of the Ramsey planners problem are computed subject to the nonlinear constraints (first order conditions of the private economy). And only then, the first order conditions of planners problem are a approximated to the first order. Such a procedure preserves the second order terms that are required for a second-order correct welfare evaluation.

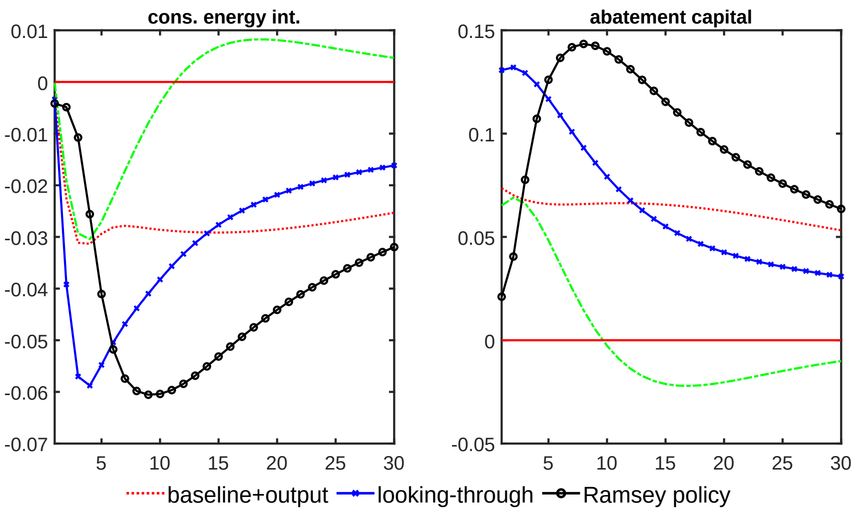
[17] We do not discuss the possibility for the central bank to switch between policy rules as it has implications for central bank’s credibility, from which we abstract in this paper.

Figure 7: Policy Responses, 1% Energy Price Shock



Note: All responses are reported as percentage deviations from steady state. Inflation and interest rates are annualized.

Figure 8: Policy Responses, 1% Energy Price Shock



Note: All responses are reported as percentage point differences relative to the baseline policy. Positive values mean a larger reaction than under the baseline policy.

and larger abatement capital as investment into abatement insulates the economy from the energy shock and results in lower consumption volatility.

5.1 Welfare Analysis

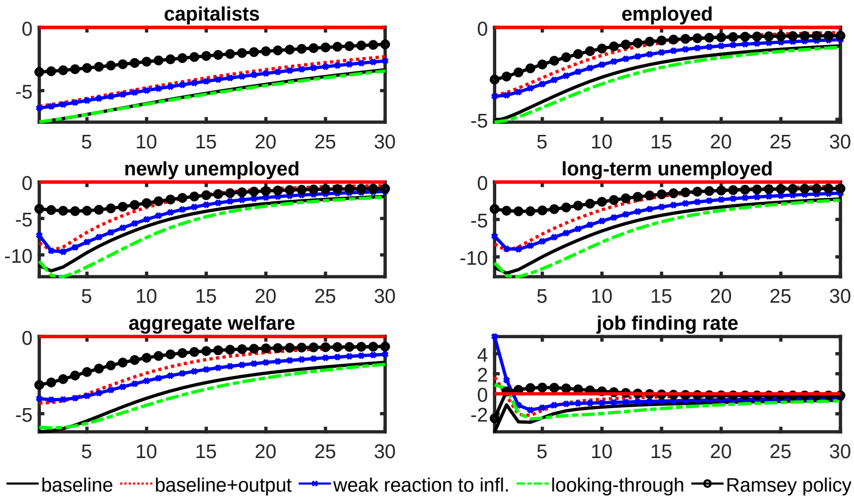
In this section we study the welfare effects of central bank policies in response to energy price shocks for different agents. To do this, we calculate welfare as a discounted infinite stream of utility for every group of households, where for workers, the job-finding rate enters their probability of being employed in future periods. We do the analysis conditional on a energy price shock as in Figure 5. Extrapolation of the findings to other types of shocks should be made with caution.

The simulations in Figure 9 show the welfare responses for different agent groups. Capitalists are firm owners who receive firms' dividends. They also have large debt. As such, their welfare is greater under a policy which results in higher output and employment and lower interest rates. For all types of workers – whether employed or unemployed – welfare is greater under the more supportive policies - due to higher job-finding rate and larger investment in abatement capital. As welfare is calculated over the infinite future, the looking-through policy does not result in welfare improvements for the agents, as it rather shifts the increase in the interest rate to the future. Looking at the "Ramsey policy" which implies initially higher but lower later rates than the Taylor-type policies, it results in larger welfare for all types of agents than. Larger investment in abatement capital under "Ramsey policy" limits agents exposure to energy price shock and thus, together with larger job opportunities, increases welfare.

Considering social welfare in a model with heterogeneous agents is not straightforward. However, one can calculate an aggregate – consisting of all the agents' welfare weighted by their relative time-varying shares – as an average indicator. Such an indicator suggests that a weak reaction to energy price inflation and output support may be preferable in terms of welfare for the agents we consider. It should be noted that if the model contained agents who are not interested in job opportunities – whether creditors or agents dependent on social security – a stronger monetary policy response would be preferable for such agents.

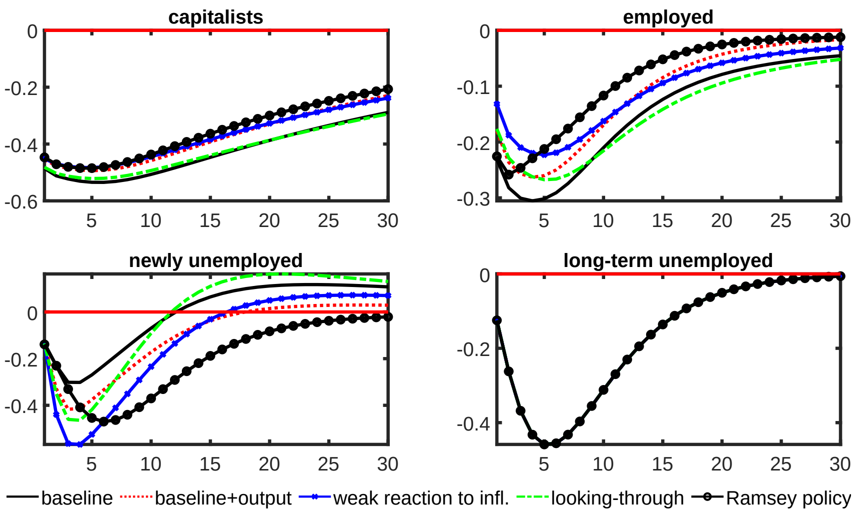
To shed some light on this, we plot the contemporaneous responses of agents' consumption, which do not reflect job prospects in Figure 10. Figure 10 shows that the contemporaneous consumption of capitalists is higher under the least restrictive policies. Capitalists' income depends on firms revenues, and they have large debt. Supportive policy stimulates firms' revenues and lowers debt service costs. Employed workers consume more under more supportive policies, as they have fewer precautionary incentives to save. Furthermore, large investment in abatement capital insulates these groups of agents from energy price shock. On the contrary, newly unemployed workers consume less under more supportive policies, as they have large savings and lower interest rates reduce their return on precautionary savings. The welfare of creditors who are not interested in job opportunities and cannot use abatement for building resilience to the energy price shock will resemble the consumption responses of first-period unemployed workers. Long-term unemployed workers consumption does not change depending on the monetary policy rules because their unemployment benefits are fully indexed under this scenario.

Figure 9: Policy Responses: Welfare and Job-Finding Rate, 1% Energy Price Shock



Note: All responses are reported as percentage deviations from steady state.

Figure 10: Policy Responses: Consumption Bundle, 1% Energy Price Shock



Note: All responses are reported as percentage deviations from steady state.

Welfare ranking of the policies can be influenced by the indexation of unemployment benefits and wage rigidities, as well as steady state values of households savings and debt. Therefore we provide welfare analysis for the economy without full indexation of unemployment benefits, or with lower wage stickiness, or larger steady state household savings in Appendix D. In the aggregate, the policy welfare rankings are similar without full indexation and larger steady state savings and debt. At the same time the welfare benefits of more accommodative policies are smaller without full indexation or with more flexible wages. Moreover, with more flexible wages the policies welfare ranking for the capitalists is reversed: as wages adjust stronger to market conditions, the capitalists benefit more under baseline strict inflation targeting. The larger steady state household savings and larger capitalist debt increases welfare benefits of accommodative policies for these agents.

To sum up, in our simple model framework with distributional aspects of monetary policy, working through both direct factors – the intertemporal elasticity of substitution – and indirect factors – labor market tightness and changes in precautionary savings – there is an interaction between monetary policy and household investment aimed at reducing energy intensity of consumption. The distributional effects depend on the presence of hand-to-mouth households, who cannot increase their level of abatement capital, and the precautionary savings of workers, who increase their saving more when facing a higher probability of unemployment or when interest rates are higher. Larger investment into abatement capital reduces households' exposure to energy price shocks and reduces the volatility of aggregate consumption.

6. Conclusion

In this paper, we show that monetary policy influences energy conservation decisions and energy intensity through its distributional effects and a possibility of abatement. By changing labor market tightness, monetary policy affects agents' precautionary motives and the share of unemployed workers with limited possibility to invest in energy saving. By changing the rate of return on savings, monetary policy influences agents' incentives to invest in abatement capital as it changes the attractiveness of the savings and debt service expenditure. When raw energy prices rise, all agents have incentives to invest in energy-saving capital. We find that rising policy rates, on the other hand, can dampen these incentives by suppressing the creation of new jobs, increasing the number of unemployed workers and rising returns on nominal savings.

Our welfare analysis indicates that the policies which have a weaker response to inflation and/or output support result in smaller welfare losses for workers and firm owners when facing a persistent energy price shock, despite rising inflation. The agents benefit from larger abatement capital and smaller exposure to energy price shocks. Furthermore, the workers benefit when there are more job opportunities. The rich households, who are also firm owners, benefit when the interest rate is lower and firms profits are larger. The looking-through policy which reacts to core inflation is more accommodative when energy prices rise, but becomes more restrictive when energy prices start falling. As such, the policy of looking-through energy prices does not result in welfare benefits. We calculate Ramsey optimal policy which minimizes volatility of social utility. Comparing with the Taylor-type rules, Ramsey policy implies initially higher spike in the policy rate and sharp decline afterwards. It predicts larger investment in abatement capital as it reduces household exposure to energy price fluctuations, thus reducing aggregate consumption volatility.

We further consider alternative scenarios for welfare analysis. We study the economies without full indexation of unemployment benefits, with more flexible wages or with larger initial levels of savings. The policy trade off is mostly preserved for aggregate welfare under all alternative specifications. The policy trade-off in terms of aggregate welfare are narrower under the first two simulations, and wider under the latter.

We abstract from the policy rules with variable coefficients, as a more careful analysis is required for how this affects confidence in the central bank. Furthermore, our framework studies the economy under full-information rational expectations and neither allows for wage-price spirals nor for the unanchoring of inflation expectations, which can increase the economic costs of inflation. As such, our results should be considered with caution, but we believe they can provide useful guidance for central banks and other policy institutions. While many central banks do not have environmental goals in their mandate, we believe it is important to be aware of the possible consequences of their decisions and to be able to communicate these consequences to the relevant institutions.

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Appendix A: Solution to Households' Problem

In the model, the distribution of agents collapses to four groups: employed workers, first-time unemployed, long-term unemployed and capitalists. All agents maximise their utility in (1). We define long-term unemployed as workers who have been unemployed for longer than one period. It is convenient to solve the problem for each group separately.

To solve the model, we redefine the budget constraint in real terms by dividing both sides by the price of consumption goods P_t. For convenience, we denote relative energy prices and wages as $\tilde{P}^e$ and $\tilde{W}$, and real bonds as $\tilde{B}$. We define domestic CPI inflation as $\Pi_{t+1} \equiv \frac{P_{t+1}}{P_t}$.

The head of the family optimizes workers' allocations taking into account possible changes in their employment status. We denote choices for employed workers, first-period unemployed workers, and long-term unemployed workers with the subscripts *e, eu*, and *uu* respectively. The probability of an unemployed worker finding a job is the job-finding rate η_t. The probability of an employed worker becoming unemployed equals the probability of losing their job, ω, and not finding a match at the beginning of the same period $1-\eta_t$: $\omega(1-\eta_t)$. The probability of an employed worker remaining employed is the opposite to losing their job: $1-\omega(1-\eta_t)$. Note that the level of abatement capital is the same for all types of unemployed workers, denoted as $K^e_{u,t}$ for unemployed workers, and $K^e_{e,t}$ for employed workers.

Employed workers are unconstrained agents. They consume, invest in abatement capital and save from their wages, taking into account that next period they may become unemployed. Their Lagrangian is formulated as

$$L \equiv \max_{C_{e,t},\tilde{B}_{e,t},I^e_{e,t}} E_t \sum_{t=0}^{\infty} \beta^t U_t + +\lambda_{bc} \Bigg(\tilde{W}_t(1-\tau_t) + \frac{R_{t-1}}{\Pi_t}\tilde{B}'_{e,t-1} \tag{A1}$$

$$-C_{e,t} - \tilde{P}^e_t E^r_{e,t} - \tilde{B}_{e,t}\left(1+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{e,t}}{\bar{\tilde{B}}_e}-1\right]^2\right) - I^e_{e,t}\left[1+\frac{\psi_i}{2}\left(\frac{I^e_{e,t}}{I^e_{e,t-1}}-1\right)^2\right]\Bigg),$$

with the following Kuhn-Tucker conditions:

$$[\frac{\partial L}{\partial I^e_{e,t}}]: \quad -\lambda_{bc}\left(\frac{1-\phi_e}{\phi_e}\right)^{\frac{1}{\lambda_e}} \mathbb{C}^{-\mu}_{e,t}\left(\frac{\mathbb{C}_{e,t}}{C_{e,t}}\right)^{\frac{1}{\lambda_e}}\left(1+\psi_i\left(\frac{I^e_{e,t}}{I^e_{e,t-1}}-1\right)\left[\left(\frac{I^e_{e,t}}{I^e_{e,t-1}}-1\right)/2+\frac{I^e_{e,t}}{I^e_{e,t-1}}\right]\right)+ \tag{A2}$$

$$+\beta\left[(1-\omega(1-\eta_{t+1}))\mathbb{C}^{-\mu}_{e,t+1}\left(\frac{\mathbb{C}_{e,t+1}}{E^s_{e,t+1}}\right)^{\frac{1}{\lambda_e}} E^r_{e,t+1} f'(K^e_{e,t})\psi_i\left[\frac{I^e_{e,t+1}}{I^e_{e,t}}-1\right]\left(\frac{I^e_{e,t+1}}{I^e_{e,t}}\right)^2\right] \leq 0,$$

$$I^e_{e,t}\frac{\partial L}{\partial I^e_{e,t}} = 0, \tag{A3}$$

$$[\frac{\partial L}{\partial \tilde{B}_{e,t}}]: \quad -\lambda_{bc}\mathbb{C}^{-\mu}_{e,t}\frac{\mathbb{C}_{e,t}}{C_{e,t}}^{\frac{1}{\lambda_e}}\left(1+\psi_b\left[\frac{\tilde{B}_{e,t}}{\bar{\tilde{B}}_e}-1\right]\frac{\tilde{B}_{e,t}}{\bar{\tilde{B}}_e}+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{e,t}}{\bar{\tilde{B}}_e}-1\right]^2\right) \tag{A4}$$

$$+\beta E_t\frac{R_t}{\Pi_{t+1}}\left[(1-\omega(1-\eta_{t+1}))\mathbb{C}^{-\mu}_{e,t+1}\left(\frac{\mathbb{C}_{e,t+1}}{C_{e,t+1}}\right)^{\frac{1}{\lambda_e}}+\omega(1-\eta_{t+1})\mathbb{C}^{-\mu}_{eu,t+1}\left(\frac{\mathbb{C}_{eu,t+1}}{C_{eu,t+1}}\right)^{\frac{1}{\lambda_e}}\right] \leq 0,$$

$$\tilde{B}_{e,t}\frac{\partial L}{\partial \tilde{B}_{e,t}} = 0, \tag{A5}$$

$$\lambda_{bc}\left(\tilde{W}_{e,t}(1-\tau_t)+\frac{R_{t-1}}{\Pi_t}\tilde{B}'_{e,t-1}\right. \tag{A6}$$

$$\left.-C_{e,t}-\tilde{P}^e_t E^r_{e,t}-\tilde{B}_{e,t}\left(1+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{e,t}}{\bar{\tilde{B}}_e}-1\right]^2\right)-I^e_{e,t}\left[1+\frac{\psi_i}{2}\left(\frac{I^e_{e,t}}{I^e_{e,t-1}}-1\right)^2\right]\right)=0, \tag{A7}$$

$$\tilde{W}_{e,t}(1-\tau_t)+\frac{R_{t-1}}{\Pi_t}\tilde{B}'_{e,t-1}-C_{e,t}-\tilde{P}^e_t E^r_{e,t}-\tilde{B}_{e,t}\left(1+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{e,t}}{\bar{\tilde{B}}_e}-1\right]^2\right)-I^e_{e,t}\left[1+\frac{\psi_i}{2}\left(\frac{I^e_{e,t}}{I^e_{e,t-1}}-1\right)^2\right]\geq 0. \tag{A8}$$

For unconstrained, employed workers, $I^e_{e,t}>0$, $\tilde{B}_{e,t}>0$ and their budget is exhausted. Consumption-saving and abatement capital investment decisions are determined by setting (A4), (A8), and (A2) to zero.

The relationship between energy and non-energy consumption goods is given by the expenditure minimization problem:

$$\frac{C_{e,t}}{E^r_{e,t}}=\frac{1-\phi_e}{\phi_e}\frac{(\tilde{P}_{e,t})^{\lambda}}{(f(K^e_{e,t-1}))^{\lambda_e-1}}. \tag{A9}$$

For both types of unemployed workers $j=\{eu,uu\}$ and with $\tilde{W}_{\mu,eu}=0.75\tilde{W}_{\mu,uu}$, the problem can be formulated as follows:

$$L\equiv\max_{C_{j,t},\tilde{B}_{j,t},I^e_{j,t}}E_t\sum_{t=0}^{\infty}\beta^t U_t+\lambda_{bc}\left(\tilde{W}_{\mu,j}+\frac{R_{t-1}}{\Pi_t}\tilde{B}_{j,t-1}-\right.$$
$$\left.C_{j,t}-\tilde{P}^e_t E^r_{j,t}-\tilde{B}_{j,t}\left(1+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{j,t}}{\bar{\tilde{B}}_j}-1\right]^2\right)-I^e_{j,t}\left[1+\frac{\psi_i}{2}\left(\frac{I^e_{j,t}}{I^e_{j,t-1}}-1\right)^2\right]\right), \tag{A10}$$

$$[\frac{\partial L}{\partial I^e_{j,t}}]:\quad -\left(\frac{1-\phi_e}{\phi_e}\right)^{\frac{1}{\lambda_e}}\mathbb{C}^{-\mu}_{j,t}\left(\frac{\mathbb{C}_{j,t}}{C_{j,t}}\right)^{\frac{1}{\lambda_e}}\left(1+\psi_i\left(\frac{I^e_{j,t}}{I^e_{j,t-1}}-1\right)\left[\left(\frac{I^e_{j,t}}{I^e_{j,t-1}}-1\right)/2+\frac{I^e_{j,t}}{I^e_{j,t-1}}\right]\right)+$$
$$\beta(1-\eta_{t+1})\mathbb{C}^{-\mu}_{j,t+1}\left(\frac{\mathbb{C}_{j,t+1}}{E^s_{j,t+1}}\right)^{\frac{1}{\lambda_e}}E^r_{j,t+1}f'(K^e_{u,t})\psi_i\left[\frac{I^e_{j,t+1}}{I^e_{j,t}}-1\right]\left(\frac{I^e_{j,t+1}}{I^e_{j,t}}\right)^2\leq 0, \tag{A11}$$
$$I^e_{j,t}\frac{\partial L}{\partial I^e_{j,t}}=0,$$

$$[\frac{\partial L}{\partial \tilde{B}_{j,t}}]:\quad -\mathbb{C}^{-\mu}_{j,t}\frac{\mathbb{C}_{j,t}}{C_{j,t}}^{\frac{1}{\lambda_e}}\left(1+\psi_b\left[\frac{\tilde{B}_{j,t}}{\bar{\tilde{B}}_j}-1\right]\frac{\tilde{B}_{j,t}}{\bar{\tilde{B}}_j}+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{j,t}}{\bar{\tilde{B}}_j}-1\right]^2\right)+ \tag{A12}$$
$$\beta E_t\frac{R_t}{\Pi_{t+1}}\left[\eta_{t+1}\mathbb{C}^{-\mu}_{e,t+1}\left(\frac{\mathbb{C}_{e,t+1}}{C_{e,t+1}}\right)^{\frac{1}{\lambda_e}}+(1-\eta_{t+1})\mathbb{C}^{-\mu}_{j,t+1}\left(\frac{\mathbb{C}_{j,t+1}}{C_{j,t+1}}\right)^{\frac{1}{\lambda_e}}\right]\leq 0,$$
$$B_{j,t}\frac{\partial L}{\partial B_{j,t}}=0,$$

$$\lambda_{bc}\left(\tilde{W}_\mu+\frac{R_{t-1}}{\Pi_t}\tilde{B}_{j,t-1}-\right.$$
$$\left.C_{j,t}-\tilde{P}^e_t E^r_{j,t}-\tilde{B}_{j,t}\left(1+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{j,t}}{\bar{\tilde{B}}_j}-1\right]^2\right)-I^e_{j,t}\left[1+\frac{\psi_i}{2}\left(\frac{I^e_{j,t}}{I^e_{j,t-1}}-1\right)^2\right]\right)=0,$$
$$\tilde{W}_\mu+\frac{R_{t-1}}{\Pi_t}\tilde{B}_{j,t-1}-C_{j,t}-\tilde{P}^e_t E^r_{j,t}-\tilde{B}_{j,t}\left(1+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{j,t}}{\bar{\tilde{B}}_j}-1\right]^2\right)-I^e_{j,t}\left[1+\frac{\psi_i}{2}\left(\frac{I^e_{j,t}}{I^e_{j,t-1}}-1\right)^2\right]\geq 0.$$

We guess and verify that $\frac{\partial L}{\partial I^e_{j,t}}<0$ and $\frac{\partial L}{\partial B_{j,t}}<0$, see Figure A1. It follows that unemployed workers choose not to invest in abatement capital $I^e_{j,t}=0$. The steady state level of K^e_u is maintained from the unemployment benefits. Unemployed workers choose not to save. We set the borrowing limit for unemployed workers to zero $\underline{b}^u=0$, so that $\tilde{B}_{j,t-1}=0$. The relationship between energy and non-energy consumption is as in (A9), and the budget is exhausted. As a result, workers unemployed for longer than one period have identical endowment and make identical decisions: they have the same level of abatement capital, nominal assets and unemployment benefits.

For capitalists, who are definitively out of the labor force, the problem is modified to include the decision to invest in physical capital. Capitalists invest in capital, K, used in the production of goods. The law of motion for capital is:

$$K_{t+1}=(1-\delta)K_t+I_t, \tag{A13}$$

where I_t is investment and δ is the depreciation rate.

Capitalists receive firms' dividends.

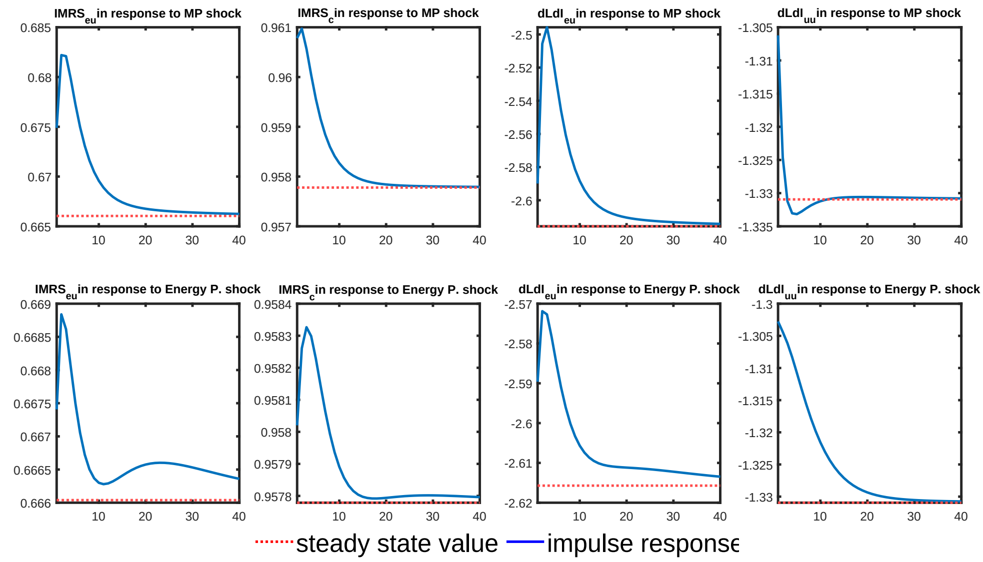
$$L\equiv\max_{C_{c,t},\tilde{B}_{c,t},I^e_{c,t},I_t} E_t\sum_{t=0}^{\infty}\beta^c_t U_t+\lambda_{bc}\left(div_t(1-\tau_t)+\frac{R_{t-1}}{\Pi_t}\tilde{B}_{c,t-1}\right. \tag{A14}$$
$$\left.-C_{c,t}-\tilde{P}^e_t E^r_{c,t}-\tilde{B}_{c,t}\left(1+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{c,t}}{\bar{\tilde{B}}_c}-1\right]^2\right)-I^e_{c,t}\left[1+\frac{\psi_i}{2}\left(\frac{I^e_{c,t}}{I^e_{c,t-1}}-1\right)^2\right]-I_t\left[1+\frac{\psi_i}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2\right]\right),$$

with the following Kuhn-Tucker conditions:

$$[\frac{\partial L}{\partial I^e_{c,t}}]:-\lambda_{bc}\mathbb{C}^{-\mu}_{c,t}\left(\frac{1-\phi_e}{\phi_e}\right)^{\frac{1}{\lambda_e}}\left(\frac{\mathbb{C}_{c,t}}{C_{c,t}}\right)^{\frac{1}{\lambda_e}}\left(1+\psi_i\left(\frac{I^e_{c,t}}{I^e_{c,t-1}}-1\right)\left[\left(\frac{I^e_{c,t}}{I^e_{c,t-1}}-1\right)/2+\frac{I^e_{c,t}}{I^e_{c,t-1}}\right]\right)+$$
$$\beta^c_t\mathbb{C}^{-\mu}_{c,t+1}\left(\frac{\mathbb{C}_{c,t+1}}{E^s_{c,t+1}}\right)^{\frac{1}{\lambda_e}}E^r_{c,t+1}f'(K^e_{c,t})\psi_i\left[\frac{I^e_{c,t+1}}{I^e_{c,t}}-1\right]\left(\frac{I^e_{c,t+1}}{I^e_{c,t}}\right)^2\leq 0, \tag{A15}$$
$$I^e_{c,t}\frac{\partial L}{\partial I^e_{c,t}}=0,$$

$$[\frac{\partial L}{\partial \tilde{B}_{c,t}}]:-\lambda_{bc}\mathbb{C}^{-\mu}_{c,t}\frac{\mathbb{C}_{c,t}}{C_{c,t}}^{\frac{1}{\lambda_e}}\left(1+\psi_b\left[\frac{\tilde{B}_{c,t}}{\bar{\tilde{B}}_c}-1\right]\frac{\tilde{B}_{c,t}}{\bar{\tilde{B}}_c}+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{c,t}}{\bar{\tilde{B}}_c}-1\right]^2\right) \tag{A16}$$
$$+\beta^c_t E_t\frac{R_t}{\Pi_{t+1}}\left[\mathbb{C}^{-\mu}_{c,t+1}\left(\frac{\mathbb{C}_{c,t+1}}{C_{c,t+1}}\right)^{\frac{1}{\lambda_e}}\right]\leq 0, \tag{A17}$$
$$\tilde{B}_{c,t}\frac{\partial L}{\partial \tilde{B}_{c,t}}=0, \tag{A18}$$

Figure A1: Steady-State Values and Impulse Response for IMRS and FOCs



Note: *IMRS* stands for the intertemporal marginal rate of substitution times the interest rate R. Agents choose to borrow when $IMRS < 1$. $dLdI$ stands for the derivative of Lagrangian with respect to abatement investment in (A11). Agents do not invest in abatement capital when $dLdI < 0$. Agents are indexed with {eu, uu, c} for first-time unemployed, long-term unemployed and capitalists respectively.

$$[\frac{\partial L}{\partial I_t}]: \quad -\lambda_{bc}\mathbb{C}_{c,t}^{-\mu}\frac{\mathbb{C}_{c,t}}{C_{c,t}}^{\frac{1}{\lambda_e}}\left(1+\psi_i\left(\frac{I_t}{I_{t-1}}-1\right)\left[\left(\frac{I_t}{I_{t-1}}-1\right)/2+\frac{I_t}{I_{t-1}}\right]\right)+$$

$$+\beta_t^c E_t\left[\mathbb{C}_{c,t+1}^{-\mu}\frac{\mathbb{C}_{c,t+1}}{C_{c,t+1}}^{\frac{1}{\lambda_e}}\left(1-\delta+R^k_{t+1}\right)\right]\psi_i\left[\frac{I_{t+1}}{I_t}-1\right]\left(\frac{I_{t+1}}{I_t}\right)^2 \leq 0, \tag{A19}$$

$$I_t\frac{\partial L}{\partial I_t}=0, \tag{A20}$$

$$\lambda_{bc}\left(div_t(1-\tau_t)+\frac{R_{t-1}}{\Pi_t}\tilde{B}_{c,t-1}-C_{c,t}-\tilde{P}_t^e E_{c,t}^r\right. \tag{A21}$$

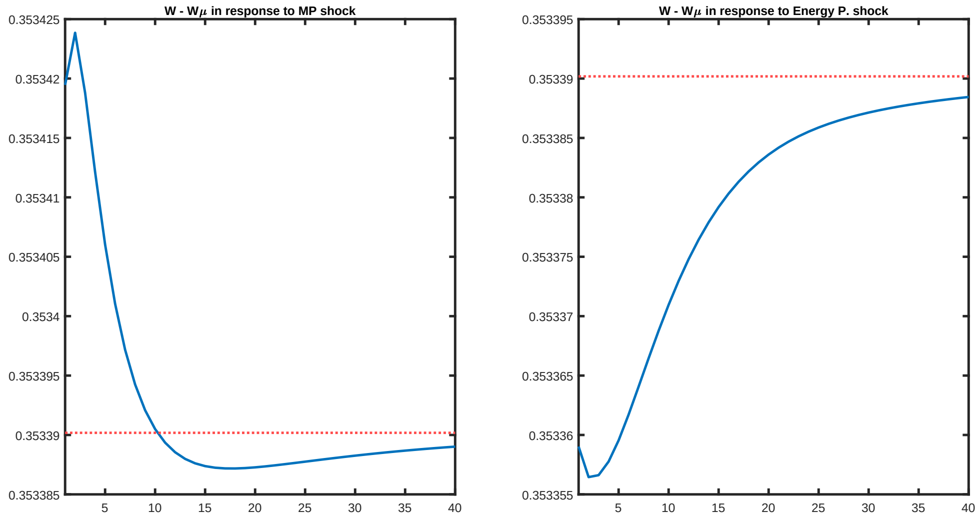
$$\left.-\tilde{B}_{c,t}\left(1+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{c,t}}{\bar{\tilde{B}}_c}-1\right]^2\right)-I_{c,t}^e\left[1+\frac{\psi_i}{2}\left(\frac{I_{c,t}^e}{I_{c,t-1}^e}-1\right)^2\right]-I_t\left[1+\frac{\psi_i}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2\right]\right)=0,$$

$$div_t(1-\tau_t)+\frac{R_{t-1}}{\Pi_t}\tilde{B}_{c,t-1}-C_{c,t}-\tilde{P}_t^e E_{c,t}^r \tag{A22}$$

$$-\tilde{B}_{c,t}\left(1+\frac{\psi_b}{2}\left[\frac{\tilde{B}_{c,t}}{\bar{\tilde{B}}_c}-1\right]^2\right)-I_{c,t}^e\left[1+\frac{\psi_i}{2}\left(\frac{I_{c,t}^e}{I_{c,t-1}^e}-1\right)^2\right]-I_t\left[1+\frac{\psi_i}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2\right]\geq 0.$$

For capitalists, the solution for I_t and $I_{c,t}^e$ is obtained by setting (A19) and (A15) respectively to zero. We also show in Figure A1 that the Euler equation for capitalists (A17) holds with strict inequality, so that capitalists savings are zero. As long as (A17) is strictly negative, capitalists are incentivized to borrow. We limit their borrowing to $\bar{b}^c < 0$.

Figure A2: Workers' Match Surplus in the Steady State and in Response to Shocks



A.1 Equilibrium

The recursive equilibrium in this economy is given by the set of policy functions and prices, such that:

- given prices W_t, P_t, R_t and taxes τ_t, workers' policy functions $[C_t(h), E_t^s(h), I^e(h)_t, B(h)_t]_{t=0}^{\infty}$ solve the workers' problem in (1);
- given prices P_t, R_t, taxes τ_t and dividends div_t, capitalists' policy functions $[C_t, E_t^s, I_t^e, I_t]$ solve the capitalists problem in (1);
- given W_t, firms demand for labor and pricing decisions $N_t(i), P_t(i)$ solve firms' problems (14);
- set of prices W_t, P_t clear the labor and goods markets respectively.
- nominal interest rate R_t is determined by (29), tax rate τ is determined by (28).
- energy price P_t^e follows an AR(1) process and is subject to an exogenous shock ε_e:

$$P_t^e = (P_{t-1}^e)^{\rho_e} e^{\varepsilon_e}. \tag{A23}$$

Appendix B: The Steady-State Solution

We consider a deterministic steady state in which we normalize $\bar{P} = 1$ and divide all the nominal variables by $\bar{P}$. Therefore, we can assume that the relative energy prices are unity in the steady state: $\bar{P}^e = 1$. Below, all nominal variables are transformed into real ones by dividing by $\bar{P} = 1$. In this section, we drop the upper bars from the steady-state notation.

Firms Problem, Output and Labor Market

Given the steady-state values of the share of unemployed workers, U, the solution to the firm's problem and the labor market allocations is straightforward. The steady-state labour supply is given by:

$$N = N(1-\omega(1-\eta)) + U\eta,$$
$$U = 1 - N - \xi,$$
$$N = \frac{\eta(1-\xi)}{\omega(1-\eta)+\eta}. \tag{B1}$$

Denoting the steady-state value of the marginal product of labor $\overline{mpl} \equiv \frac{1-\gamma_k}{1-\rho_o}(K/N)^{\gamma_k}$. From (17) and (18), we express the steady-state real wage:

$$\gamma\frac{1-\rho_o}{\overline{mpl}}\left(w + \kappa/\eta^{\frac{\alpha}{\alpha-1}} - \beta(1-\omega)\kappa/\eta^{\frac{\alpha}{\alpha-1}}\right) + \gamma\rho_o = \gamma - 1, \tag{B2}$$
$$w = \left(\frac{\gamma-1}{\gamma} - \rho_o\right)\frac{\overline{mpl}}{1-\rho_o} - (1-\beta(1-\omega))\kappa/\eta^{\frac{\alpha}{\alpha-1}}. \tag{B3}$$

Workers and Capitalists

The steady-state solution to the model is a function of employed and unemployed workers' abatement capital levels, and employed workers propensity to save. These three variables can be pinned down by the following variables: workers' savings to wealth ratio, share of workers energy expenditure, share of poor HtM energy expenditure in Table 3. We choose these particular variables as there are straightforward empirical counterparts in the Household Finance and Consumption Network (2023), and it is possible to compare our models steady state with the data on households' behavior.

For calibrated values of $\theta^e \equiv \frac{E^r_e}{(E^r_e+C_e)}\frac{(E^r_{uu}+C_{uu})}{E^r_{uu}}$, we guess the steady-state workers' saving rate and their steady-state share of raw energy consumption θ^e_1. Using these guessed values, we find steady-state levels of abatement capital for employed and unemployed workers with $\theta^e_2 \equiv \frac{E^r_{uu}}{(E^r_{uu}+C_{uu})}$:

$$K^e_u = \sqrt{1/\psi_{ab}}\left(\frac{\phi_e}{1-\phi_e}\frac{1-\theta^e_2}{\theta^e_2}\right)^{\frac{0.5}{1-\lambda_e}}, \tag{B4}$$
$$K^e_e = \sqrt{1/\psi_{ab}}\left(\frac{\phi_e}{1-\phi_e}\frac{1-\theta^e_1}{\theta^e_1}\right)^{\frac{0.5}{1-\lambda_e}}. \tag{B5}$$

Given our guess on steady-state workers propensity to save *cmrs*, we obtain the saving decisions of employed workers $\tilde{B}_e$ and their average bond holdings $\tilde{B}'_e$:

$$\tilde{B}_e = \tilde{W}\frac{1-\tau}{\omega(1-\eta)+1/cmrs}, \tag{B6}$$
$$\tilde{B}'_e = (1-\omega(1-\eta))\tilde{B}_e. \tag{B7}$$

In the steady state, capitalists' borrowing limit is equal to workers' savings:

$$\bar{b}^c = -\frac{\tilde{B}_e N}{\xi}. \tag{B8}$$

With the steady-state level of abatement capital and workers savings, we solve for the steady state interest rate $\bar{R}$ using employed workers' consumption Euler equation:

$$\frac{1}{R} \;=\; \beta\left[\omega(1-\eta)\left(\frac{\mathbb{C}_{eu}}{\mathbb{C}_{e}}\right)^{-\mu}\left(\frac{\mathbb{C}_{eu}/C_{eu}}{\mathbb{C}_{e}/C_{e}}\right)^{\frac{1}{\lambda_e}}+(1-\omega(1-\eta))\right]. \tag{B9}$$

Given our solution for $\bar{R}$ and capitalists borrowing limit, we can solve for capitalists' consumption and abatement investment by solving the following system. The first equation is the steady-state version of the abatement capital Euler equation, from which we have expressed capitalists' raw energy consumption. The second is the steady-state relationship between energy and non-energy consumption as in (A9). The last equation is capitalists' budget constraint.

$$E^r_c = 0.5\frac{K^e_c}{\beta}, \tag{B10}$$

$$C_c = \frac{1-\phi_e}{\beta\phi_e K^e_c}\left(\psi_{ab}(K^e_c)^2\right)^{2-\lambda_e}, \tag{B11}$$

$$\delta_e K^e_c + E^r_c + C_c + I - ((1-\tau)div + \bar{b}^c(\bar{R}-1)) = 0. \tag{B12}$$

We further express the energy and non-energy consumption for every agent as a function of their abatement capital.

To verify the initial guess, we utilize the remaining unused equations - resource constraint (27) and the employed workers' abatement capital Euler equation (A2). We compare the resulting steady-state ratios with those from the data as reported in Table 3.

Appendix C: Calibrated Parameters From the Literature

Table C1: Calibrated Parameters: From Ravn and Sterk (2021) and Coenen et al. (2018)

Name	Symbol	Value
Share of capital in production function	γ_k	0.3
Capital depreciation	δ_k	0.025
Elasticity of subst. goods varieties	γ	7
Households' risk aversion	μ	2
Labour market:		
Matching function elasticity	α	0.5
Separation rate	ω	0.02
Vacancy costs	κ	$0.1\bar{w}$
Real wage persistence	γ_w	0.1
Real wage flexibility	ξ	0.0001
Monetary policy parameters:		
Monetary policy persistence	ρ_r	0.93
Other variables:		
Price duration		6 months

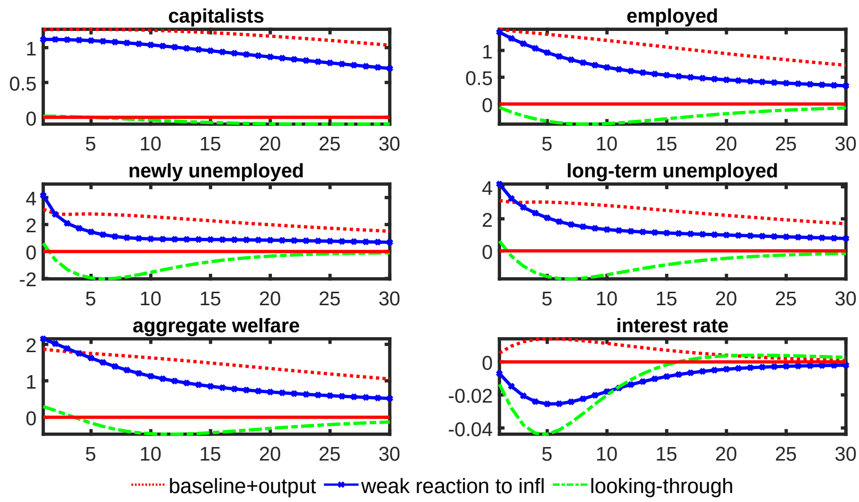
Most of the parameters are from Ravn and Sterk (2021). We set the price duration to be equivalent to a Calvo probability of 0.82 as the estimated posterior mode for price rigidities in the New-Area Wide Model II (see Coenen et al. 2018), the Taylor rule persistence parameter is fixed at 0.93. We set the vacancy costs to be equal to 10% of the steady-state quarterly wage.

Appendix D: Alternative Welfare Estimates

In this subsection we explore the importance of unemployment benefits indexation, wage rigidites and level of household savings. To highlight the role of these channels, we try to use large deviations of the respective parameter values from the version in the text. This complicates the calculations of the Ramsey policy, that is why we focus on the Taylor rule based policies as in Table 4.

With the alternative simulations, the agents' welfare differs from the specification in the text. We are interested in the changes in the policy trade-offs, so we study the differences of welfare relative to the baseline policy rule under each simulation. The differences in welfare under specification in the text are presented in Figure D1.

Figure D1: Policy Responses and Welfare, 1% Energy Price Shock



Note: All responses are reported as percentage points difference relative to the baseline policy. Positive values mean the welfare is larger than under the baseline policy.

D.1 Sticky Unemployment Benefits

In this section, we relax the assumption of fully indexed unemployment benefits. We assume that the unemployment benefits are sticky in nominal terms as in Ravn and Sterk (2021). In particular, the real unemployment benefits follow the following law of motion:

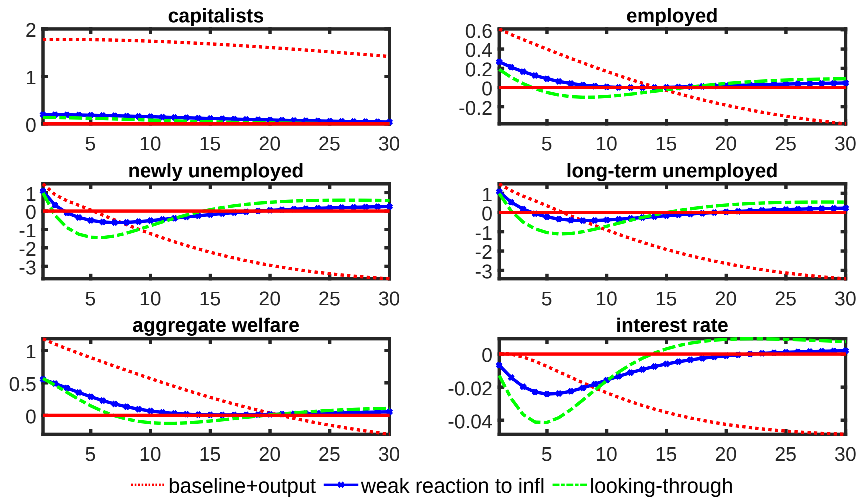
$$W_{\mu,t} = \iota \bar{W}_{\mu} + (1-\iota)\frac{W_{\mu,t-1}}{\Pi_t}, \tag{D1}$$

where ι reflects the degree of nominal stickiness. If $\iota = 1$, the benefits are fixed in real terms, if $\iota = 0$, the benefits are fixed in nominal terms.

To highlight the importance of the indexation, we assume benefits are fixed in nominal terms: $\iota = 0$.

Figure D2 shows the welfare for different types of agents in difference to "baseline Taylor rule". Comparing the results to the full indexation specification in Figure D1, the welfare ranking of the policies is preserved for capitalists and employed workers. But without indexation, there are larger costs of becoming unemployed, larger costs of inflation for unemployed workers, and deeper fall in demand after energy price shock. This explains why there are smaller benefits of under-reacting

Figure D2: Policy Responses and Welfare: No Indexation of Unemployment Benefits, 1% Energy Price Shock



Note: All responses are reported as percentage points difference relative to the baseline policy. Positive values mean the welfare is larger than under the baseline policy.

to inflation with "weak reaction to inflation" policy for workers either employed of unemployed than under full indexation. Policy of output support "baseline+output" is less beneficial for workers either employed or unemployed than under full indexation, but as it promotes stronger employment, its performance is better than for "weak reaction to inflation" policy. For capitalists, the output support is even more beneficial than under full indexation as higher share of employed workers results in stronger demand.

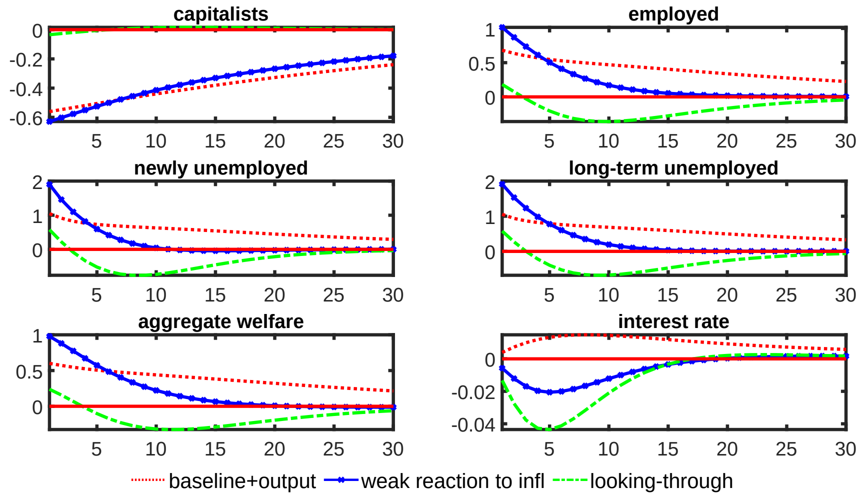
D.2 Flexible Wages

In this section we do the welfare analysis with more flexible wages in an economy with full indexation of unemployment benefits by core inflation. In our model, wage flexibility in (24) is governed by 2 parameters: γ_w which is real wage persistence and χ which is real wage sensitivity to business cycle. In what follows we increase the wage sensitivity to business cycle χ from 0.0001 to 0.1 and decrease γ_w from 0.1 to 0.01. We plot the welfare responses as a difference to the baseline policy conditional on energy price shock as in Figure 5. Figure D3 shows that when the real wages are more flexible, there are smaller welfare differences between the policies. Thus, wage flexibility narrows the policy trade-offs. At the same time the benefits of "weak reaction to inflation" policy now are relatively larger than that of output support as there are smaller labor market frictions. As for the capitalists, their welfare trade-offs become small but reversed. With more flexible wages they loose more with more accommodative policies.

D.3 Larger Steady-State Households Savings

In this section we explore the effects of steady state level of households‘ savings and larger capitalists‘ debt holdings on policy trade-off. We consider a steady of the model with larger workers’ propensity to save and steady state nominal bond holdings as described in Table D1. The comparison between such an economy and the one in the text is not straightforward, as it implies different level of steady state interest rate. Providing workers’ with much larger or lower savings also modifies their incentives and can lead to violations of conditions allowing us to group the agents into

Figure D3: Policy Responses and Welfare: More Flexible Wages, 1% Energy Price Shock



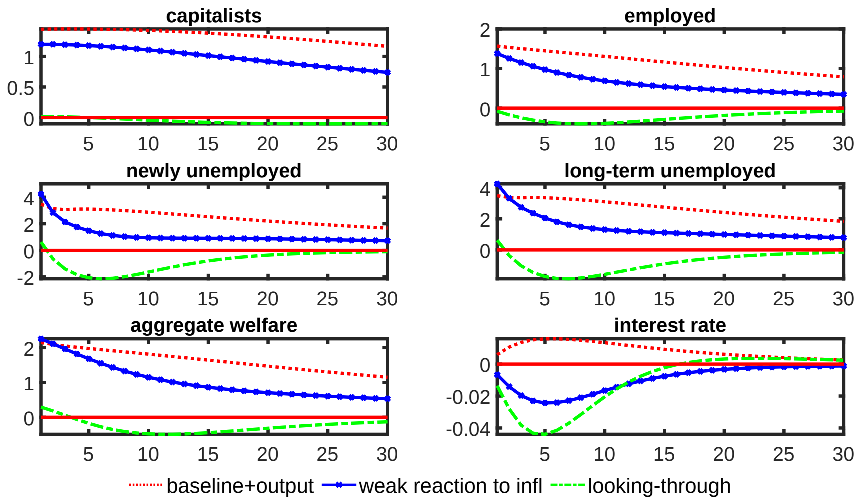
Note: All responses are reported as percentage points difference relative to the baseline policy. Positive values mean the welfare is larger than under the baseline policy.

Table D1: Workers Propensity to Save and Bond Holdings

	Value in the Text	New Value
propensity to save	0.068	0.1
workers individual bond holding	0.055	0.08
interest rate, annualized	1.034	1.06

four groups. That is why we consider a moderate increase in workers savings relative to the scenario in the text. We plot welfare comparison in Figure D4. Comparing the results with Figure D1, there are somewhat larger differences in aggregate welfare between policies than with lower steady state bond and debt holdings. The largest difference is for capitalist and employed workers. While the latter enjoy returns on their savings, the former benefit from stronger demand despite of having larger debt.

Figure D4: Policy Responses and Welfare: Larger Steady State Savings, 1% Energy Price Shock



Note: All responses are reported as percentage points difference relative to the baseline policy. Positive values mean the welfare is larger than under the baseline policy.

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