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ABSTRACT

The effects of energy price increases are heterogeneous between households and firms. Financially constrained poorer households, who spend a larger relative share of their income on energy, are particularly affected. In this analysis, we examine the macroeconomic and welfare effects of energy price shocks in the presence of credit-constrained households that have subsistence-level energy demand. Within a Dynamic Stochastic General Equilibrium (DSGE) model calibrated for the German economy, we compare the performance of different policy measures (transfers and energy subsidies) and different financing schemes (income tax vs. debt). Our results show that credit-constrained households prefer debt over tax financing regardless of the compensation measure due to their difficulty to smooth consumption. On the contrary, rich households tend to prefer tax-financed measures as they increase the labor supply of poor households. From an aggregate perspective, tax-financed measures targeting firms effectively cushion aggregate output losses.

Keywords: energy prices, E-DSGE, fiscal policy, welfare
JEL Codes: E62, E64, H31, H32, Q43, Q52

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1 Introduction

In 2022, Europe faced the most severe energy crisis since the oil price shock in 1973. Due to its historical dependence on energy imports, the continent is particularly adversely affected by the recent surge in fossil energy prices. However, Europe was not only affected by higher fossil resource prices in general, but also specifically by the limited supply of gas. The supply of gas in 2022 was restricted due to the sharp reduction in Russian imports and the scarcity of import capacity for liquefied natural gas (Ruhnau et al., 2023). In this context, policy makers were caught between a rock and a hard place. Due to the limited gas supply in Europe, reducing the absolute levels of fossil resource use is a conflicting target, since both households and the production side are strongly dependent on fossil energy in the short to medium run. A hike in fossil energy prices can cause an economic downturn and impede low-income households in meeting their subsistence energy level, causing what is termed *energy poverty* in public debates.

Across Europe, governments addressed the energy crisis with expansionary fiscal policy. In detail, governments took a wide range of different measures to mitigate the impact of higher energy prices on firms and households. Price and income support measures, both targeted and untargeted, were enacated (see Figure 1). For example, compensation measures included a reduction in energy taxes, transfers to vulnerable households, and regulations of retail or wholesale energy prices. In addition to the compensation packages, governments allocated funds to meet the liquidity needs of utility companies. When considering both sets of policies, the total cost of support measures in Germany amounted to more than 6 percent of GDP.[1]

Due to the mere size of the fossil price hike and the expansion of fiscal policy, it is important to improve our understanding of the macroeconomic and welfare impact of specific policy instruments. From a macroeconomic perspective, energy is an essential input factor, which implies that reductions in energy supply translate into significant output losses. From a welfare-economic perspective, energy is a basic consumption good for consumers, implying that real income and well-being of low-income households fall strongly when energy prices increase.

The contribution of this paper is to analyze this nexus by providing a comprehensive assessment of different fiscal policy measures that address the adverse effects of an estimated energy price shock. A central aspect of our analysis is that we jointly analyze the macroeconomic and the distributional (welfare) impacts of energy price shocks. The policies we consider are transfers to households (both targeted to poor households and paid out to all households) and a variety of energy price subsidy schemes. They differ in their type and target. In detail, the government can choose between untargeted energy price subsidies and price subsidies that specifically target energy prices for households or

[1]There is a large heterogeneity across European countries, but the majority of countries have allocated more than 3 percent of funds (relative to GDP) to protect households from the energy crisis.

firms. For all policies, we also distinguish between tax financing and debt financing.

The setup of our analysis combines a dynamic model that captures important aspects of the energy demand from firms and households with an estimation of the recent fossil energy price shock. We consider different fossil energy dependencies among households, as well as between households and firms. In our setup, poor households spend a larger share of their expenditures on fossil energy due to non-homothetic preferences. We estimate the parameters that govern the energy consumption pattern from German household data. We apply and calibrate our DSGE model to the German economy and provide a quantitative evaluation of policy measures in response to the current energy crisis. Using energy-related data for Germany from 2006-2022, we are able to estimate the volatility of energy prices, as well as the recent price hike in 2022.

In our analysis, we model an energy price shock comparable to the one that hit Germany in early 2022 and consider both the macroeconomic dynamics and the welfare impact on poor and rich households. In this context, we compare the performance of the different compensation packages. When we analyze the macroeconomic impact of the recent price shock in 2022, we find that no policy instrument can prevent a recession. However, policy instruments differ in their impact on output or on the consumption of specific household types. Furthermore, we find that poor and rich households prefer different policy instruments and financing schemes. For poor households, debt financing can help to cope with the energy price shock and increase their ability to smooth consumption. In contrast, rich households prefer tax-financed compensation measures due to their impact on aggregate labor supply. We further show that representing the energy crises through a total factor productivity (TFP) shock in a standard macroeconomic model without explicit energy consumption substantially underestimates the welfare losses of the energy crisis.

This paper relates to several branches of the literature. Our contribution builds on the large macroeconomic literature that analyzes the effects of energy price shocks. Important empirical contributions on the effect of oil price shocks on macroeceonomic aggregates include Hamilton (1983); Barsky and Kilian (2004); Kilian (2008, 2009); Baumeister and Hamilton (2019); Känzig (2021), who analyze the effects of oil price shocks on the US economy. This literature finds that oil price shocks can be an important driver of national and global recessions, justifying concerns about the macroeconomic impact of the energy price crisis sparked by the war in Ukraine. Complementing the empirical literature, a large literature studies energy price shocks in macroeconomic models (e.g. Kim and Loungani (1992), Harrison et al. (2011), Kilian and Vigfusson (2017)). Auclert et al. (2023) study the effect of an energy price shock in an energy-importing economy with heterogeneous agents, as well as the effect of monetary and fiscal policy. In their setup, the only source of heterogeneity between households are discount rates. In particular, they assume homothetic preferences over energy consumption. We complement their analysis by introducing non-homothetic preferences, which we consider to be a key heterogeneity in the context of energy consumption. In our setup, we include a fixed share of borrowing-constrained

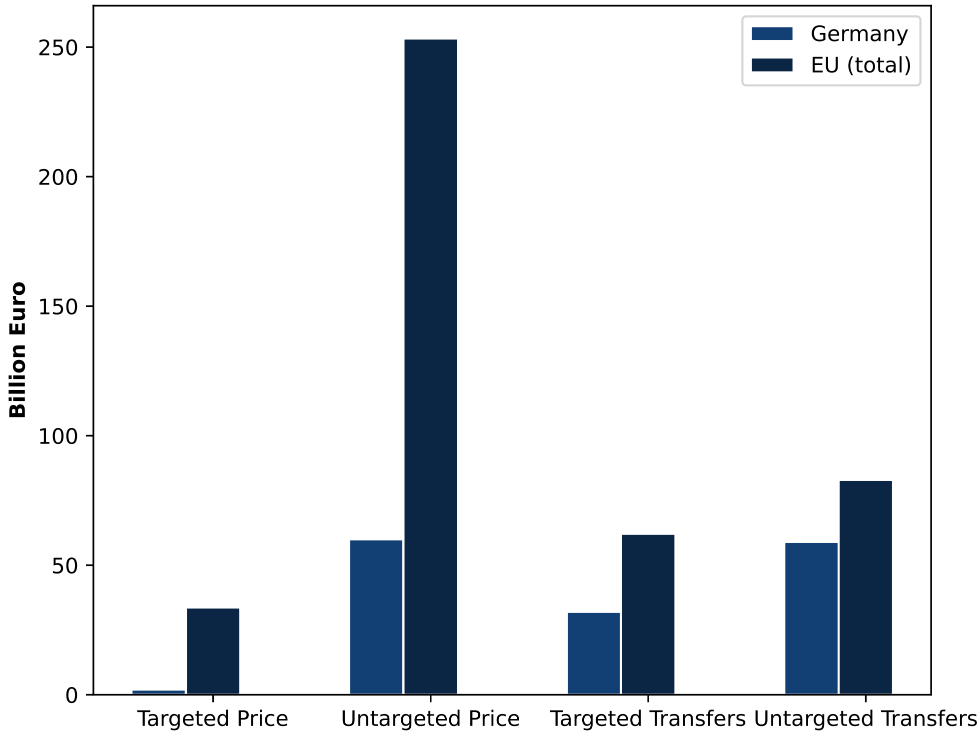

Figure 1: Allocated and earmarked funding to shield households (Sep 2021 - Jan 2023) according to the type of compensation measure, Germany and EU (total). Source: Sgaravatti et al. (2023)

households as in Galí et al. (2007) that spend a greater share of their expenditures on energy.[2] We contribute to this literature by estimating the model energy price shock using 2022 data and calibrating our model and, in particular, the non-homothetic preferences for energy consumption using household data from the Einkommens- und Verbraucherstichprobe (EVS), a German income and expenditure survey. In addition, we analyze a variety of fiscal policy measures including price subsidies that were discussed and used in numerous countries as a reaction to the crisis and their financing schemes.

Furthermore, we contribute to the recent literature that explores the macroeconomic impact of the current energy crisis (Turco et al. (2022); Liadze et al. (2022)), as well as its distributive impact (Bauermann et al., 2022). Bachmann et al. (2022) combine both aspects and focus on the adjustment of the German economy after a potential gas embargo in the absence of relief measures. An overview of the effect of the energy crisis on European countries, including a sectoral breakdown and estimates of the effects along the income distribution, is given by Ari et al. (2022) and complemented and updated by Arregui et al. (2022). They show how the energy price shock has regressive effects on consumers' purchasing power and nicely illustrate the characteristics of the relief measures announced by the national governments as well as their fiscal impact and current debt

[2] A similar setup with a fixed share of constrained households has been used to analyze the fiscal response of the German COVID-19 fiscal stimulus package (Hinterlang et al., 2023). Eydam and Diluiso (2022) also use an extension in the context of climate policy and study the double dividend hypothesis.

levels. Closest to our paper is a recent contribution by Pieroni (2023), who uses a heterogeneous agent New Keynesian model to analyze the consequences of a significant drop in energy supply for Germany and Italy. The results show that low-income households bear a disproportionately higher share of the cost. Although fiscal policy can mitigate these effects in the analysis, the only fiscal policy instrument is a transfer scheme targeted at the poorest households. We complement this analysis by considering different fiscal policy measures enacted by EU governments during the recent crisis. Thereby, we are able to take on a welfare perspective on the household level while considering aggregate dynamics and the impact of public finances.

The remainder of the paper is structured as follows. Section 2 describes our model environment. Section 3 discusses the calibration, including the estimation of the preference parameters and the energy price shock. Section 4 reports the results of the comparison of compensation policies. Section 5 concludes.

2 Model

We extend a standard real business cycle (RBC) model in various dimensions to study the implications of energy price increases for economic welfare and assess the potential scope of fiscal policies. As is common in the literature, we assume that energy is used as an input factor in production (cf. Bretschger and Schaefer (2017); Pieroni (2023)). Additionally, we explicitly model household energy consumption through a constant elasticity of substitution (CES) demand structure. Furthermore, we take into account the specific nature of energy consumption and incorporate a subsistence level through Stone-Geary preferences (Geary, 1950; Stone, 1954). As in Galí et al. (2007), we also distinguish between financially constrained and unconstrained households. Therefore, households differ in their ability to smooth consumption when energy prices increase.

2.1 Households

There exists a continuum of households $I \in [0,1]$. We assume that a fraction λ of households do not have access to financial markets. We refer to this type of household as non-Ricardian households. The fraction of Ricardian households, which are financially unconstrained, is $(1-\lambda)$. Both types of households seek to maximize their life-time utility over consumption c_t, work time h_t, and energy consumption $c_{e,t}$. The objective function is the same across households and is given by:

$$W\left((c_t, c_{e,t}, h_t)_{t=1,2,\ldots}\right) = \sum_{t=0}^{\infty} \beta^t u(c_t, c_{e,t}, h_t) \quad (1)$$

where β is a time discount factor and the period utility is given by:

$$u(c_t, c_{e,t}, h_t) = \frac{\left([\eta c_t^{-\rho_H} + (1-\eta)(c_{e,t} - \bar{c}_e)^{-\rho_H}]^{-1/\rho_H}\right)^{(1-\rho)}}{1-\rho} - \phi \frac{h_t^{1+\xi}}{1+\xi}, \quad (2)$$

where $\bar{c}_e$ denotes the subsistence level of energy consumption, ρ_H denotes the elasticity of substitution between goods consumption and energy consumption, and η denotes the share of goods consumption in the consumption aggregate. Furthermore, ρ is the inverse of the intertemporal elasiticity of substitution, ϕ captures the disutility from working and ξ denotes the inverse Frisch elasticity. The assumption of Stone-Geary preferences over energy consumption implies that households have decreasing expenditure shares in energy consumption. However, the optimal allocation across goods is static. Consequently, households can optimize intertemporally total consumption expenditures $x_t = c_t + p_{h,t}c_{e,t}$. Note that the price of consumption goods serves as a numeraire and $p_{h,t}$ denotes the price households pay for energy consumption. Furthermore, we assume that investment is subject to convex adjustment costs, which are governed by the parameter κ. In this framework, Ricardian households maximize discounted life-time utility subject to the following constraints:

$$x_{R,t} + \frac{(k_{t+1} + b_{t+1})}{(1-\lambda)} = \left(w_t \tilde{h}_{R,t} + z_t \frac{k_t}{(1-\lambda)} \right) (1-\tau_t) + \left((1-\delta)k_{t-1} + R_t \frac{b_t}{(1-\lambda)} \right) + T_{R,t} \quad (3)$$

$$k_{t+1} = \left[1 - \frac{\kappa}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right] i_t + (1-\delta)k_t \quad (4)$$

where i_t denotes investment into physical capital k_t and b_t denotes the holdings of government bonds. Households earn wages w_t and receive pre-tax returns on capital z_t. Effective hours $\tilde{h}_{R,t}$ are obtained by multiplying the hours worked $h_{R,t}$ with a productivity parameter $\theta_{R,t}$. Together with its non-Ricardian counterpart $\theta_{NR,t}$, it determines the difference in labor income between the two types of households. Labor income $w_t\tilde{h}_{R,t}$ and capital income $z_t k_t$ are subject to income taxation τ_t. $R_t = (1-\tau_t)z_t$ is the interest borne by government bonds. $T_{R,t}$ denote government transfers to the Ricardian household. The solution to the intertemporal optimization problem yields the following first-order conditions for consumption, labor supply, capital, and investment:

$$\mu_t = M_t q_t (x_{R,t} q_t - p_{c,t}\bar{c}_e(1-q_t))^{-\rho} \quad (5)$$

$$\phi_R h_{R,t}^{\xi} = (1-\tau_t) w_t \theta_R \mu_t \quad (6)$$

$$p_{k,t} = \beta \frac{\mu_{t+1}}{\mu_t} ((1-\tau_{t+1})z_{t+1} + (1-\delta)p_{k,t+1}) \quad (7)$$

$$1 = p_{k,t} \left(1 - \frac{\kappa}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 - \kappa \left(\frac{i_t}{i_{t-1}} - 1 \right) \frac{i_t}{i_{t-1}} \right) + \beta \frac{\mu_{t+1}}{\mu_t} p_{k,t+1} \kappa \left(\frac{i_{t+1}}{i_t} - 1 \right)^2 \quad (8)$$

where μ_t denotes the marginal utility of consumption, with auxiliary variables $M_t \equiv \left(\eta + (1-\eta)^{\frac{1}{1+\rho_H}} \eta^{\frac{\rho_H}{1+\rho_H}} p_{h,t}^{\frac{\rho_H}{1+\rho_H}} \right)^{-\frac{1}{\rho_H}}$ and $q_t \equiv (1-p_{h,t}) \left(\left(\frac{\eta p_{h,t}}{(1-\eta)} \right)^{\frac{1}{1+\rho_H}} p_{h,t} \right)^{-1}$. Furthermore, $p_{k,t}$ denotes the price of capital relative to consumption. Non-Ricardian households face the same objective function as Ricardian households, but have no access to financial markets and thus must rely on their labor supply to smooth consumption. The budget constraint of non-Ricardian households reads:

$$x_{NR,t} = (1-\tau_t) w_t \tilde{h}_{NR,t} + T_{NR,t} \quad (9)$$

where effective hours are given by $\tilde{h}_{NR,t} \equiv \theta_{NR}\, h_{NR,t}$. The first-order condition for labor supply of Non-Ricardian households is given by:

$$\phi_{NR} h_{NR,t}^{\xi} = (1-\tau_t) w_t M_t q_t (x_{NR,t} q_t - p_e \bar{c}_e (1-q_t))^{-\rho}. \quad (10)$$

2.2 Aggregation

Aggregate consumption x_t, aggregate goods consumption c_t, aggregate energy consumption $c_{e,t}$, and effective labor supply of households h_t are weighted averages of the household specific consumption variables:

$$x_t = \lambda x_{NR,t} + (1-\lambda)x_{R,t} \tag{11}$$

$$c_t = \lambda c_{NR,t} + (1-\lambda)c_{R,t} \tag{12}$$

$$c_{e,t} = \lambda c_{e,NR,t} + (1-\lambda)c_{e,R,t} \tag{13}$$

$$h_t = \lambda\theta_{NR}h_{NR,t} + (1-\lambda)\theta_R h_{R,t}. \tag{14}$$

2.3 Firms

Firms combine effective labor h_t, physical capital k_t and fossil energy e_t to produce final consumption goods. Production takes place according to the following production function:

$$y_t = h_t^{1-\alpha-\gamma}\left(\frac{\alpha}{\alpha+\gamma}k_t^{-\rho_f} + \frac{\gamma}{\alpha+\gamma}e_t^{-\rho_f}\right)^{-\frac{\alpha+\gamma}{\rho_f}}, \tag{15}$$

where α denotes the production elasticity of physical capital, γ denotes the production elasticity of energy and ρ_f denotes the elasticity of substitution between physical capital and energy. Markets are competitive and production factors are paid according to their marginal product. The profit maximisation of firms yields the following wage and real interest rate:

$$w_t = (1-\alpha-\gamma)y_t/h_t \tag{16}$$

$$z_t = \alpha k_t^{(-1-\rho_f)}h_t^{(1-\alpha-\gamma)}\left(\frac{\alpha}{\alpha+\gamma}k_t^{-\rho_f} + \frac{\gamma}{\alpha+\gamma}e_t^{-\rho_f}\right)^{-\frac{\alpha+\gamma}{\rho_f}-1}. \tag{17}$$

Firms buy fossil energy at the price $p_{f,t}$. The energy demand of firms is then given by:

$$p_{f,t} = \gamma e_t^{(-1-\rho_f)}h_t^{(1-\alpha-\gamma)}\left(\frac{\alpha}{\alpha+\gamma}k_t^{-\rho_f} + \frac{\gamma}{\alpha+\gamma}e_t^{-\rho_f}\right)^{-\frac{\alpha+\gamma}{\rho_f}-1}. \tag{18}$$

We assume that fossil energy is bought on international markets at the exogenous price p_t. However, fossil energy prices are volatile due to price shocks. The persistence and standard deviation of these shocks are estimated from the data. Specifically, we model the price of fossil energy as being subject to stochastic innovations:

$$p_t = (1-\rho_p)\bar{p} + \rho_p p_{t-1} + \epsilon_{p,t}, \tag{19}$$

where $\bar{p}$ denotes the steady state price level, ρ_p denotes the autocorrelation of the energy price and ϵ denotes stochastic innovations. Furthermore, the final price of fossil energy paid by households and firms can differ due to targeted price subsidies sub_t^i paid by the government:

$$p_{h,t} = p_t - sub_t^h \tag{20}$$

$$p_{f,t} = p_t - sub_t^f. \tag{21}$$

In absence of energy price subsidies households and firms pay the same price for fossil energy, i.e. $p_t = p_{h,t} = p_{f,t}$. The total energy consumption of the economy is given by $m_t = c_{e,t} + e_t$.

2.4 Government

In the model, the government issues risk-free bonds and levies income taxes to finance its expenditures. The government budget constraint is given by:

$$b_{t+1} = \bar{g} + g_t - \tau_t(w_t h_t + z_t k_t) + R_t b_t, \tag{22}$$

where $\bar{g}$ denotes the exogenous level of steady state government expenditures and g_t denotes the time-variant government expenditures that are either used for transfers or to finance energy price subsidies . To ensure stationarity of the government budget, we employ the following fiscal rule:

$$\tau_t = \bar{\tau} + \Phi(b_t - \bar{b}), \tag{23}$$

where $\bar{b}$ denotes the steady state debt target and Φ regulates how strong taxes adjust in response to deviations of debt from target.

In the following, we assume that the size of the financial support g_t is dynamic and proportional to the increase in energy prices associated with the average energy consumption of households $\bar{x}$, i.e. $g_t = \omega(p_t - \bar{p})\bar{x}$. The parameter ω determines how much of the direct burden of fluctuating energy prices is covered by the compensation measures. We rely on the average ex-ante energy consumption for two reasons. First, since this is a fiscal policy rule, the government cannot anticipate the dynamic behavioral adjustment of households. Furthermore, the adjustment of energy consumption depends on the specific fiscal policy instrument. In the competitive equilibrium of the model, the budget constraints of Ricardian households (3), the budget constraint of Non-Ricardian households (9), and the government budget (22) must hold.

3 Calibration

The aim of the calibration is two-fold. First, our aim is to reproduce the essential characteristics of the increase in energy prices and the compensation measures implemented in Germany. For this reason, estimate the energy price shock using data from 2006-2022. Furthermore, we calibrate the fiscal burden of the compensation measures (in percent of GDP) to match the fiscal spending of Germany since the beginning of the energy crisis. The second objective is to match key characteristics of the German economy and to replicate consumption patterns from household data. For example, our objective is to match the average energy expenditures of households in Germany. Table 1 describes how the model matches the empirically observed ratios of consumption as a fraction of GDP c/y, investment as a fraction of GDP i/y, energy expenditures of Ricardian and

Non-Ricardian households $\frac{p_h c_{e,R}}{y_R}$ and $\frac{p_h c_{e,NR}}{y_{NR}}$ in steady state. We set the share of non-Ricardian households equal to the share of German households who do not receive any income from capital-related sources. Table 2 summarizes the calibration.

3.1 Estimation of Energy Price Shock

In order to specify the properties of the energy price shock, we construct an energy price index for the German economy based on data from BMWI (2022) and the World Bank (2022). For the consumption price index, we rely on data from the Federal Statistical Office of Germany (Destatis 2022). In the construction of the index, we use quarterly import commodity prices on oil, natural gas, and hard coal, weighted by their annual energy consumption shares.[3] To isolate the cyclical component in energy price movements, we apply HP-Filter to the logarithms of the quarterly price data. As common in the literature, we estimate the shock process using ordinary least squares (OLS). The estimation results yield $\rho_p = 0.88$ and $\sigma_p = 0.17$, both coefficients are significantly different from zero at the 1 percent level. Figure 2 depicts the cyclical deviations of the energy price index for

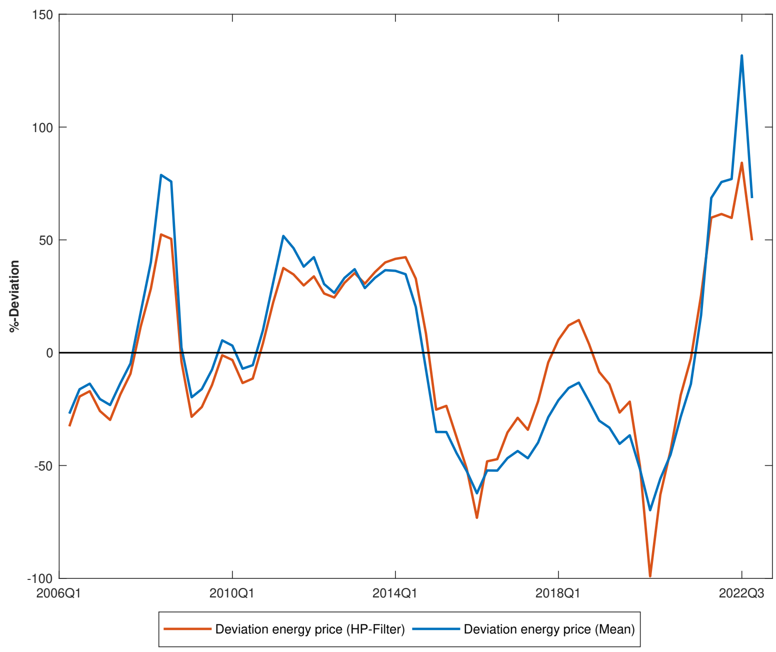

Figure 2: Energy price dynamics for Germany 2006Q1-2022Q4 based on quarterly data. The red line shows the cyclical deviations of the energy price index from trend extracted via HP-Filter. The blue line shows deviations of the energy price from the average energy price.

the sample period. Between 2006 and 2022, volatility in energy prices has increased. The increase in volatility appears to be especially pronounced since the start of the pandemic in 2020. Starting from the lowest observation during the Covid-19 pandemic, the recent

[3]The energy consumption shares are calculated relative to their energy-equivalent amounts, i.e. in petajoules per year.

price increase is the largest fossil energy price hike in the entire sample. As can be inferred from the blue line, energy prices in 2022 increased by about 130 percent compared to the average energy price during the sample period. In particular, the sample includes changes in energy imports and energy use during 2022. Thus, substitution across fossil resource types (natural gas, oil, hard coal) and the change in import shares in reaction to the energy price increase are taken into account in the estimation of the shock. Therefore, the modeled energy price shock is the increase in energy prices net of the fuel substitution effects that took place on the production side.

3.2 Calibration of Non-homothetic Preference Parameters

We continue with the parameters that govern household preferences. To estimate these parameters, we rely on German household data, namely the Einkommens- und Verbraucherstichprobe (EVS). The EVS is a representative household survey for Germany in which around 80,000 households are interviewed every five years. In detail, fossil energy expenditures are reported for several activities, such as heating or transport. The survey includes a high resolution of consumption expenditures. However, because we simplify the income and wealth distribution, the levels of total consumption expenditures will not reflect the entire distribution from the household data. Instead, our model can replicate how households optimally allocate consumption between the two goods at a given level of total consumption expenditure. Non-homothetic preferences imply that Engel curves are nonlinear. The slope of the Engel curves depends on the specification and parameterization of preferences. With our specification of the utility function, a CES structure, three parameters are relevant for the non-linearity: η, ρ_H, and the subsistence level of energy consumption $\bar{c}_e$. For the estimation, we proceed as follows. First, we derive the demand function for energy for a given expenditure level. Through this static partial equilibrium derivation, we can express how households optimally split up total consumption expenditures x_t between energy and non-energy consumption, depending on the level of subsistence energy consumption $\bar{c}_e$. For both Ricardian and non-Ricardian households, we can express the individual demand for energy as:

$$c_{e,t} = \frac{x_t + \tilde{p}_{h,t} a_t \bar{c}_e}{p_{h,t} + \tilde{p}_{h,t} a_t} \tag{24}$$

where $\tilde{p}_{h,t} \equiv (p_{h,t})^{1/(1+\rho_H)}$ and $a_t \equiv \left(\frac{\eta}{1-\eta}\right)^{1/(1+\rho_H)}$. Second, we derive a regression equation from the model energy demand. In more detail, we multiply both sides of equation (24) with the household price for energy $p_{h,t}$ and the euro value of the numeraire good p^{euro}. Furthermore, we must take into account that the EVS data measures annual expenditures, but our model is calibrated to quarterly time steps. We simplify this step by assuming that total expenditures and energy expenditures are constant throughout the year, and therefore convert quarterly expenditures to annual expenditures by a factor of 4. We thus obtain a Euro-valued regression equation of yearly energy expenditures on total expenditures of the form:

$$expy_{i,t}^{energy} = \beta_0 + \beta_1\, expy_{i,t}^{total} + \epsilon_{i,t} \tag{25}$$

that can be related to Equation (24) through the relationships between data points and model variables energy expenditures $expy_{i,t}^{energy} \equiv 4 \cdot p^{euro}\, p_{h,t,}\, c_{e,t}$ and total expenditures $expy_{i,t}^{total} \equiv 4 \cdot p^{euro}\, p_{h,t}\, x_t$ as measured in the EVS. The regression coefficients correspond to $\beta_0 \equiv 4 \cdot p^{euro} \frac{p_{h,t}\, \tilde{p}_{h,t}\, a_t\, \bar{c}_e}{p_{h,t}+\tilde{p}_{h,t}\, a_t}$ as well as $\beta_1 \equiv \frac{1}{p_{h,t}+\tilde{p}_{h,t}\, a_t}$. Taking household-level energy expenditure and total expenditure data from the EVS dataset, we estimate coefficient values of $\beta_0 = 1684.7$ and $\beta_1 = 0.041$ with ordinary least squares. Third, we use the expression $\beta_1 \equiv \frac{1}{p_{h,t}+\tilde{p}_{h,t}\, a_t}$ to derive the following expression, plugging in steady-state household energy prices p_h^*:

$$a_t = \left(\frac{\eta}{1-\eta}\right)^{1/(1+\rho_H)} = \frac{(1-\beta_1)}{\beta_1}\, (p_h^*)^{\frac{\rho_H}{1+\rho_H}} \tag{26}$$

Assuming a steady state household energy price of $p_h^* = 1$, Equation (26) gives us an expression with one degree of freedom between η and ρ_H based on the estimate for β_1. Furthermore, we can also derive an expression for $\bar{c}_e$ depending on the same three parameters and the Euro price of the numeraire good p^{euro} from Equation the correspondence between β_0 and the model variables described above:

$$\bar{c}_e = \frac{\beta_0\, (p_h^* + \tilde{p}_h^*\, a_t)}{4 \cdot p^{euro}\, p_h^*\, \tilde{p}_h^*\, a_t} \tag{27}$$

To match the average energy expenditure shares in the EVS dataset, i.e. 11% for Ricardian and 14% for non-Ricardian households, we set $\eta = 0.995$. From this, we obtain $\rho_H = 1.4$ which is equivalent to an elasticity of substitution between the energy good and the consumption good of $\sigma^{(c,c_e)} = 0.59$. We further set $\bar{c}_e = 0.035$ to obtain energy expenditure shares of 11.38% for Ricardian households and 16% for non-Ricardian households. What does achieving our calibration targets imply for the rest of the model variables? Our calibration implies a Euro price of the numeraire good of $p^{euro} = 12,548.04$ Euro and consequently a steady-state per capita GDP of about 9000 Euro per quarter. This roughly matches the annual German GDP per capita from 2017-2022 of 40,000 Euro. Furthermore, we obtain a ratio of total energy consumption expenditure to subsistence energy consumption level $\bar{c}_e$ in steady state of 1.29 and 1.5 for non-Ricardians and Ricardians, respectively. In other words, the average household belonging to the bottom three (top seven) deciles of the income distribution in Germany can reduce its energy consumption by about 22% (33%) before reaching its subsistence level. This, in turn, is consistent with the goals of the German federal institutions, which have declared an energy reduction target of 20% for households. At the same time, it highlights how parts of the population would have been pushed very close to their subsistence energy consumption level in order to achieve this target.

3.3 Other Calibration

A range of parameters is adopted from the relevant macroeconomic literature focusing on Germany. Additionally, we calibrate the model to match key variables, such as hours

	c/y	i/y	$\frac{p_h c_{e,R}}{y_R}$	$\frac{p_h c_{e,NR}}{y_{NR}}$
Model	57.67	19.8	11.38	16
Data	53.00	21.00	11.00	14.00

Table 1: Model fit; $\sigma_f = 0.99$, $\eta = 0.995$, $\sigma_h = 0.59$, $c_e = 0.035$

worked and the aggregate consumption-to-output ratio. When it comes to the parameters that govern the labor supply of households, we take the inverse Frisch elasticity parameter ξ from Drygalla et al. (2020) and calibrate the labor disutility parameters ϕ_R and ϕ_{NR} for Ricardian and non-Ricardian households to match the value of hours worked of $h_{R,t} = h_{NR,t} = 1/3$. Using the average income of the top 73 % (Ricardian) versus bottom 27% (non-Ricardian) of the income distribution in the EVS, we set the earning of the Ricardians to be 48% higher than the earnings of the non-Ricardians in steady state ($\theta_R/\theta_{NR} = 1.48$). Productivity parameters are then normalized to $\theta_R = 1.096$ and $\theta_{NR} = 0.7405$ to obtain a steady state value of aggregated effective hours $h_{SS} = 0.33$. The household parameters that govern the households' interperiod preferences, i.e. the discount factor β, the inverse of the intertemporal elasticity of substitution ρ, and the investment adjustment cost κ are taken from Drygalla et al. (2020). The share of non-Ricardian households $\lambda = 0.27$ is again calculated from the EVS data. In detail, we calculate λ from the data as the share of households who do not receive income from any capital-related source. The value of λ is in line with previous estimates for the case of Germany (Grabka and Halbmeier, 2019).

Finally, we choose the parameters of the production function as follows. The output elasticity of capital and the capital depreciation rate are set to values that are standard in the literature, $\alpha = 0.3$ and $\delta = 0.025$ respectively. This implies an annual depreciation rate of 10 percent, which is a common value in the literature. Furthermore, the choice of α is consistent with Drygalla et al. (2020) and matches the average capital share in Germany between 1991–2021.[4] The elasticity of substitution between capital and energy σ_f is taken from van der Werf (2008).

We estimate the output elasticity of fossil energy based on the energy expenditures of the German industrial sector. For the estimation of γ, we extend the energy data set from the estimation of the fossil energy price shock to include energy from non-fossil sources. For the price of the non-fossil energy sources, we use data on industrial energy prices from the Federal Statistical Office of Germany from 2006 to the end of 2022. Based on our computations, γ is set to 0.03. Lastly, in our policy comparison, we set the fiscal rule parameter $\Phi = 0.05$ in tax financing scenarios (see Equation (23)). This value ensures that policy measures are fully financed out of tax increases. On the contrary, in debt financing scenarios, we set $\Phi = 999$ to ensure that spending is fully financed through increases in government debt.

[4]According to annual data used by the German Ministry of Finance (BMWF) and published by the Federal Statistical Office, the average labor share, defined as $(1-\alpha)$, is about 0.7 between 1991 and 2021.

Parameter	Value	Description	Target/Source
β	0.995	Discount factor	Drygalla et al. (2020)
η	0.995	CES share	Energy expenditures (EVS)
$\bar{c}_e$	0.035	Subsistence level energy consumption	Energy expenditures (EVS)
ρ	1.5226	Inverse intertemp. EOS	Drygalla et al. (2020)
α	0.30	Output elasticity capital	BMWF data
δ	0.025	Depreciation rate	Annual depreciation of 10%
λ	0.27	Share of Non-Ricardian households	EVS data
σ_f	0.99	Elasticity of substitution (Firms)	Van der Werf, 2008
ρ_f	$\frac{1}{\sigma_f} - 1$		
σ_h	0.596	Elasticity of substitution (Households)	EVS data
ρ_h	$\frac{1}{\sigma_h} - 1$		
γ	0.03	Output elasticity energy (fossil)	BMWI, Destatis and World Bank data
ξ	1.6732	Inverse Frisch elasticity	Drygalla et al. (2020)
$\phi_{L,NR}$	87.9	Labor disutility Non-Ricardian	$h = 1/3$
$\phi_{L,R}$	56.7	Labor disutility Ricardian	$h = 1/3$
θ_R/θ_{NR}	1.48	Productivity ratio Ricardian vs. Non-Ricardian	EVS data
κ	3.9065	Investment Adj. Costs	Drygalla et al. (2020)
ρ_p	0.84	Auto correlation price shock	BMWI and World Bank data
σ_p	0.16	Standard deviation price shock	BMWI and World Bank data

Table 2: Model Parameters

4 Quantitative Analysis

In this section, we aim to quantitatively assess the different compensation measures introduced to mitigate the adverse effects of an unexpected energy price increase of the magnitude observed in Germany in 2022. Since the beginning of 2020 fossil energy prices in Germany have more than doubled (see Figure 2). The increase in 2022 followed after a period of low fossil energy prices due to the COVID pandemic and the associated drop in production and energy demand. In the recent past, fluctuations in energy prices have been mainly driven by oil prices. Gas prices in Germany were very stable at a low level. Coal prices fluctuated, but less than oil prices (Blanz et al., 2022). In contrast to the frequently observed fluctuations in energy prices, the recently observed increase in energy prices in Germany was extraordinarily large. Plausibly, neither households nor firms anticipated such a marked increase in energy prices. Hence, in the following computations, we treat this shock as an unexpected event and abstract from the effects of uncertainty on aggregate dynamics. Specifically, we assume that the economy is initially in steady state and in period $t = 1$ economic agents are confronted with an increase of energy prices that lasts for one year and peaks at 130 percent, in accordance with the dynamics depicted in 2. Subsequently, energy prices start to gradually decline.

Fiscal policy can address the adverse effects of energy price shocks through a variety of instruments. In 2022, Germany and other European countries introduced a wide range of compensation measures to address the energy price hike to which they faced (see figure 1).[5] These measures included price support through an adjustment of energy taxes or regulation of retail prices. Furthermore, various income-related support measures were introduced, such as lump-sum payments for vulnerable households (Sgaravatti et al., 2023). Our analysis consists of a graphical comparison of short- to medium-run aggregate dynamics and an assessment of the general welfare implications associated with different policies. Policy scenarios differ only with respect to their type and target of policy support. We distinguish between price subsidies, which seek to dampen energy price increases for consumers and firms, and direct transfers to households. We ensure that all scenarios entail an equal quarterly fiscal burden. Thereby, we provide a consistent assessment of policy instruments that are comparable in their fiscal size.

On the demand side, we examine both direct transfers and price subsidies for households. Due to distributional concerns and a possible increase in energy poverty, the government may wish to target low-income households that spend a larger share of their income on energy. Therefore, we distinguish between equal per capita transfers, where the total transfers are $T_t = \lambda T_{NR,t} + (1 - \lambda)T_{R,t}$ and transfers that target only non-Ricardian households, where the total transfers are $T_t = T_{NR,t}$. Moreover, we compare both transfer schemes with subsidies that lower the price of energy for consumers $p_{h,t} = p_t - sub_t^h$.

On the supply side, we consider price subsidies instead of income support measures. Due to the ownership structure that is common in the DSGE literature, it would be difficult to distinguish transfers to firms from transfers to households. Thus, the main policy instrument we consider is an energy price subsidy for firms. Firms buy fossil energy at international prices and use it as a production input. In the absence of policy interventions, the energy price that firms and households pay is equal, that is, $p_{f,t} = p_{h,t} = p_t$. A direct fiscal intervention of the government to stabilize energy use is an energy price subsidy that reduces the price that firms pay $p_{f,t} = p_t - sub_t^f$. Lastly, we also consider untargeted energy price subsidies, where energy prices for households and firms are reduced by the

[5]Note that the categories used by Sgaravatti et al. (2023) do not perfectly coincide with our policy measures. For example, their "Transfer" categories also include transfers from governments to firms. In Germany, these included inter alia grants for energy-intensive companies and costs associated with creating and dissolving gas reserves.

same amount.

As the aim of the exercise is to isolate the impact of specific policy instruments, we keep the cumulative fiscal burden constant across scenarios. In our main specification, we consider compensation packages that match the size of German relief measures. [6] The fiscal burden of the transfer scenarios acts as a reference point for the subsidy scenarios. The fiscal burden of energy price subsidies depends on the energy consumption, since the subsidy is paid per unit of energy. Therefore, we ensure that the fiscal burden of subsidies, $sub_t^f e_t$ for firm subsidies and $sub_t^h c_{e,t}$ for household subsidies, matches the cumulative financial support by the government from the transfer scenarios. Furthermore, we explicitly consider how compensation measures are financed. In detail, the government can finance the expansionary fiscal policy either through an increase in distortionary taxes or an increase in public debt. This holds for all policy instruments regardless of their type or target.

The benchmark of the present analysis is the case where the unexpected energy price shock hits the economy but no compensation policy is enacted. As preferences are non-homothetic, the same increase in energy prices affects households differently (Muellbauer, 1974). Non-Ricardian households are more strongly affected by higher energy prices because they spend a larger share of their expenditures on energy. Additionally, these poorer households have only limited possibilities to smooth their consumption due to their lack of savings. Therefore, the welfare loss under the no-policy benchmark is larger for non-Ricardian households than for Ricardian households.

4.1 Macroeconomic Dynamics

We start by analyzing the reaction of aggregate variables to the energy price shock before turning to household-level variables. Figure 3 summarizes the responses to the energy price shock for the transfer scenarios. On the contrary, Figure 4 describes the responses to the same shock for the subsidy scenarios.[7]

In all scenarios, the increase in fossil energy prices causes an economic downturn. While all compensation measures cannot prevent a recession, they differ in their impact on output. Energy price subsidies for firms lead to the smallest decline in output.[8] In this case, the recession is comparatively mild and the decline in output is smaller than in the no-policy case. In all other cases, the shock leads to a significant drop in output between

[6]According to Sgaravatti et al. (2023), the total volume of German relief measures amounts to 249.37 billion Euro. Based on a GDP figure of 3,876.8 billion Euro in 2022 (current prices) as reported by the German Federal Statistical Office, the relief measures amount to 6.45% of the German GDP in 2022.

[7]The results for the untargeted price subsidies can be found in the appendix B.

[8]It is important to emphasize that the present model does not consider the overall effect of energy price subsidies on European energy prices. To the extent that energy price subsidies reduce energy savings, this may affect European energy prices. Appendix A.1 provides some calculations on these effects.

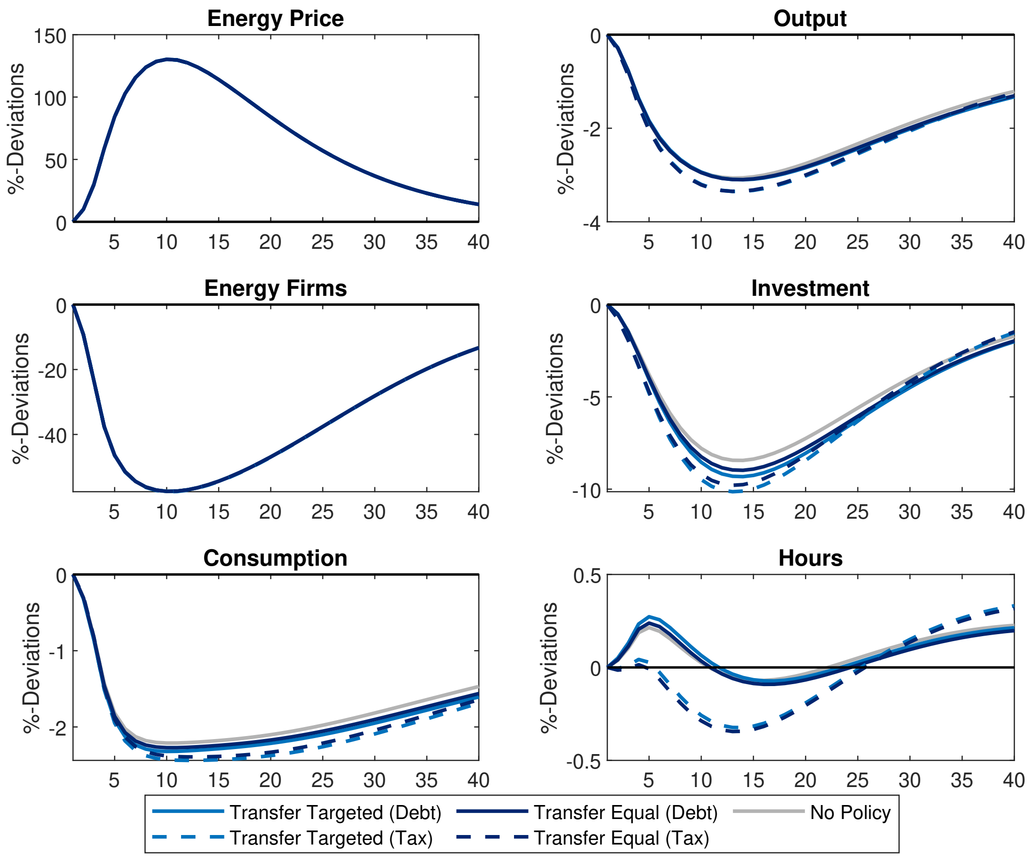

Figure 3: Unexpected increase in energy prices, transfers, macroeconomic variables. Quarterly time steps.

3 and 3.5 percent, similar to the no-policy benchmark. Intuitively, during the economic downturn, aggregate consumption falls and mimics the response of economic output to the energy price shock.

In line with the decline in output and consumption, the rise in energy prices leads to a drastic decline in investment activity. This decline in investment is remarkable given the presence of adjustment costs. However, the decline in investment activity differs between instruments. Due to their heterogeneous impacts on households and firms, compensation measures differ in their ability to stabilize investments. Energy price subsidies for firms affect investment from the production side as they increase the demand for capital. In contrast, demand-side compensation measures, such as transfers or price subsidies for households, affect investments by supporting Ricardian households, the savers in our setup. Even if firm price subsidies perform slightly better than transfers and household subsidies, neither instrument is able to fully stabilize investments.

The energy price shock severely affects the energy demand in the economy. Reducing aggregate energy use was an important target for policy makers in the energy crisis. Total energy savings are predominantly affected by the energy demand of firms, which is in line

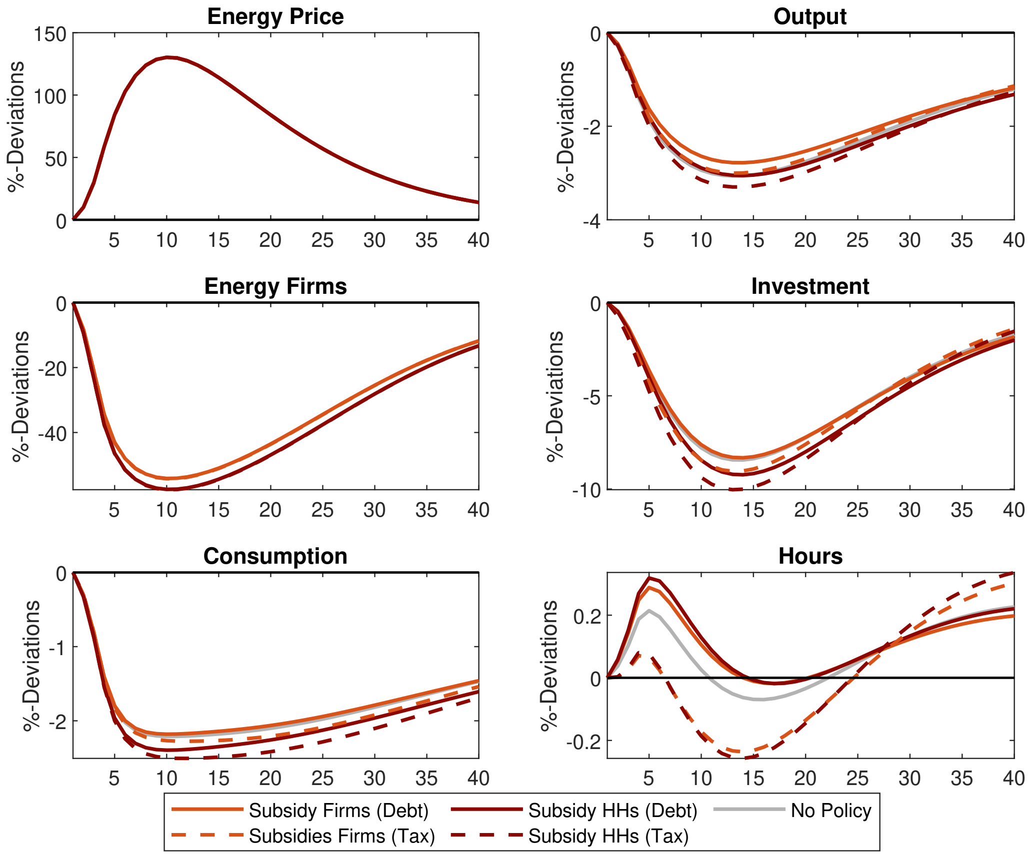

Figure 4: Unexpected increase in energy prices, energy price subsidies, macroeconomic variables. Quarterly time steps.

with existing empirical estimates (see for example Ruhnau et al. (2023)). Firms initially use a larger share of total energy and are better able to substitute energy. As a result of the strong price increase, firms drastically reduce their energy demand. For all the demand side measures, firms reduce their energy demand exactly as in the no-policy case. As firms are not affected by the distortions stemming from the financing scheme of fiscal policies, firms adjust their energy demand differently only when energy prices for firms are subsidized. However, in this case, firms reduce their energy demand less, resulting in lower aggregate energy savings in the economy.

The dynamics of the aggregate labor market is critically dependent on the financing scheme of the relief measure. In all scenarios, the adjustment of hours worked happens in two waves. The impact of the financing scheme is identical for all policies. When compensation measures are financed through an increase in public debt, we observe a greater increase in aggregate hours during the first wave. However, labor supply increases less compared to tax financing during the second wave. While aggregate hours predominantly increase in debt-financing scenarios, they initially decline for tax financing. For transfer policies, aggregate labor supply follows the adjustment in the no-policy benchmark. However, this holds only when transfers are debt-financed. It is necessary to study household-level dynamics to understand aggregate labor supply dynamics in more detail. The underlying driver is the presence of non-Ricardian households. For hand-to-mouth agents, adjusting hours worked is the only way to smooth consumption. Next, we turn to the household level to study this aspect in more detail.

4.2 Household-level Dynamics

In our setup, macroeconomic dynamics can be partially explained by the heterogeneous behavior of households. We distinguish between Ricardian households, which can smooth consumption through their savings in response to shocks, and non-Ricardian households, which have great difficulty smoothing consumption because these households do not have access to savings. For analyzing the dynamics at the household level in more detail, it is useful to separate consumption decisions from the adjustment of labor supply. Although both are components of the utility function, the underlying drivers of the heterogeneous responses of households differ. For the impact on household consumption decisions, the nature of the shock plays a detrimental role. On the contrary, labor supply decisions are best understood through the lens of the impact of compensation policies on poor households. We start by analyzing the impact of the energy price shock on household consumption decisions. To do this, we compare the dynamics of energy price shocks with the dynamics of a shock to total factor productivity (TFP). The TFP shock is calibrated to match the effect of the energy price shock on output.

When comparing the effect of the energy price shock from our baseline calibration to a standard TFP shock, we observe differences for the demand- and the supply-side. The dynamics of the macroeconomic aggregates after the TFP shock are a decent approximation of what we observe after the energy price shock (aside from the dynamics of energy consumption, see Figure 10 in the appendix). However, considering explicitly the nature of the price shock leads to differences in the three variables entering the household utility function: energy consumption, non-energy consumption, and hours worked. The differences are greatest for consumption-related variables. Modeling the energy price shock explicitly considers the impact on households. Since energy consumption is a basic need, households are directly affected by the unexpected increase in prices. This adverse impact is greater for poor households, which spend a larger share of their income on energy. As can be seen in Figure 5, the response of energy and non-energy consumption is much more pronounced and differs between the household types. In this context, a TFP shock significantly underestimates the adverse impact of the energy price shock on consumption of households.

From the comparison with the TFP shock, we can derive important insights for the comparison of compensation policies. Figures 6 and 7 summarize the response of household-level variables to an energy price shock for the set of compensation policies.

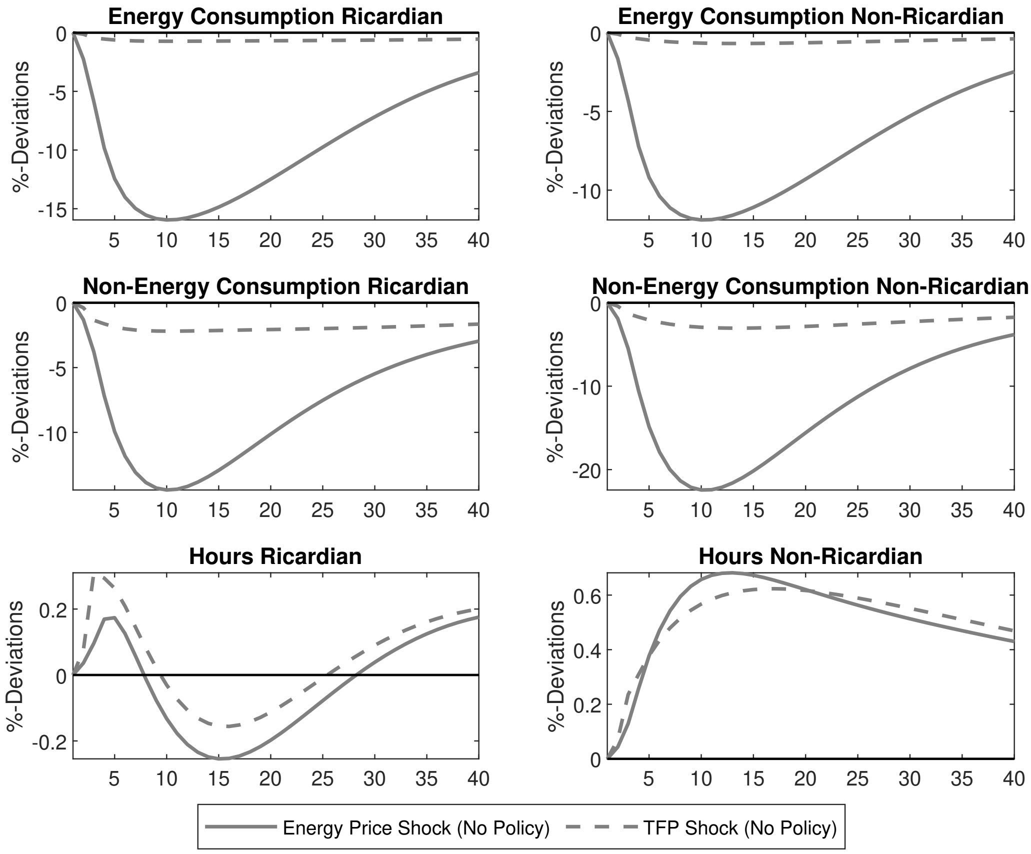

Figure 5: Comparison: Energy Price Shock vs. TFP Shock - Distributional Variables. Quarterly time steps.

The first observation is that consumption decisions are primarily driven by the energy price shock and not by compensation policies. The large and unexpected price increase makes energy consumption less attractive. However, households also reduce non-energy consumption as their income temporarily declines. Households adjust their consumption portfolios heterogeneously. Due to non-homothetic preferences, non-Ricardian households react by reducing their energy consumption less than Ricardian households. Instead, non-Ricardian households reduce their non-energy consumption more strongly. Compensation policies do not affect the consumption dynamics compared to the no-policy case. In principle, energy price subsidies that target households can weaken the price signal and thereby affect consumption dynamics. However, compared to the increase in fossil prices, the magnitude of the intervention is not sufficient to significantly affect the price signal. In contrast, the other policy interventions do not affect relative prices and thereby have no direct impact on consumption portfolios of households. For example, direct transfers to households support the incomes, and thus leave the price signal unaffected.

The primary impact of compensation policies can be observed in the labor market. Across all scenarios, we observe an asymmetric adjustment of hours worked for both types of households. Through the adjustment of labor supply, the key source of heterogeneity

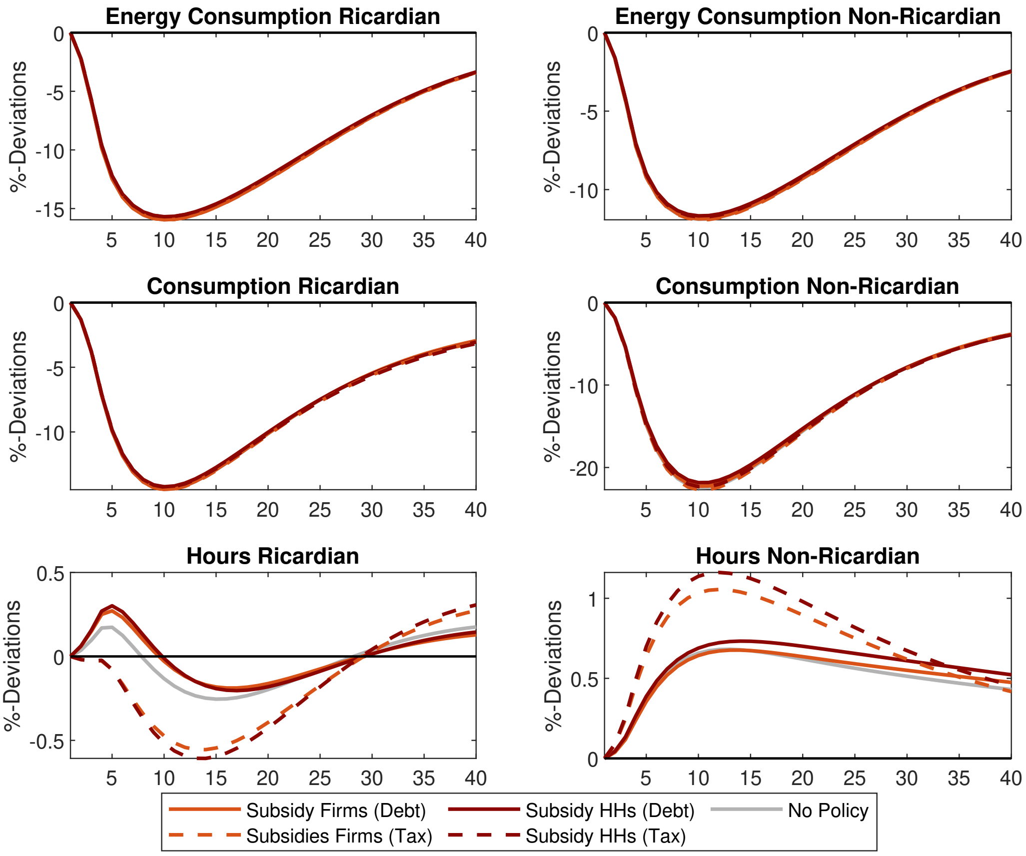

Figure 6: Unexpected increase in energy prices, energy price subsidies, distributional variables. Quarterly time steps.

becomes eminent. Non-Ricardian households do not have access to financial markets. Hence, poor households have limited ability to smooth consumption. Increasing their labor supply is the only way they can cope with higher energy prices. However, increasing their labor supply comes at the cost of higher disutility of labor. Compensation policies can help poor households smooth consumption and reduce the need to increase hours worked. Both the type of intervention and the financing scheme play an important role in the labor supply response. In general, for the same type of intervention, non-Ricardian households increase or decrease their hours worked depending on the financing scheme. Poor households tend to work less when compensation measures are debt-financed, as debt financing increases their ability to smooth consumption. Financing the policy intervention through an increase in public debt shifts part of the burden of higher energy prices to the future. Intuitively, this helps poor households to cope with the adverse effects of the increase in energy prices. In contrast, poor households significantly increase their labor supply relative to the no-policy benchmark when the relief measures are tax-financed. This response results from the adverse income effect of distortionary tax-financed measures.

The type of policy intervention additionally affects the labor supply of non-Ricardian

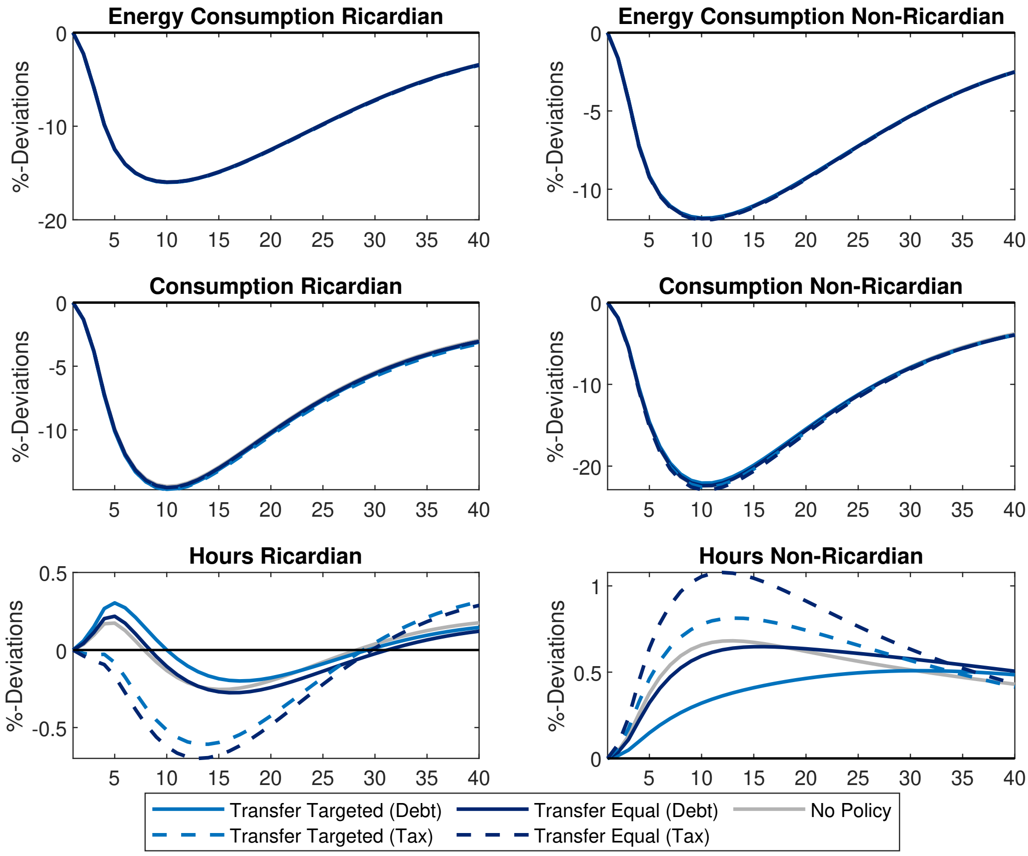

Figure 7: Unexpected increase in energy prices, transfers, distributional variables, quarterly time steps.

households. Comparing untargeted with targeted transfers is useful to understand the impact of the type of policy intervention. In the case of targeted transfers, poor households are the only recipients of transfers and receive a large income support. Thus, poor households are better able to smooth consumption without adjusting their labor supply. Consequently, for targeted transfers, the increase in hours worked is smaller than for other compensation measures. For all other compensation policies, the impact of the policy intervention on the ability to smooth consumption is dominated by the financing scheme. Thus, for the labor supply adjustment of poor households, the choice of the specific policy instrument and the financing scheme is essential.

For Ricardian households, the situation is different, as they have access to savings and dispose of additional means to counter the increase in energy prices. As these households are able to cope with the shock, the type of intervention does not affect the labor supply response. In contrast, the financing scheme has a direct impact on hours worked. Ricardian households anticipate that initially issued debt implies an increase of distortionary taxes in the future. Consequently, they initially increase their labor supply when compensation measures are financed via an increase in public debt. In contrast, when transfers are tax-financed, they initially reduce their labor supply. This decrease in hours worked

Scenario	Ricardian	Non-Ricardian	Aggregate	Output	Multiplier
Targeted Transfer (Tax)	-0.13	-0.25	-0.16	-6.78	-1.66
Targeted Transfer (Debt)	-0.20	0.26	-0.07	-2.27	-0.56
Equal Transfer (Tax)	0.01	-0.56	-0.14	-6.40	-1.57
Equal Transfer (Debt)	-0.06	-0.05	-0.06	-1.95	-0.48
Subsidy Firms (Tax)	0.06	-0.39	-0.07	2.27	0.57
Subsidy Firms (Debt)	-0.01	0.08	0.01	6.42	1.63
Subsidy HH (Tax)	-0.04	-0.64	-0.20	-5.67	-1.39
Subsidy HH (Debt)	-0.11	-0.13	-0.12	-1.19	-0.29
Subsidy Untargeted (Tax)	-0.02	-0.58	-0.17	-3.89	-0.97
Subsidy Untargeted (Debt)	-0.09	-0.08	-0.09	0.51	0.13

Table 3: Welfare effects of different policy scenarios in consumption equivalent variations over a 10 year horizon. The welfare effects are reported relative to the no-policy scenario. Changes in output are reported as discounted cumulative output difference relative to the no-policy scenario in percentage points.

is significant and indicates that tax financing is beneficial for Ricardian households.

So far, we describe the dynamics of the model for the different policy scenarios. For the evaluation of the performance of specific policy instruments, we perform a welfare analysis. Specifically, we compute the welfare effects of the different policy instruments in light of an energy price shock relative to the deterministic steady state of the model. Furthermore, as computed by Uhlig (2010), we also report the discounted cumulative changes of output and the fiscal multipliers relative to the no-policy scenario. Since compensation measures are a crisis support, they aim to provide short-term relief. Therefore, we focus our analysis on the welfare effects in the first ten years after the energy price shock.[9] Formally, to compute the welfare effects we solve for the compensating variation $\Delta^{(j)}$ of scenario j for household $i = R, NR$:[10]

$$\sum_{t=0}^{T} \beta^t u((1 - \Delta_i^{(j)}) x_{i,ss}, h_{i,ss}) = \sum_{t=0}^{T} \beta^t u^{\text{policy}}(x_{i,t}^{(j)}, h_{i,t}^{(j)}), \tag{28}$$

where $x_{i,t} \equiv c_{i,t} + p_{h,t}\, c_{e,i,t}$ encompasses both consumption types. We compute the difference between $\Delta_i^{(\text{Policy})}$ and $\Delta_i^{(\text{No-Policy})}$ as the measure of welfare.

The results of the 10-year comparison displayed in Table 3 offer several insights. As shown in the table, the discounted cumulative output loss in response to the energy price shock is largest under the transfer scenarios. The largest overall output loss is observed

[9]The welfare effects and output losses over a 40 years horizon are reported in Appendix C.

[10]In this case, $\Delta^{(j)} \cdot x_{i,ss}$ is the payment *per period* in steady state that makes the household $i = R, NR$ indifferent between this steady state setup and being exposed to the energy price shock combined with the combination of government policy and financing scheme for T periods in the scenario j. In other words, welfare effects are expressed as receiving a payment of $\Delta_i^{(j)} \cdot x_{i,ss}$ *per period* for being exposed to the particular scenario.

in a scenario with targeted transfers to non-Ricardian households financed by taxes. In contrast, a cumulative gain in output is observed in the scenarios with firm subsidies and for mixed price subsidies financed via debt. The largest gain of about 6.4 percentage points is observed when firm subsidies are financed by debt. These results clearly confirm the visual impression that firm subsidies perform best in terms of output stabilization. The described pattern is also confirmed when considering the fiscal multipliers associated with the different policies. A positive fiscal multiplier is observed only for firm energy price subsidies and debt-financed mixed subsidies. The finding that debt-financed measures have a larger fiscal multiplier can be explained in part by the additional distortions associated with tax increases that manifest themselves directly.

The results of the welfare analysis clearly indicate that poor and rich households prefer different compensation measures, as well as financing schemes. Regardless of the policy instrument, poor households prefer debt financing over tax financing. As they cannot smooth consumption, financing relief measures through an increase in public debt leads to a smoother consumption profile. Regardless of the specific policy instrument, debt-financed measures always lead to a higher welfare for poor households compared to the no-policy benchmark. However, the specific compensation measure matters for the size of the welfare effects. In general, non-Ricardian households benefit most from targeted transfers, for which we observe welfare gains of around 0.3 percentage points for non-Ricardian households, which translates into a gain of roughly 340 Euro over the entire period (see Table 5 in appendix C).[11] The debt-financed targeted transfers best prevents low-income households from meeting their subsistence level. However, the cost imposed on Ricardian households is sizeable. Thus, a government would prefer this policy measure only if sufficient weight was given to the non-Ricardian households. This might be the case, when evaluating the welfare effects with a utilitarian social welfare function.[12] Surprisingly, non-Ricardian households prefer firm subsidies over equal transfers or household energy price subsidies. This finding is directly related to the stabilization of production associated with subsidies for energy prices for firms, which mitigate labor market adjustments. As explained earlier, this represents an important channel through which non-Ricardian households maximize their utility. Furthermore, unlike price subsidies to households, firm subsidies do not affect the optimal choice of the consumption basket and favor a larger reduction in energy expenditures.

The picture is different for Ricardian households. Since they can perfectly smooth consumption, they do not explicitly benefit from this aspect of debt financing. In contrast, they tend to prefer compensation measures that are financed by adjusting distortionary taxes. The reason is the adjustment in the labor supply of non-Ricardian households.

[11] We compute the euro-valued welfare gains over the whole period since, when calibrating the model, we match the cumulative fiscal cost of the analyzed policy measures. In detail, we compute the discounted sum of consumption equivalent variations $\sum_{t=0}^{T} \beta^t \cdot \left(\Delta_i^{(j)} - \Delta_i^{(\text{No Policy})} \right) x_{i,ss}$ of household type i and scenario j over $T = 40$ periods and multiply it with the Euro conversion factor p^{euro} derived in Section 3.2.

[12] In this case, the relatively higher marginal utility of non-Ricardian households would add weight to their welfare gains.

When compensation measures are tax-financed, poor households respond by increasing their labor supply relatively more. This benefits rich households by stabilizing capital income. From a welfare perspective, Ricardian households clearly prefer tax-financed firm subsidies over alternative measures. Again, this is a matter of stabilizing overall production, from which Ricardian households benefit doubly through their wage and capital income. In contrast, Ricardian households face the largest welfare losses when transfers are exclusively for non-Ricardian households. In this case, they must pay for the measures but do not receive any benefits and their loss amounts to around 430 Euro (see Table 5). The differences in individual welfare effects are directly reflected in the differences in aggregate welfare effects. Tax-financed firm subsidies are the only Kaldor-Hicks-improving option in our setup. While this is the option that best stabilizes output, it increases firms' energy demand and conflicts with potential energy saving goals.

5 Conclusion

The recent hike in fossil energy prices challenges governments, as it adversely affects both industry and household income. Given the magnitude and cause of the shock, the goals of crisis management measures range from stabilizing economic performance to incentivizing energy savings to preventing an increase in energy poverty. In this context, we provide a comprehensive assessment of different policy instruments and their financing schemes. In terms of policy instruments, we compare energy price subsidies with direct transfers. In both cases, we allowed for targeted and untargeted compensation measures. Therefore, we are able to analyze the macroeconomic and distributional impact of several policy measures that Germany implemented to address the energy crisis.

When we explicitly analyze the recent hike in fossil energy prices in 2022, the macroeconomic impact depends on the fiscal policy response. In any case, and despite drastic reductions in energy demand, the hike in energy prices leads to a recession. We find that the reductions in energy demand are asymmetrically distributed between households and firms. While poor and rich households reduce their energy demand by a similar magnitude, firms reduce their energy demand even further. Financing fiscal policy interventions through an increase in public debt leads to a quicker rebound at the expense of a prolonged recovery. However, the rebound is not large enough to prevent the recession.

The impact on welfare differs for both types of households. Poor and rich households prefer different policies and financing schemes. On the one hand, poor households prefer debt-financed instruments, as they help them to smooth consumption in response to the energy price shock. They prefer targeted transfers but also profit from the stabilizing effect firm subsidies exert on output. On the other hand, rich households have a strong preference for tax financing. As rich households are able to cope with increasing energy prices, they benefit from a higher labor supply of poor households. Both firm subsidies and equal transfers have a positive welfare effect on them.

Our findings imply that the evaluation of compensation policies depends on the target of the policy maker. If the goal is to prevent an increase in energy poverty, debt-financed targeted transfers or energy price subsidies for consumers are a suitable policy. However, the same policy may not be suitable for protecting firms and stabilizing economic output. In the evaluation of supply-side instruments, we acknowledge that welfare is not the appropriate measure to account for the concerns regarding the permanent deindustrialisation in response to the increase in fossil energy prices. However, if we assume that larger declines in output increase the probability of permanent reallocation of production, tax-based financing of compensation measures may be beneficial in addressing these concerns. These, in turn, may compromise the goal of maximizing energy savings that was particularly important in the face of limited natural gas supply.

In general, fossil energy price hikes adversely affect both households and firms. As the dependency on fossil energy, as well as the coping ability, differs between the agents in the economy, there is no single policy that protects both the industry and the households from the adverse effects.

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A Pass-through of subsidies

A.1 Augmenting the price-process

Consider the share of energy ψ that is imported but where supply is restricted due to capacity constraints for a group of countries that share a common energy market. With a binding capacity shock (i.e. due to banning of Russian gas imports while remaining gas import infrastructure being at its capacity limit), aggregate demand for gas in these countries is limited $\sum_i E_i \leq E^*$. Hence, any unilateral domestic increase in gas demand has to be offset by reductions of gas demand in other countries of the common market.

Assuming a common gas price p and uniform price elasticities of demand demand of country j is

$$E^i = (p + \tau^i)^\varepsilon \bar{E}^i \tag{29}$$

with $\bar{E}^i \equiv E_0^i p_0^\varepsilon$ calibrated such that energy demand matches baseline demand E_0^i at baseline price p_0. Considering the case of a unilateral domestic price intervention at country j while assuming that other countries do not intervene, aggregate demand is

$$E = \sum_j E_j = (1 - \lambda^j) p^\varepsilon \bar{E} + \lambda^j (p + \tau^j)^\varepsilon \bar{E} \tag{30}$$

$$= p^\varepsilon \bar{E} \left((1 - \lambda_j) + \lambda_j \left(\frac{p + \tau_j}{p} \right)^\varepsilon \right) \tag{31}$$

with λ^j the share of j's energy demand on total demand in the baseline and $\bar{E} \equiv \sum_i \bar{E}^i$. In the case of a binding capacity constraint, a change in the domestic tax τ_j will leave aggregate energy demand unaffected, $dE/d\tau_j = 0$. Hence, considering that the price level of the common market is affected by the domestic price policy, $p = p(\tau_j)$ taking the derivative of (31) with respect to τ_j and with $dE/d\tau_j = 0$ gives after rearranging

$$\frac{dp}{d\tau_j} = -\lambda^j \bar{E} (p + \tau)^{\varepsilon - 1} \frac{p}{E} \tag{32}$$

When the baseline domestic price distortion is zero $\tau^j = 0$, we have from (31) $E = p^\varepsilon \bar{E}$ and (32) becomes for $\tau^j = 0$:

$$\frac{dp}{d\tau_j} = -\lambda^j \tag{33}$$

Hence, a marginal increase of a unit tax (subsidy) on the domestic energy price from a non-distortive baseline ($\tau^j = 0$) implies a a reduction (increase) of the energy price in the capacity-constrained common market by λ^j. The net price effect of a domestic tax after the price adjustment on the common market will therefore be $\tau^j(1 - \lambda^j)$.

During the energy crises, Germany was part of a 'high-price island' of the countries as infrastructure bottlenecks prevented price convergence to international liquefied natural gas prices.[13] Germany's gas consumption share on this groups of country is 35%, implying

[13]Examples of these countries include among others Denmark, Austria, Hungary, Bulgaria, Italy and Poland.

$\lambda^{DEU} = 0.35$. As natural gas constituted 39% of the fossil energy imported (measured in energy content), $\psi = 0.39$. Hence, the effect of German natural gas subsidies on the aggregate energy price index are $\lambda^{DEU} \times \psi \approx 0.14$.

Note that in case of a subsidy, $\tau^j < 0$, the additional energy price increase by λ^j falls on a scarcity rent of the owner of the import capacity which is on its limit. In the case of Germany, limiting import capacities like liquefied natural gas terminals were largely out of the country, implying that the price increase by λ^j can be understood as a loss to the German economy.

To integrate the second-round effect of subsidies into the stochastic price process, we add the pass-through of the subsidy $sub_t = -\tau_t$ on the energy price index. We correct for the auto-regressive impact of the previous-period subsidy to prevent an accumulation of the pass-through effect through the autoregressive price term:

$$p_t = \rho p_{t-1} + \epsilon_t + \psi \lambda sub_{t-1} - \rho \psi \lambda sub_{t-2} \tag{34}$$

B Figures

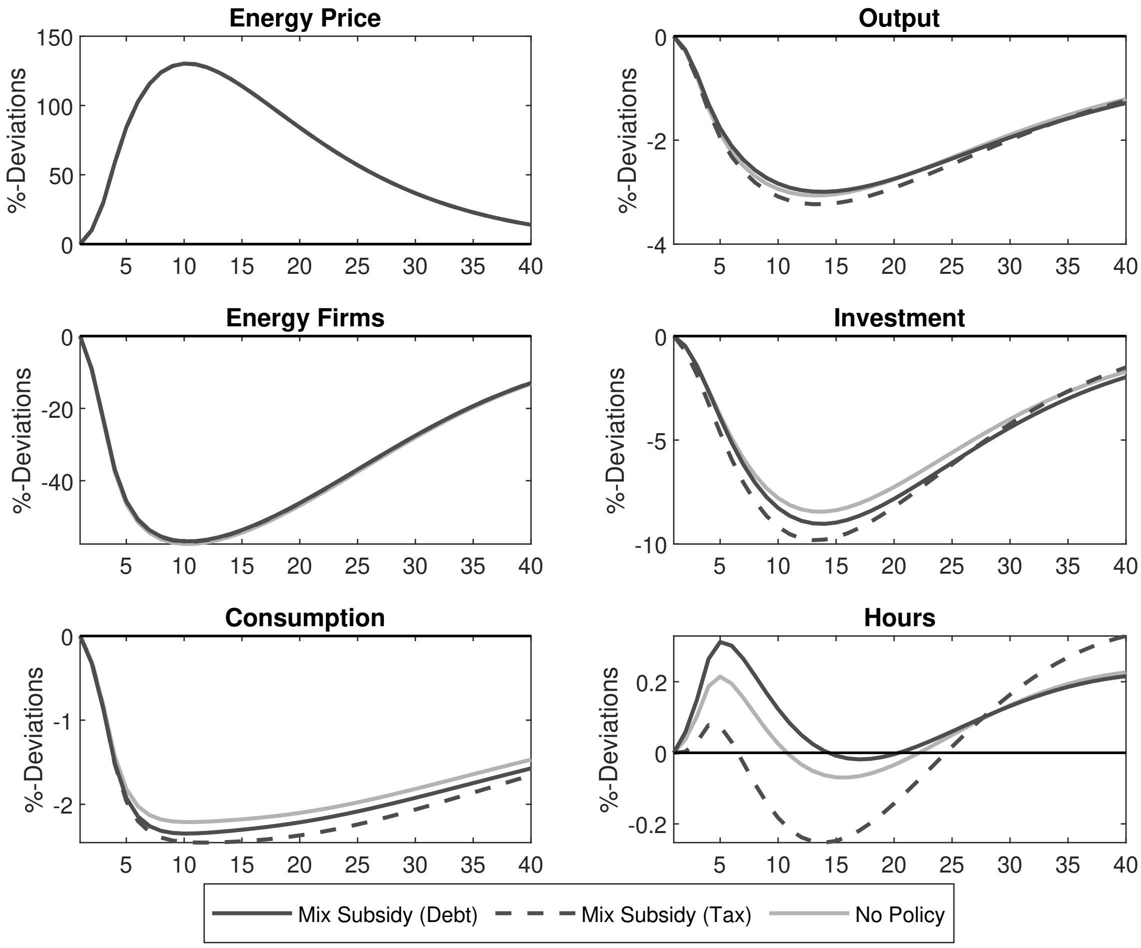

Figure 8: Unexpected increase in energy prices,untargeted energy price subsidies, macroeconomic variables. Quarterly time steps.

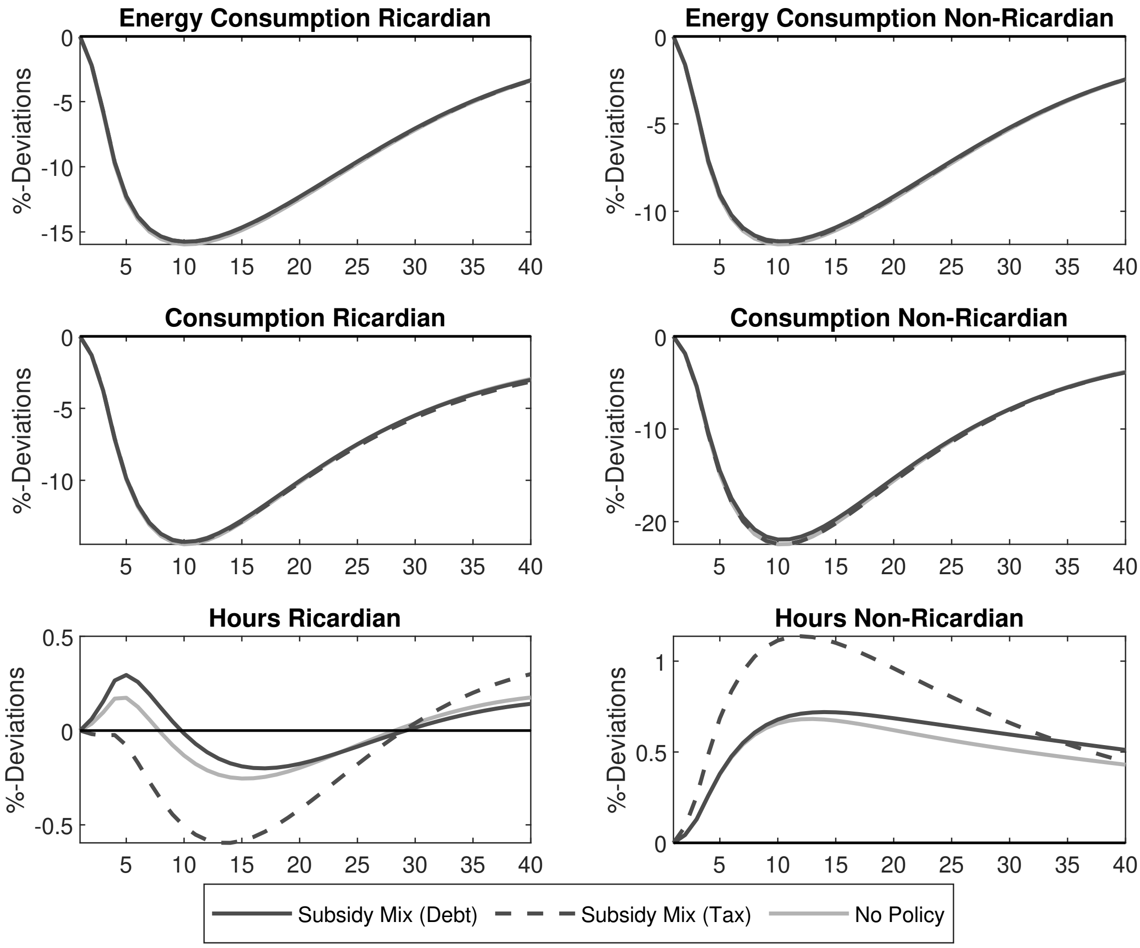

Figure 9: Unexpected increase in energy prices,untargeted energy price subsidies, distributional variables. Quarterly time steps.

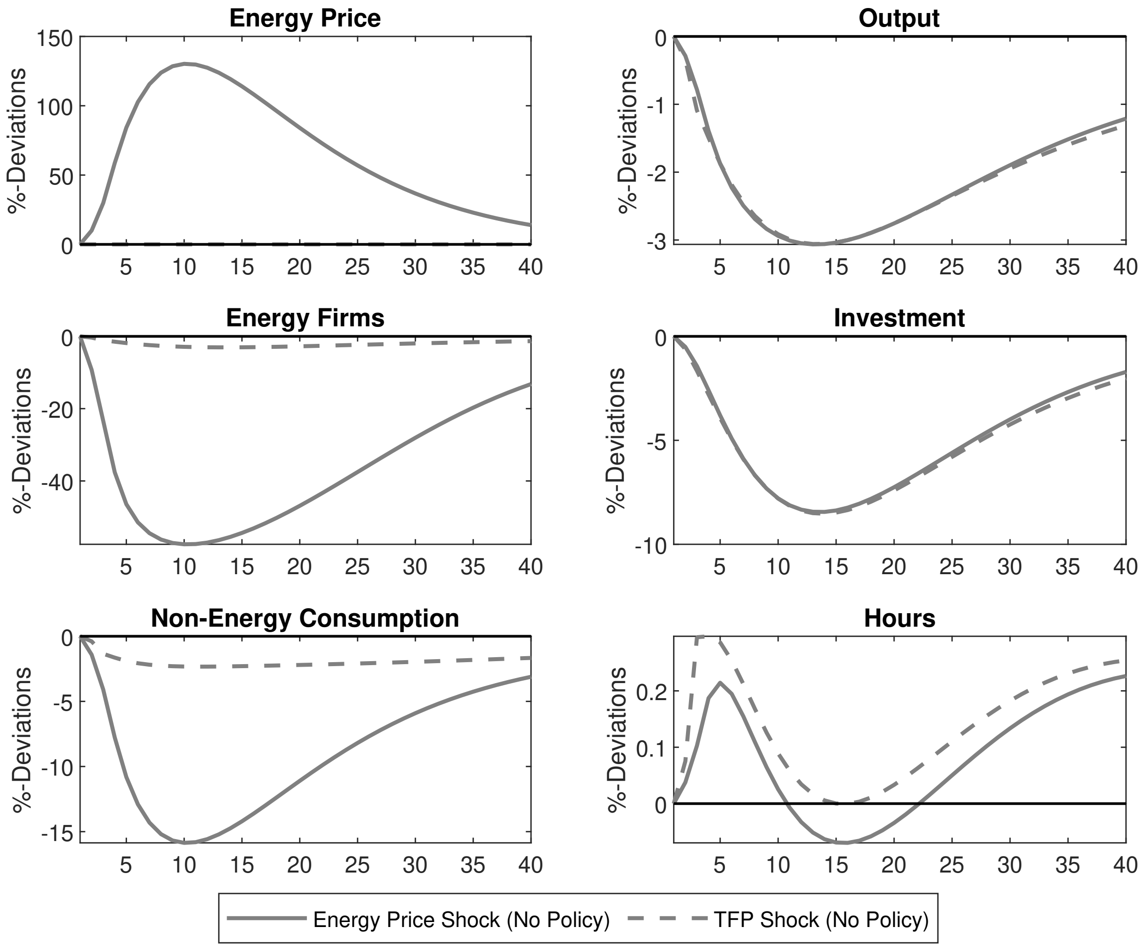

Figure 10: Comparison: Energy Price Shock vs. TFP Shock - Macroeconomic Aggregates. Quarterly time steps.

C Tables

Scenario	Ricardian	Non-Ricardian	Aggregate	Output	Multiplier
Targeted Transfer (Tax)	-0.11	0.02	-0.08	-2.94	-0.69
Targeted Transfer (Debt)	-0.11	-0.00	-0.08	-6.45	-1.52
Equal Transfer (Tax)	-0.05	-0.07	-0.06	-1.96	-0.46
Equal Transfer (Debt)	-0.05	-0.09	-0.06	-5.47	-1.29
Subsidy Firms (Tax)	-0.01	0.00	-0.00	8.38	1.99
Subsidy Firms (Debt)	-0.00	-0.01	-0.00	5.20	1.24
Subsidy HH (Tax)	-0.08	-0.11	-0.09	-1.72	-0.41
Subsidy HH (Debt)	-0.08	-0.13	-0.09	-5.20	-1.22
Subsidy Untargeted (Tax)	-0.06	-0.08	-0.07	0.54	0.13
Subsidy Untargeted (Debt)	-0.06	-0.10	-0.07	-2.86	-0.68

Table 4: Welfare effects of different policy scenarios in consumption equivalent variations over a 40 years horizon. The welfare effects are reported relative to the no-policy scenario. Changes in output are reported as discounted cumulative output difference relative to the no-policy scenario in percentage points.

Scenario	Ricardian (Euro)	Non-Ricardian (Euro)
Targeted Transfer (Tax)	-279.3719	-330.0037
Targeted Transfer (Debt)	-429.8029	343.2039
Equal Transfer (Tax)	21.4901	-739.2084
Equal Transfer (Debt)	-128.9409	-66.0007
Subsidy Firms (Tax)	128.9409	-514.8058
Subsidy Firms (Debt)	-21.4901	105.6012
Subsidy HH (Tax)	-85.9606	-844.8096
Subsidy HH (Debt)	-236.3916	-171.6019
Subsidy Untargeted (Tax)	-42.9803	-765.6087
Subsidy Untargeted (Debt)	-193.4113	-105.6012

Table 5: Welfare effects of different policy scenarios in Euro over a 10 years horizon.