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Abstract

We study the aggregate, distributional, and welfare effects of fiscal policy responses to Germany's energy crisis using a novel Ten-Agents New-Keynesian (TENK) model. The energy crisis, compounded by the COVID-19 pandemic, led to sharp increases in energy prices, inflation, and significant consumption disparities across households. Our model, calibrated to Germany's income and consumption distribution, evaluates key policy interventions, including untargeted and targeted transfers, a value-added tax cut, energy tax reductions, and an energy cost brake. We find that untargeted transfers had the largest short-term aggregate impact, while targeted transfers were most cost-effective in supporting lower-income households. Other instruments, as the prominent energy cost brake, yielded comparably limited welfare gains. These results highlight the importance of targeted fiscal measures in addressing distributional effects and stabilizing consumption during economic crises.

Keywords: DGE, energy crisis, fiscal policy, income distribution, TENK

JEL classification: E21, E62, Q43, Q48

1 Introduction

Following a relatively long period with low inflation rates and deflationary pressure during the COVID-19 recession, from late 2021 inflation rates began to increase. After the invasion of Ukraine in February 2022 by Russia, inflation in Germany increased significantly due to concerns about energy supplies in the near and distant future. The strong German dependency on Russian energy led to high energy and core inflation.

In the late 2022, the year-over-year change in the harmonized consumer price index for energy surged to nearly 45 percent. Although energy costs were not the sole driver of the overall inflation of consumer prices, their sharp increase significantly burdened households and businesses through higher expenses. Financially constrained households, in particular, were disproportionately affected due to limited savings, leaving them vulnerable to rising consumption costs. The uncertainty surrounding future price developments further complicates decisions about consumption, savings, and production capacities, with direct implications for purchasing power of labor income. In response, Germany introduced a range of policy measures, including lump-sum transfers, energy price caps, and tax reductions, to mitigate recession risks. Using a structural model, we quantify the economic and distributional impacts of these individual measures.

Developing (to our knowledge as the first) a Ten-Agents New-Keynesian (TENK) Model, we analyze aggregate, distributive, and welfare effects of negative energy supply shocks and fiscal policies during an energy crisis following a pandemic. Implementing households with different financial situations, we provide information on the reactions of various wealth groups and the channels through which these effects work. In particular, we look at Germany and calibrate our model given data on the income and consumption distribution between deciles as well as aggregate data on GDP, consumption, and inflation. Matching the development of key variables in our model to the data, we compare policy scenarios to a counterfactual scenario without any intervention. These scenarios contain fiscal shocks representing single implemented instruments in Germany during the energy crisis and the total package. In addition, we provide a simple welfare analysis.

It turns out that depending on the duration and cost of the measures, untargeted transfers have the largest effects, while targeted transfers show the best performance regarding welfare gains given the fiscal cost. The energy cost brake as measure directly targeting the main variable of this crisis, causes comparably low welfare gains, whereas gas and fuel tax cuts are performing better in terms of cost-effectiveness. In conclusion, one can say that the German fiscal policy during the energy crisis has been stabilizing private consumption of lower-income deciles while considering distributive issues and that politicians should focus on targeting the vulnerable groups.

The structure of the paper is as follows. Section 2 reviews the classification of our topic within the existing literature. Sections 3 and 4 detail the model framework and the calibration process. The main results are presented in Section 5 and discussed in Section 6. Finally, Section 7 concludes.

2 Related Literature

From a more general perspective, our paper contributes to the broad branches of theoretical macroeconomic models with energy, often related to climate change issues[1], heterogeneous agents models (HANK)[2], and fiscal policy analyses in general equilibrium models[3]. There already exists research on the current energy crisis. A prominent study of Bachmann et al. (2022) calculates the expected loss in German GDP in case of an embargo of Russian energy. Given their investigations, they announce a fall in GDP of 0.5 to 3 percent for a 30 percent reduction in gas consumption in such a scenario in the short run, depending on the ability to substitute energy that is no longer imported from Russia. Furthermore, they give policy recommendations to first provide aid for financially constrained households because of a higher share of energy expenditures on total consumer spending, but without the violation of energy-saving incentives. Second, one should ensure that it becomes more attractive as quickly as possible to use substitutes for fossil energy.

Poorer households are disproportionately affected by this crisis, as highlighted in the report by the German Council of Economic Experts (Grimm et al. (2022)). They document that personal inflation rates differ between income deciles, and poorer households experience higher consumer price index growth rates. This disparity is attributed to the larger share of energy and food expenditures in their total consumption relative to wealthier groups. Figure 1 illustrates this pattern, showing shares of energy and food expenditure ranging from below 4 percent for the highest income decile to nearly 9 percent for the lowest. Grimm et al. (2022) estimate that the maximum difference in inflation rates between deciles is 1.29 percentage points, with inflation burdens varying between 3.7 percent for the richest and 8.3 percent for the poorest decile. These findings underscore the greater vulnerability of lower-income households.

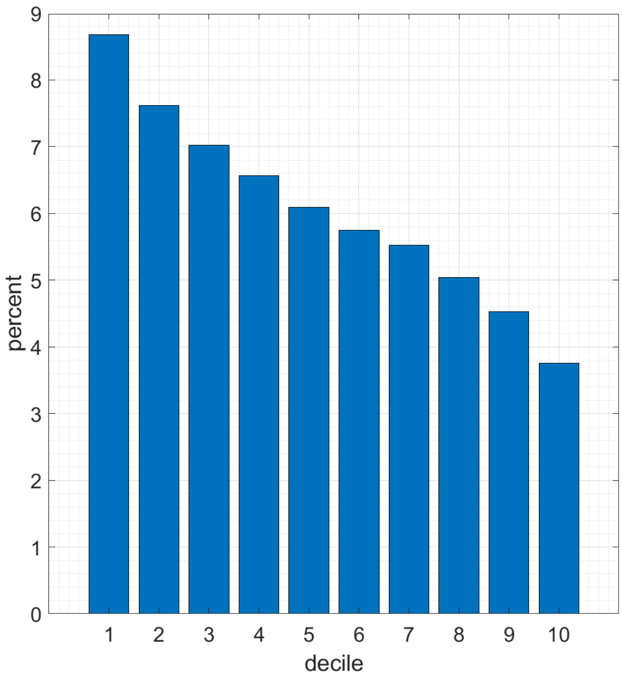
The inflation burden measures the additional amount a household must pay to maintain the same consumption basket as in the previous year, assuming that nominal gross wages increased by 2.9 percent (from 2021-Q2 to 2022-Q2). Poorer households face a more severe burden due to their higher consumption-to-income ratio. With minimal savings, they are less able to maintain their consumption levels during price increases. In addition, lower-income households have limited substitution possibilities, as they already purchase lower-cost products. The survey data from Peersman and Wauters (2024) further indicate heterogeneity in consumer responses to increases in energy prices, driven by differences in income and savings, highlighting the unequal impact of the crisis between households.

[1]One example is from Golosov et al. (2014) about optimal fossil fuel taxes on a green transition path. Hassler et al. (2021) is a further paper with energy, in particular on the role of technological change under resource shortages.

[2]Different labor productivity risk of agents is assumed in Aiyagari and McGrattan (1998). For others, also related to fiscal policy, see, for example, Seidl and Seyrich (2021) who analyze unconventional fiscal policy in a HANK model or Bayer et al. (2023a) about the liquidity channel of fiscal policy.

[3]An example about fiscal intervention in Germany is from Drygalla et al. (2020) about the stimulus during the great recession in a model with two agents.

Figure 1: Share of Energy Expenditures on Total Expenditures per Income Decile



Note: Illustration of the different energy expenditure shares of households depending on their income group during the energy crisis.
Source: Statistical Office of Germany, own exhibition.

This shows the potential distributional problems, raising the question of targeted support for needy household groups. Celasun et al. (2022) analyze the impact of fossil fuel inflation on private households and highlight significant differences both within and between European countries. Politicians should focus on easing the burden for the most vulnerable groups instead of distorting price signals. That is also stated in a follow-up by Arregui et al. (2022), who recommend independent rebates on current use of energy bills or block tariffs, for example, coupled with taxes for richer households. Pieroni (2023) reports that, based on a HANK model, especially households with lower income are suffering from energy shortages. Fiscal and monetary intervention can address this issue.
A paper that brings together the three branches of the macroeconomic literature is Auclert et al. (2023). The context is an open economy framework with energy imports, examining the effects of fiscal and monetary policy in the presence of energy price shocks. In addition to different dynamics in the representative agents (RANK) and HANK models, they indicate that fiscal policy can help single countries prevent inflationary pressure and economic downturn through losses in real wages. But when implemented by all importers, especially energy subsidies are driving world market prices under a fixed supply, and countries with low fiscal possibilities are worse off.

Close to our project are the papers of Roeger and Welfens (2022), Clemens and Roeger

(2023), and Bayer et al. (2023a). Clemens and Roeger (2023) develop a two-agents New-Keynesian (TANK) model with liquidity-constrained and unconstrained households and compare the case of a fossil fuel embargo to a fossil fuel price mark-up shock. Testing various fiscal policy intervention scenarios, they find differences in the effectiveness depending on the kind of shock, which is lower under an embargo. Roeger and Welfens (2022) analyze fiscal measures regarding stabilising output and employment and distributional effects in a model based on Clemens and Roeger (2023) with gas usage for electricity production. They report that a temporary gas price subsidy for electricity firms can prevent losses in output and employment and partly reduce the distributional effects of a gas crisis because of less windfall profits in the context of the merit-order system. Especially together with transfers for vulnerable groups, this instrument would address economic and distributional issues. Bayer et al. (2023a) use a HANK model with an open economy representing a country operating in a currency union. They show that under welfare aspects an energy subsidy benefits the home country but harms the rest of the currency union, while transfers are superior.
Further papers looking at welfare effects during the energy crisis are from Gustafsson et al. (2024) and Blanz et al. (2023). The former look at the Swedish case, in a DSGE (Dynamic Stochastic General Equilibrium) model with a domestic energy producer and liquidity (un-)constrained households, and find that subsidizing investments in the energy sector are the dominating strategy in terms of effectiveness. From a welfare perspective it is better to support the vulnerable household group by supplying energy vouchers. Differentiating between energy subsidies and (un-)targeted transfers financed by either debt or taxes, Blanz et al. (2023) find that the suitability of policy depends on the question if households should be protected from so-called energy poverty or the production should be stabilized. Their DSGE model also constitutes an economy with households who have no access to financial markets.

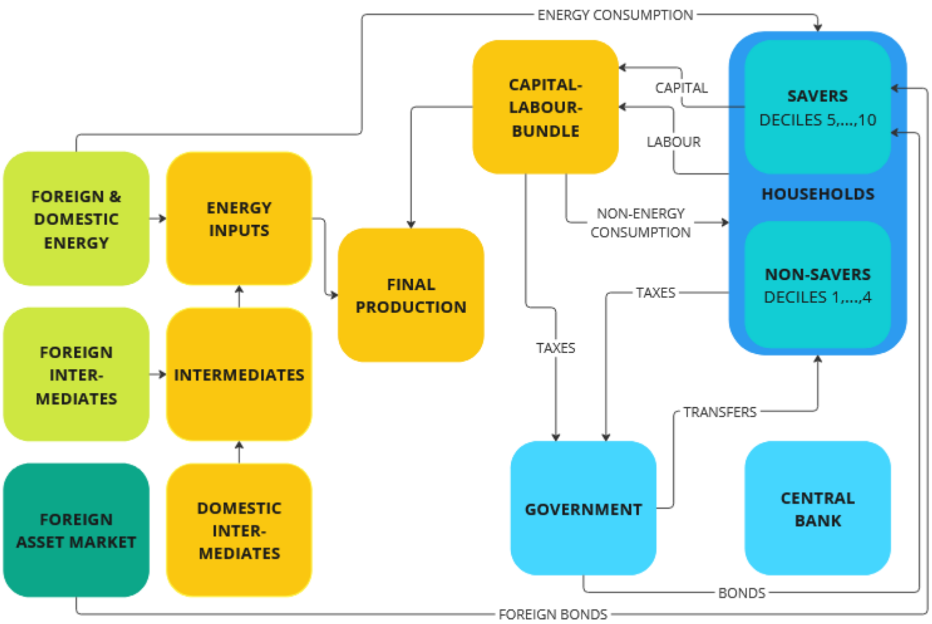
Turco et al. (2023) use an agent-based model with households, firms, and banks to explore the economic impacts of fiscal policy on the wealth and income distribution in case of a fossil fuel price shock. According to their analysis, a fuel price tariff reduction and an extra profit tax on energy firms would be the first-best strategy. Related to this paper, Ciola et al. (2023) concentrate on distributional and overall economic implications of energy shocks: positive fossil fuel price shocks, negative productivity shocks, and negative fossil fuel supply shocks. It turns out that aggregate effects do not differ, but for distributional concerns, the nature of the disturbance plays a role.

In our project, there are distinct differences from the existing papers. Firstly, we (depending on the related paper) diverge by not solely examining oil, gas, and electricity, but instead taking a broader perspective on energy as a whole. Secondly, we put more emphasis on the demand side of energy, incorporating a wide range of heterogeneity among households by considering income deciles. Our paper will contain a comprehensive analysis of these distinct groups, and our TENK model can be used for further distributive and energy-related analyses. Moreover, we will contribute to the literature by providing not an abstract but a realistic and tractable analysis with an accurate calibration of the German economy during this crisis closely replicating the actually observed development and policy measures and not neglecting that the energy crisis followed a pandemic.

3 TENK Model

Our model represents an open economy,[4] in which energy endowments (E_t) are treated as exogenous. In this setting, the energy consumption of companies or households constitutes a net wealth loss, reflecting the dependence of Germany on energy imports, which represent 68% of the total energy demand. Figure 2 provides an illustrative overview of the structure of the model.

Figure 2: Structure of the Model.



Source: own exhibition.

A part $E_{Y,t}$ of the total energy supply, including domestic energy inputs $E_{D,t}$, is used as a complementary input factor to a capital-labor bundle in the firm sector, which produces a non-energy-consumption good. The other part $C_{E,t}$ is consumed by the household sector in combination with non-energy consumption goods.

$$E_t = E_{Y,t} + C_{E,t} \tag{1}$$

Energy prices are set internationally and considered exogenous in our analysis. Therefore, the price $P_{E,t}$ evolves according to the following process:

$$P_{E,t} = (1 + \epsilon_{E,t})\bar{P}_E, \tag{2}$$

where $\bar{P}_E$ is the steady state energy price and $\epsilon_{E,t}$ deviates from zero in case of a shock. Domestic energy is given as

$$E_{D,t} = share_{ED,t}\bar{E}\left(P_{E,t-1}/\bar{P}_E\right)^{\epsilon_{P_E}}, \tag{3}$$

[4]Examples of other open economy models include Christiano et al. (2011), Drygalla et al. (2020), Atkeson et al. (2022), and Eugeni (2024).

with steady state energy $\bar{E}$ and ϵ_{P_E} as elasticity of domestic energy inputs with respect to changes in the energy price in the last period relative to its steady state value. All households supply labor and earn decile-specific wages. Capital, the other input factor, is owned by households who also have access to the domestic and foreign bond markets for investment opportunities. The population is divided into two groups: individuals in income deciles 5 through 10, comprising 60 percent of the population, are Ricardian agents who can save a portion of their income.[5] Hand-to-mouth or rule-of-thumb households consume their complete net labor income in each period without receiving from or directing income to capital and bond investments. They react strongly to negative income shocks because of their inability to smooth consumption. Every income group pays taxes to the government: labor income taxes, consumption taxes on energy and non-energy (indirectly as value-added tax transferred by the domestic firm to the government), and savers pay a capital revenue tax as well as taxes on profit income. Additionally, households pay decile-specific lump sum taxes to the government or receive social transfers. The government finances expenditures through these taxes and debt, while the central bank reacts to fluctuations in inflation and output by setting the nominal interest rate on bonds.

3.1 Production Sector

We adopt the approach by Atalay (2017) including materials in the production function. However, we only differentiate between energy and non-energy inputs. A representative firm i in the intermediate sector uses material inputs $M_{E,i,t}$ and a Cobb-Douglas bundle $Z_{i,t}$ of aggregate capital $K_{i,t}$ and total effective labor hours $N_{i,t}$

$$Z_{i,t} = A_{i,t} K_{i,t}^{\alpha} N_{i,t}^{1-\alpha}, \tag{4}$$

where $A_{i,t}$ is the factor productivity of the bundle and α is the output elasticity of aggregate capital provided by the household sector.

$$Y_{i,t} = \left[\gamma_m^{1/\sigma_m} M_{E,i,t}^{\frac{\sigma_m - 1}{\sigma_m}} + (1-\gamma_m)^{1/\sigma_m} Z_{i,t}^{\frac{\sigma_m - 1}{\sigma_m}} \right]^{\frac{\sigma_m}{\sigma_m - 1}}, \tag{5}$$

$M_{E,i,t}$ consists of energy inputs $E_{Y,i,t}$ weighted by energy productivity $A_{E,i,t}$ and non-energy material inputs $M_{i,t}$:

$$M_{E,i,t} = \left[\gamma^{1/\sigma} \left(A_{E,i,t} E_{Y,i,t} \right)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)^{1/\sigma} M_{i,t}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{6}$$

These material inputs are either foreign or domestic input factors $M_{F,i,t}$ and $M_{D,i,t}$:

$$M_{i,t} = \left[\gamma_f^{1/\sigma_f} M_{F,i,t}^{\frac{\sigma_f - 1}{\sigma_f}} + (1-\gamma_f)^{1/\sigma_f} M_{D,i,t}^{\frac{\sigma_f - 1}{\sigma_f}} \right]^{\frac{\sigma_f}{\sigma_f - 1}} \tag{7}$$

[5]This fits to the value of 37.37% for the share of non-savers, which is estimated by Drygalla et al. (2020).

Equation (5) defines the production technology similar to Hassler et al. (2021) with a very small elasticity of substitution σ_m between the Cobb-Douglas-bundle and energy in the short-run, and γ_m as energy intensity parameter. The other parameters can be understood in a similar way. Total costs are made up of interest payments for capital units to households, wage compensation for labor to workers after taxes paid by the firm $\tau_{W,Y}$, and cost for energy containing intermediate input usage:

$$\begin{aligned} Cost_{Y,i,t} &= (r_{K,t}+\delta)K_{i,t} + (1+\tau_{W,Y,t})W_t N_{i,t} + P_{M,E,t}M_{E,i,t} \\ &= (r_{K,t}+\delta)K_{i,t} + (1+\tau_{W,Y,t})W_t N_{i,t} + (1+\tau_{E,t})P_{E,t}E_{Y,i,t} + P_{M,t}M_{i,t} \\ &= (r_{K,t}+\delta)K_{i,t} + (1+\tau_{W,Y,t})W_t N_{i,t} + (1+\tau_{E,t})P_{E,t}E_{Y,i,t} \\ &+ P_{F,t}M_{F,i,t} + P_{Y,t,gross}M_{Y,i,t} \end{aligned}$$

W_t is the real wage expressed in relation to the gross price $P_{Y,t,gross}$ of the numéraire good non-energy (including a value-added tax), $P_{E,t}$ the price of energy (other input prices analogous), $r_{K,t}$ the rental rate of capital, and δ the depreciation rate.
Cost minimization leads to the following first-order conditions with symmetric firms i with respect to capital, labor, foreign materials, domestic materials, and energy:

$$\frac{r_{K,t}+\delta}{MC_t} = (1-\gamma_m)^{1/\sigma_m}\alpha(Y_t/Z_t)^{1/\sigma_m}Z_t/K_t \tag{8}$$

$$\frac{(1+\tau_{W,Y,t})W_t}{MC_t} = (1-\gamma_m)^{1/\sigma_m}(1-\alpha)(Y_t/Z_t)^{1/\sigma_m}Z_t/N_t \tag{9}$$

$$\frac{(1+\tau_{E,t})P_{E,t}}{MC_t} = \gamma_m^{1/\sigma_m}\gamma^{1/\sigma}A_{E,t}^{\frac{\sigma-1}{\sigma}}(Y_t/M_{E,t})^{1/\sigma_m}(M_{E,t}/E_{Y,t})^{1/\sigma} \tag{10}$$

$$\frac{P_{F,t}}{MC_t} = \gamma_m^{1/\sigma_m}(1-\gamma)^{1/\sigma}\gamma_f^{1/\sigma_f}(Y_t/M_{E,t})^{1/\sigma_m}(M_{E,t}/M_t)^{1/\sigma}(M_t/M_{F,t})^{1/\sigma_f} \tag{11}$$

$$\frac{P_{Y,t,gross}}{MC_t} = \gamma_m^{1/\sigma_m}(1-\gamma)^{1/\sigma}(1-\gamma_f)^{1/\sigma_f}(Y_t/M_{E,t})^{1/\sigma_m}(M_{E,t}/M_t)^{1/\sigma}(M_t/M_{D,t})^{1/\sigma_f} \tag{12}$$

$$\frac{P_{M,t}}{MC_t} = \gamma_m^{1/\sigma_m}(1-\gamma)^{1/\sigma}(Y_t/M_{E,t})^{1/\sigma_m}(M_t/M_{E,t})^{1/\sigma} \tag{13}$$

$$\frac{P_{M,E,t}}{MC_t} = \gamma_m^{1/\sigma_m}(Y_t/M_{E,t})^{1/\sigma_m} \tag{14}$$

As in Calvo (1983)[6], a producer can set the individual gross price $P_{Y,i,t,gross} = (1+\tau_{NE,t})P_{Y,i,t,net}$ including a value-added tax (VAT) rate $\tau_{NE,t}$ with a probability of $(1-\theta_p)$ optimally. The other fraction θ_p of firms acts according to the pricing rule

$$P_{Y,i,t,gross} = P_{Y,i,t-1,gross}.$$

The demand for intermediate inputs is given as

$$Y_{i,t} = \left(\frac{P_{i,t,gross}}{P_{t,gross}}\right)^{-\frac{\varsigma_p}{\varsigma_p-1}} Y_t,$$

[6] We follow here Christiano et al. (2011).

with $\varsigma_p > 1$ capturing the market power of a firm that maximizes discounted profit

$$E_t \sum_{s=0}^{\infty} (\theta_p \beta)^s \nu_{t+s} D_{i,t+s},$$

where

$$D_{i,t+s} = 1/(1+\tau_{NE,t})\tilde{P}_{i,Y,t,gross} Y_{i,t+s} - \tilde{P}_{i,Y,t+s,gross} mc_{t+s} Y_{i,t+s}$$

with respect to optimal price $\tilde{P}_{i,t,gross}$. The real marginal cost mc_{t+s} is the same for all producers, and $(\theta_p \beta)^s \nu_{t+s}$ is the stochastic discount factor of the owners of the firm. Staggered price setting causes price dispersion $p^*_{Y,t,gross}$, such that output under flexible prices Y_t and actually produced output Y^*_t are related as follows:

$$Y_t = p^*_{Y,t,gross} Y^*_t \tag{15}$$

3.2 Household Sector

Produced non-energy consumption goods $C_{NE,t}$ are consumed together with energy $C_{E,t}$ by income groups $hh = 1, ..., 10$ of the same size. With decile-specific utility weight ψ_{hh} for energy and again an elasticity of substitution ϵ between non-energy and energy, the consumption basket is defined as

$$C_{hh,t} = \left[(1-\psi_{hh})^{\frac{1}{\epsilon}} C_{NE,hh,t}^{\frac{\epsilon-1}{\epsilon}} + \psi_{hh}^{\frac{1}{\epsilon}} C_{E,hh,t}^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}. \tag{16}$$

The instantaneous utility function is given by

$$U_{hh,t} = \log C_{hh,t} - A_{hh,t} \frac{N_{hh,t}^{1+\varphi}}{1+\varphi},$$

where $N_{hh,t}$ is the individual labor supply per representative household with disutility weight $A_{hh,t}$ in a decile and φ is the inverse Frisch elasticity. Depending on the type of household, there are different budget constraints.

Ricardian Households Households with savings possibilities, we refer to them as Ricardians or savers, receive capital and wage income from the firm as well as income from public and foreign bond holdings. Their capital stock evolves according to the law of motion

$$K_{hh,t+1} = (1-\delta) K_{hh,t} + I_{hh,t} \tag{17}$$

and they can decide in every period on their investments $I_{hh,t}$. They maximize their utility with respect to consumption of non-energy and energy goods, capital and domestic as well as foreign bonds subject to the real budget constraint in terms of the non-energy good price

$$C_{NE,hh,t} + (1 + \tau_{E,t} + \tau_{CE,hh,t}) P_{E,t}/P_{Y,t,gross} C_{E,hh,t}$$

$$+ K_{hh,t+1} AC_{K,hh,t} + AC_{B,hh,t} B_{hh,t+1} + AC_{B,F,hh,t} B_{F,hh,t+1} P_{F,t} + T_{hh,t}$$

$$= [1 + (1 - \tau_{K,t}) r_{K,t}] K_{hh,t} + (1 - \tau_{W,hh,t}) W_{hh,t} N_{hh,t}$$

$$+ \frac{1 + r_{B,t-1}}{1 + \pi_{Y,t,gross}} B_{hh,t} + \frac{1 + r_{F,t-1}}{1 + \pi_{Y,t,gross}} B_{F,hh,t} s_{F,t} + (1 - \tau_{D,hh,t}) D_{hh,t}/P_{Y,t,gross},$$

where $\tau_{E,t}$ and $\tau_{CE,hh,t}$ are general and individual energy consumption sales tax rates, $\tau_{W,hh,t}$ are decile specific labor income tax rates and $\tau_{K,t}$ is a capital revenue tax rate. $T_{hh,t}$ are lump sum taxes or social transfers and firm profit D_t is distributed according to their share on aggregate capital $share_{K,hh}$.

$$AC_{K,hh,t} = \exp^{\kappa_{hh}\left(I_{hh,t} - share_{K,hh} I_{t-1}\right)}$$
$$AC_{B,hh,t} = \exp^{\kappa_{F,hh}\left(B_{hh,t} - \bar{B}_{hh}\right)}$$
$$AC_{B,F,hh,t} = \exp^{\kappa_{B,F,hh}\left(B_{F,hh,t} - \bar{B}_{F,hh}\right)}$$

Lifetime utility maximization leads to the following first-order conditions:

$$\Lambda_{hh,t} = C_{hh,t}^{-1} (1 - \psi_{hh})^{\frac{1}{\epsilon}} \left(C_{NE,hh,t}/C_{hh,t}\right)^{-\frac{1}{\epsilon}} \quad (18)$$

$$\Lambda_{hh,t} P_{E,t}/P_{Y,t,gross} (1 + \tau_{E,t} + \tau_{CE,hh,t}) = C_{hh,t}^{-1} \psi_{hh}^{\frac{1}{\epsilon}} \left(C_{E,hh,t}/C_{hh,t}\right)^{-\frac{1}{\epsilon}} \quad (19)$$

$$\Lambda_{hh,t} AC_{K,hh,t} = \beta \mathbb{E}_t \Lambda_{hh,t+1} [1 + (1 - \tau_{K,t}) r_{K,t+1}] \quad (20)$$

$$\Lambda_{hh,t} AC_{B,hh,t} = \beta \mathbb{E}_t \Lambda_{hh,t+1} \frac{1 + r_{B,t}}{1 + \pi_{Y,t+1,gross}} \quad (21)$$

$$\Lambda_{hh,t} AC_{B,F,hh,t} = \beta \mathbb{E}_t \Lambda_{hh,t+1} \frac{1 + r_{F,t}}{1 + \pi_{Y,t+1,gross}} s_{F,t+1} \quad (22)$$

Euler-Equations (20) to (22) show the consumption smoothing possibility of Ricardians because they can freely choose their amount of savings and furthermore decide between investment alternatives. Note that s_f is the exchange rate.[7] $r_{F,t}$ and $r_{B,t}$ are interest rates for foreign and domestic bonds $B_{F,hh,t}$ and $B_{hh,t}$ and equal for all households.

Non-Ricardian Households Missing investment possibilities are the difference from the other group of households, so-called Non-Ricardians, hand-to-mouth or rule-of-thumb

[7] Assume that a domestic investor buys bonds worth of 100 US dollars today. The value is then given in euros per dollar, the exchange rate then is $s_{f,t} = 1\frac{EUR}{USD}$. After one year we get a return of $100USD \times (1 + r_{f,t}) s_{f,t+1}/s_{f,t}$, because the investment is denominated in the foreign currency which has to be changed back into domestic currency at exchange rate $s_{f,t+1}$. This amount has to be changed back into euros given the exchange rate $s_{f,t+1} = 2EUR/USD$. That's an appreciation of the foreign currency and a depreciation of the domestic currency which results in an effective return of $200EUR \times (1 + r_{f,t})$.

households as in Bilbiie (2008) and Galí et al. (2007). They account for 40 percent of the total population. Given their budget constraint

$$C_{NE,hh,t} + (1 + \tau_{E,t} + \tau_{C,E,hh,t})P_{E,t}/P_{Y,t,gross}C_{E,hh,t} + T_{hh,t} = (1 - \tau_{W,hh,t})W_{hh,t}N_{hh,t}$$

they get similar first-order conditions as the savers, but no Euler-equations. That implies different responses to shocks, since these households cannot use savings in the case of a crisis and spend all of their net income on consumption.

Wage Setting As in Christiano et al. (2011), all various households j per decile group have wage setting power, but only a fraction $1 - \theta_w$ can reset their wage optimally in the current period. Other households follow the rule

$$W_{hh,j,t+1} = \tilde{\Pi}_{W,hh,t+1}W_{hh,j,t},$$

where

$$\tilde{\Pi}_{W,hh,t+1} = (1 + \pi_{hh,t})^{\kappa_w}(1 + \pi_{hh})^{1-\kappa_w},\ \kappa_w \in (0, 1),$$

when setting their wage. $\tilde{\Pi}_{W,hh,t+1}$ is the underlying decile-specific expected optimal wage growth and κ_w is an indexation parameter that determines the degree to which this inflation factor is depending on current or steady state price inflation. The demand for labor varieties is given as

$$h_{hh,j,t} = \left(\frac{W_{hh,t}}{W_{hh,j,t}}\right)^{-\frac{\varsigma_w}{\varsigma_w - 1}} N_{hh,t} \tag{23}$$

and households optimize their expected lifetime disutility from labor subject to their net compensation for hours worked. Due to the staggered wage adjustment, there will be wage dispersion $w^*_{hh,t}$ which will determine the link between labor hours under flexible prices $N^*_{hh,t}$ and effective labor hours $N_{hh,t}$:

$$N^*_{hh,t} = w^*_{hh,t}N_{hh,t} \tag{24}$$

3.3 Public Sector

In the public sector real government consumption of non-energy G_t (and potential transfers to households) are financed by collected real tax revenues TR_t (in terms of $P_{Y,t,gross}$)[8]:

$$G_t = TR_t + T_t + B_t - \frac{1 + r_{B,t-1}}{1 + \pi_{Y,t,gross}}B_{t-1} - cost_{brake,t} - cost_{T,t}, \tag{25}$$

[8]The VAT rate is levied on the net price $P_{Y,t,net} = 1/(1 + \tau_{NE,t})P_{Y,t,gross}$, so the firms pay $\tau_{NE,t}P_{Y,t,net} = \tau_{NE,t}/(1 + \tau_{NE,t})P_{Y,t,gross}$ per consumption unit to the public sector. VAT payments for intermediates must be paid back to the firms, otherwise there would be double taxation.

where

$$TR_t = \frac{\tau_{NE,t}}{1+\tau_{NE,t}} Y_t^* + \sum_{hh=1}^{hh=10} \left(\frac{(\tau_{E,t} + \tau_{CE,hh,t}) P_{E,t}}{P_{Y,t,gross}} C_{E,hh,t} + \tau_{W,hh,t} W_t N_{hh,t} \right)$$

$$+ \sum_{hh=1}^{hh=6} \left(\tau_{K,t} r_{K,t} K_{hh,t} + \frac{\tau_{D,hh,t}}{P_{Y,t,gross}} D_{hh,t} \right) + \frac{\tau_{E,t} P_{E,t}}{P_{Y,t,gross}} E_{Y,t} + \tau_{W,Y,t} W_t N_t - \frac{\tau_{NE,t} P_{M,t}}{P_{Y,t,gross}} M_t.$$

In case of an energy cost brake, the government has to pay $cost_{brake,t}$ and in case of transfer policies $cost_{T,t}$. Lump taxes react according to the fiscal rule

$$\frac{T_t}{Y} - \frac{T}{Y} = \phi_b \left(\frac{B_{t-1}}{Y} - \frac{B}{Y} \right) + \phi_g \left(\frac{G_t}{Y} - \frac{G}{Y} \right), \tag{26}$$

which implies that they react to deviations in the public debt to GDP share and the government spending to GDP ratio as in Galí et al. (2007).

3.4 Monetary Policy

The central bank reacts to deviations of inflation from steady state $\bar{\pi}$ and output from its growth rate. Parameters ϕ_π and ϕ_y capture the intensity of this reaction. η_r is an interest rate smoothing parameter, since the European Central Bank operated for a long time at the zero lower bound and gradually increased the nominal interest rate during the energy crisis. $\epsilon_{r,t}$ is a term for possible monetary policy shocks.[9]

$$\frac{1+r_{B,t}}{1+\rho} = \left(\frac{1+r_{B,t-1}}{1+\rho} \right)^{\eta_r} \left[\left(\frac{1+\pi_t}{1+\bar{\pi}} \right)^{\phi_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\phi_y} \right]^{1-\eta_r} \exp(\epsilon_{r,t}) \tag{27}$$

3.5 Rest of the World

Germany as small open economy conducts trade with the rest of the world. Net exports NX_t are given as

$$NX_t = P_{Y,t,gross} X_t - P_{F,t} M_{F,t} + P_{E,t}(E_{D,t} - E_t), \tag{28}$$

where X_t are exports to the rest of the world. Since there is also domestic energy production, domestic energy consumption is corrected by domestic energy supply, which is part of energy production inputs.

3.6 Market Clearing

We assume that all markets are cleared in equilibrium. The gross domestic product in nominal terms consists of private consumption expenditures, investments, government spending, and net exports:

$$GDP_t = P_{Y,t,gross} C_t + P_{Y,t,gross} I_t + P_{Y,t,gross} G_t + NX_t$$

[9]This rule is quite similar to the linear rule of Christiano et al. (2011).

4 Data and Calibration

We use our TENK model to analyze actual implemented fiscal policy measures to mitigate the impacts of the energy crisis in Germany. We set shock series to approximate data for energy inflation, consumption, GDP, and (non-)energy inflation for the total time period. Time series data start in 2004-Q1, where net foreign asset positions have been approximately equal to zero, so that we declare this period as steady state in our open-economy model. The last observation is from 2024-Q3. The distributional key variables are matched to the data at the decile level.

4.1 Calibration of Key Structural Parameters

Our calibration reflects a quarterly capital depreciation rate of 1.5 percent as in Drygalla et al. (2020) and a time preference rate of 0.1 percent. The energy share on total production is set to 2.59 percent. This value is calculated given the OECD input-output tables on mining and quarrying, energy-producing products for Germany in 2018. For capital, it is set to the usual value of 30 percent, resulting in a labor share of around 67 percent. We choose a low elasticity of substitution between energy and non-energy on the production and household sector to reflect the limited ability to react by using different inputs or consumption goods in case of rising energy prices in the short run. The Frisch elasticity of labor supply is equal to 1 for households. We set the degree of wage rigidity to 0.75 and the markup parameters determined by the substitution elasticity between production and labor input to 1.2 as in Christiano et al. (2011). The monetary policy parameters are equal to $\phi_\pi = 1.5$, $\phi_y = 0.25$, and $\eta_r = 0.87$ for the smoothing parameter as in Christiano et al. (2011). We assume a zero inflation steady state. The values of the parameters are documented in Table 1, for a complete overview, please consult Appendix B. Hand-to-mouth consumers are 40 percent of the population, given the estimated share in Drygalla et al. (2020). Our model replicates the observed income and consumption distribution. For this purpose, we use data from the income and consumption survey provided by the German Statistical Office, as well as income data from the socio-economic panel by DIW. Figure 4 compares the steady state distribution between model and data. This excellent fit to the data is done using different instruments as tax rates and shares in our model. For further information, see Appendix B.

At the aggregate level, we use data from the Eurostat and OECD input-output tables to calculate shares on the gross domestic product. Furthermore, based on tax revenue data from the German Statistical Office, we check if our model can also predict the steady state shares of collected taxes on gross domestic product. Figure 3 shows the comparison between data and the model.

Table 1: Calibration of Parameters

Parameter		**Value (Source)**
$share_E$	energy share on GDP	0.03 (OECD)
δ	depreciation rate of capital	0.015 (DHK)
ρ	time preference rate	0.001 (calibrated)
φ	inverse Frisch elasticity of labor supply	1 (calibrated)
ϵ	substitution elasticity (non-)energy consumption	0.12 (calibrated)
σ_M	elasticity of substitution capital-labor and energy	0.1 (calibrated)
θ_p	degree of price rigidity	≈ 0 (calibrated)
θ_w	degree of wage rigidity	0.8 (calibrated)
κ_w	wage inflation indexation parameter	1 (CWT)
ς_p	mark-up parameter production sector	1.2 (CWT)
ς_w	mark-up parameter labor markets	1.8 (calibrated)
ϕ_π	monetary policy inflation reaction parameter	1.5 (calibrated)
ϕ_y	monetary policy output reaction parameter	0.25 (calibrated)
ρ_ν	monetary policy shock persistency	0.5 (calibrated)
η_r	interest rate smoothing parameter	0.87 (CWT)
η_g	government deficit reaction	0.86 (calibrated)

Sources: Christiano et al. (2011) (CWT), Drygalla et al. (2020) (DHK) and OECD input-output-tables. Other parameters are calibrated based on a common range of values in the literature.

4.2 Energy Crisis

Our strategy is to simulate different fiscal policy scenarios and to compare them to a benchmark scenario without any intervention during the energy crisis. We calibrate the shock variable $\epsilon_{E,t}$ to capture the observed development in energy consumer price inflation over the last two decades. Furthermore, according to AGEB reports, there has been a reduction in total energy use of 5 to 6 percent in the year 2022, around 8 percent in 2023, and roughly 2.6 percent relative to the previous year. In order to approximate this loss, we first introduce energy efficiency shocks in our production function such that the productivity of energy use deviates from steady state $\bar{A}_E$:

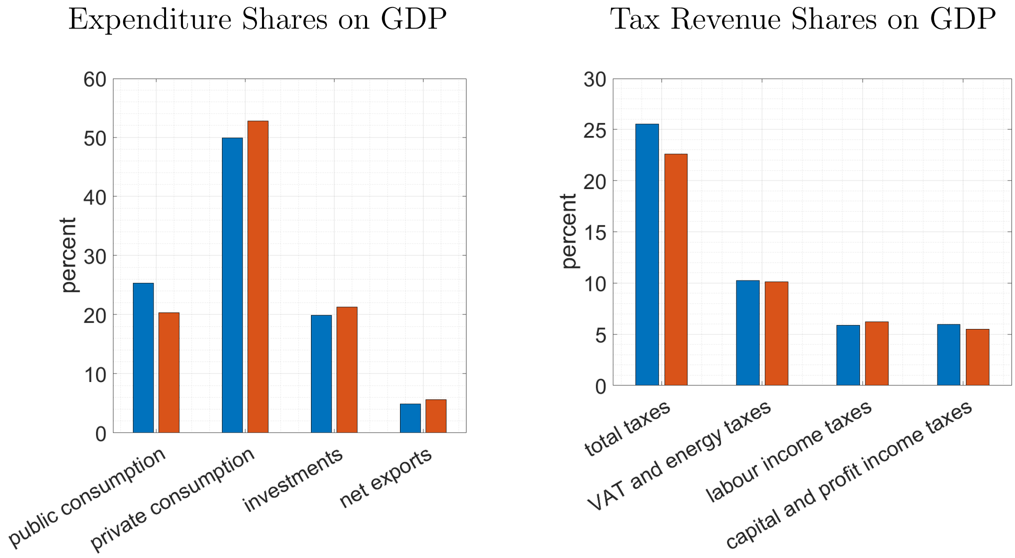
$$A_{E,t} = \exp(\epsilon_{A_{E,t}})\bar{A}_E$$

Second, we choose certain values of elasticities of substitution between non-energy and energy for consumption and production.

4.3 Fiscal Intervention

In response to the energy shock, the German government implemented a broad scope of fiscal policy measures. Our instruments can directly affect all households or company owners. In addition, our model explicitly considers instruments targeting different deciles of households. There have been three relief packages and a so-called "Abwehrschirm"

Figure 3: Aggregate shares on GDP.



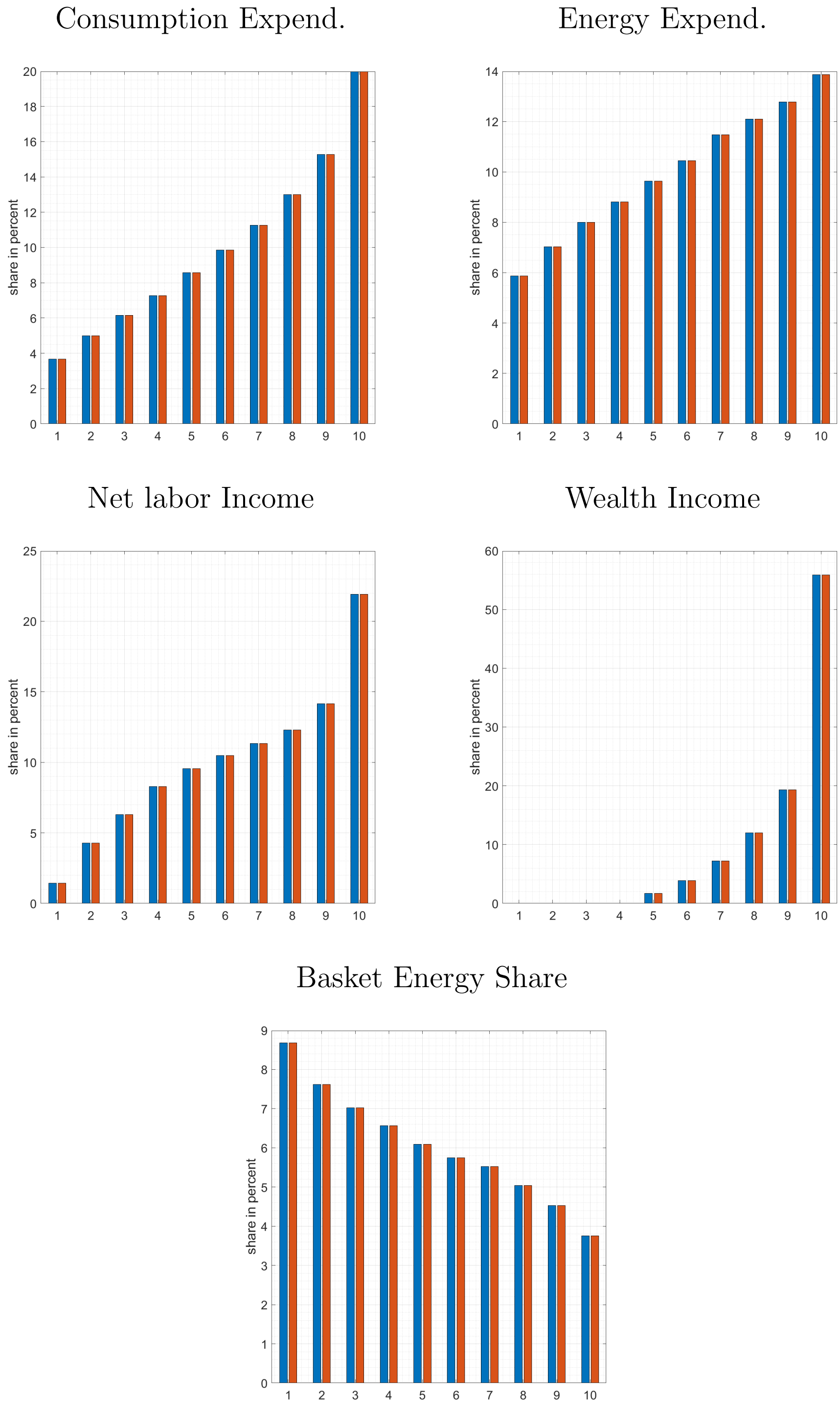
Note: steady state shares of public spending, private consumption expenditures, investments and net exports on GDP (left); steady state shares of aggregate tax revenues on GDP (right). Comparison between model (blue) and data (orange).
Sources: Eurostat and Statistical Office of Germany.

(German for defense shield), where only the defense shield has a volume of around 200 billion euros. Hence, together with the measures during the COVID-19 crisis, the 2020s have been characterized by significant fiscal interventions. In part, there has been an overlap of instruments related to Corona and the energy crisis. We use Table 1 of Bayer et al. (2023b) where all support measures are presented with cost estimates for each year. We calculate the specific amount in euros per quarter given the respective periods of implementation (where one must consider that the budget effectiveness can differ). After that, we allocate them to different policy instruments in the model. There are three groups of transfer instruments: transfers to all deciles (for example, one-off child benefit bonus and long-distance commuter allowance), transfers to Ricardians (for example business aid) and transfers targeted to poorer deciles, the Non-Ricardians (for example, one-off payments to social transfer recipients and a heating subsidy for housing benefit recipients). Furthermore, we model the energy cost brake as described in Section 5. Another energy-related measure has been the reduction of the sales tax on gas from 19 percent to 7 percent. In addition, the energy tax on fuels has been reduced. Furthermore, we will also look at the isolated effect of the temporary reduction in the VAT rate on the gastronomy sector that has already been decided during the Corona recession. Section 5 provides information on the respective simulated policy measure.

4.4 Aggregate Dynamics

Following the COVID-19 crisis, it becomes clear that the economy has been far from a long-term equilibrium when the energy crisis occurred. Our open economy set-up requires

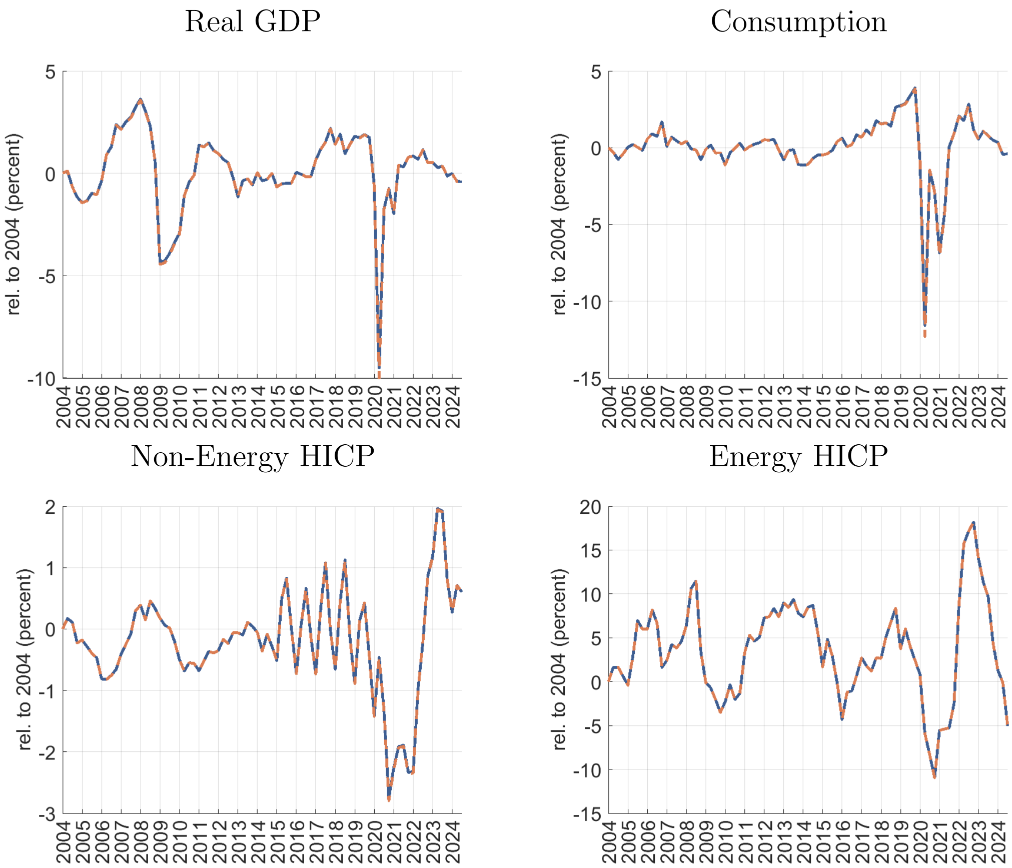
Figure 4: Distribution of income and consumption.



Note: steady state consumption and income shares in percent per decile: share of individual on aggregate consumption expenditures, share of individual on aggregate energy expenditures, share of individual energy expenditures on individual total consumption expenditures, share of individual on aggregate net labor income, share of individual on aggregate wealth income. Comparison between model (blue) and data (orange).
Sources: Statistical Office of Germany and Socio Economic Panel, DIW Berlin.

a balanced long-run foreign net wealth position and therefore an external trade balance equal to zero. Therefore, we start in 2004-Q1, the last time the net foreign asset position has been zero in Germany. We replicate the actual deviations from the trend of GDP, consumption, energy inflation, and inflation given the implemented mix of fiscal policy measures in our period of interest, the energy crisis. The variables we focus on are output, consumption, and (non-)energy inflation.[10]

Figure 5: Development of aggregate key variables over time.



Note: Data from the model (solid blue) are results from simulations with the actually implemented fiscal policy mix in Germany during the energy crisis and show the deviation from 2004-Q1. Actual quarterly data (orange dashed) are HP-filtered and represent the deviation from long-term trend with 2004-Q1 as reference period. Sources: Eurostat and own computation. For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Our model replicates the development of these aggregate variables considering all actual policies implemented using productivity shocks on the supply side to match production, preference shocks on the demand side to replicate consumption, and inflation

[10] National accounts data are from Eurostat table namq_10_gdp. We calculate real GDP and real consumption using the respective deflator. Inflation data are from the Eurostat table prc_hicp_midx and aggregated to quarterly values. We remove the trend from the time series using an HP-filter. Data for the net foreign asset position are from the Bundesbank downloaded on December 17th 2024.

shocks to capture price development (see Figure 5). Note that the data report the actual situation in Germany given the fiscal response; consequently, we use the case with all instruments for the matching scenario.

5 Effectiveness of Policy Measures

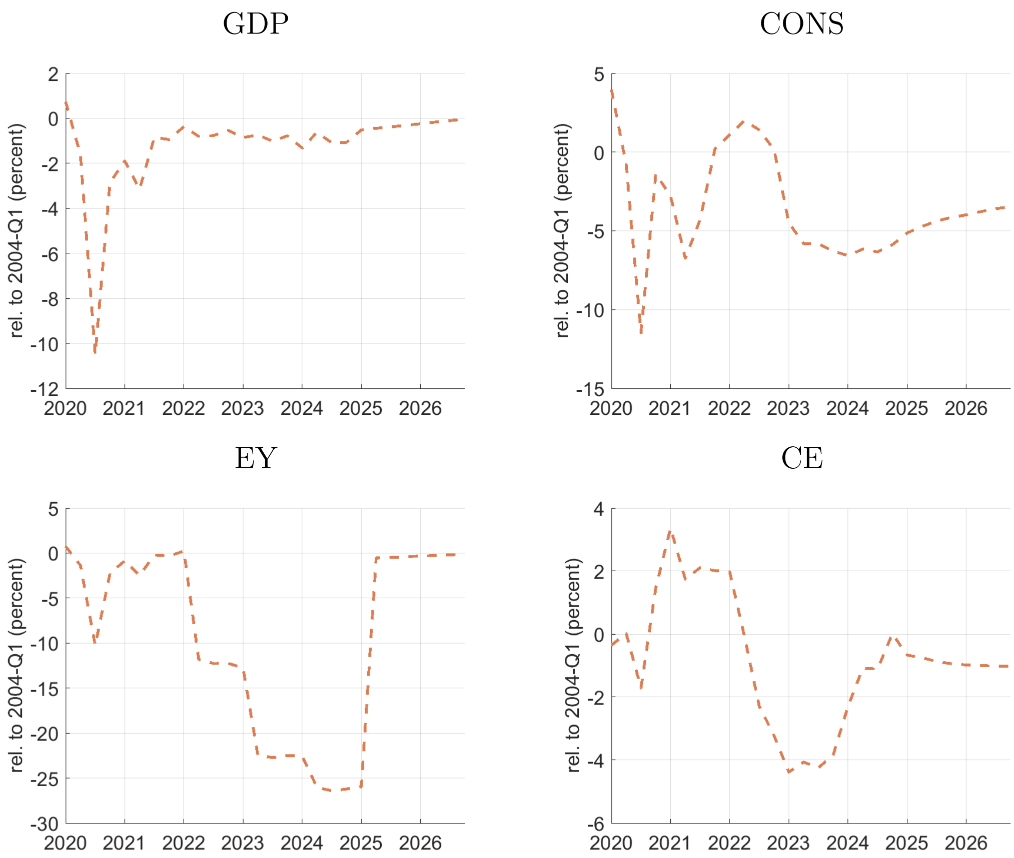
The analysis begins by examining the economic effects of the energy crisis under a baseline scenario without fiscal reaction. Therefore, the scenario represents a counterfactual world without any policy interventions. We then assess the impact of targeted transfers, focusing on low-income deciles. Next, we compare them to untargeted transfers that address all income groups. Additionally, we evaluate the implications of a value-added tax adjustment, as well as instruments such as reductions in gas and fuel taxes. The analysis also considers the role of an energy cost brake designed to limit energy bills. Finally, we examine the combined effect of all measures, providing a comprehensive overview of possible policy responses to the energy crisis.

5.1 Energy Crisis without Policy Response

The effects of the energy crisis on the aggregate level without policy interventions show how different the COVID-19 recession and the subsequent energy crisis are (see Figure 6 and Appendix A). During COVID-19 GDP dropped by almost 10 percent compared to 2004-Q1, while during the energy crisis GDP remained relatively stable. At the same time consumption declines in a counterfactual world without any policy interventions during the energy crisis, while quarterly energy inflation matches the observed development until 2024-Q3. Compared to the unprecedented impact of COVID-19, the energy crisis appears to be insignificant, but there are certain mechanisms at work and it shows that there has not been a recovery to the level in 2019-Q4 or even to the long-term trend since 2004-Q1. Higher energy cost will not only reduce energy inputs by 26 percent at the peak but also capital-labor compared to 2004-Q1. That leads to a drop in the respective factor prices wages and rental rate for capital. This loss in income and the higher cost for energy consumption, which is complementary to non-energy consumption, will cause a reduction in energy and total consumption by around 4 and around 5 percent, respectively, at the peak. Households are facing a significantly higher cost of purchasing in times of smaller income during the severe energy crisis periods. In total, GDP will shrink by around 1.5 percent at maximum and total energy use matches approximately the fall of over 6 percent in 2022 and 2023, and 3 percent in 2024, relative to the respective previous year on average. Investments exhibit significant volatility in response to changes in the interest rate. Government debt rises in both crises. During the early deflationary period of the COVID-19 pandemic, interest rates for bonds decreased. In contrast, in the subsequent quarters marked by expected inflation, these interest rates increased.

There are differences at the household level in the reactions of income deciles and individual changes in the consumer price index (see Figure 7). Deciles at the bottom of the income distribution react especially sensitively to the increase in energy prices in comparison to unconstrained households and have a more volatile response over time.

Figure 6: Dynamics on aggregate level without policy intervention.



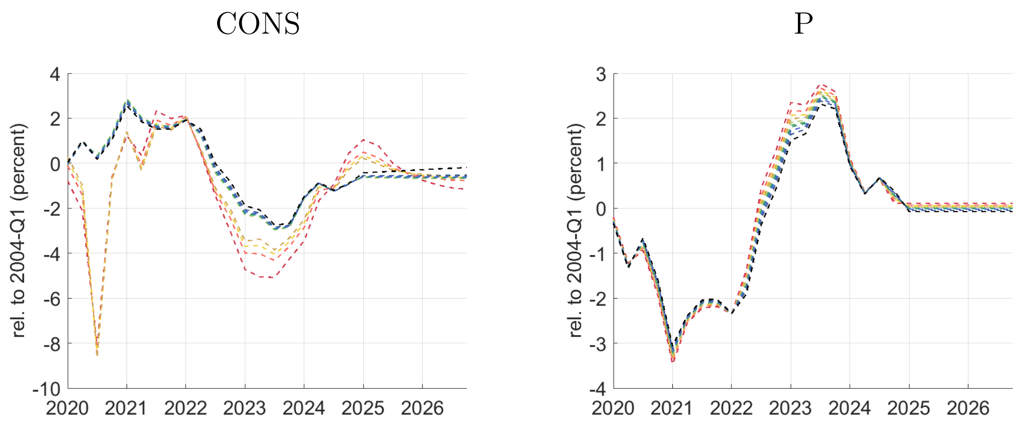
Note: Development of gross domestic product (GDP), consumption expenditures (CONS), energy input (EY), and energy consumption (CE) in the baseline scenario without any fiscal intervention. For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

One reason is that their consumption directly follows the loss in income. Second, the share of energy in the consumption basket is higher, so that the decile-specific inflation rate depends more on the development of energy prices. In general, the energy crisis leads to a recession and has distributional implications. Lower income deciles suffer more from rising energy prices than Ricardians. Our findings from this simulation raise the question of how policy interventions change the effects of the energy crisis. Therefore, the following scenarios will show instruments that have been implemented by the German government.

5.2 Targeted Transfers

One measure that addresses these distributional concerns are targeted lump sum transfers to constrained households. We understand these overall as targeted measures because they directly affect vulnerable groups during this crisis. They can potentially allow balancing consumption expenditures in times of losses in purchasing power of income. The German

Figure 7: Dynamics on decile level without policy intervention.



Note: Development of decile-specific consumption and price index in the baseline scenario without any fiscal intervention for decile 1 (dark red), decile 2 (salmon red), decile 3 (yellow), decile 4 (ocher yellow), decile 5 (light green), decile 6 (green), decile 7 (turquoise), decile 8 (blue), decile 9 (dark blue), and decile 10 (black). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

government decided on a wide range of supportive measures, listed in Table 2.

Table 2: Targeted measures to liquidity constrained households in Germany.

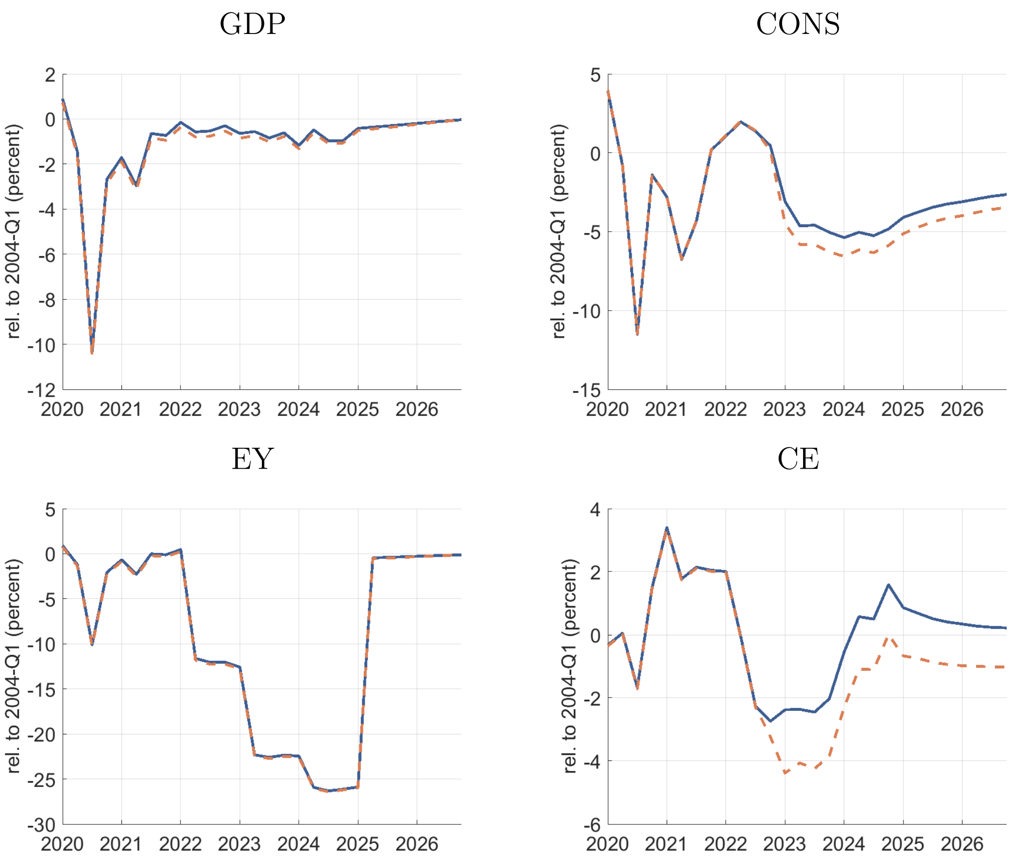
Lump Transfer Policy Measure	**Total Cost in Bill. euros 2022-2026**
Payment for recipients of unemployment benefit and social transfers 100/200 euros	1.2
Bonus for children in poverty	3.6
Heating cost subvention for low-income households and housing benefit recipients	1.0
Increase in minimum wage and changes for marginal employment	-0.7
Pensioner's bonus (300 euros)	6.4
Student bonus (200 euros)	0.7
Housing benefit reform	11.6
Introduction citizens money	21.2
Increase in midi-job limits	3.2
Elimination of double taxation of pension contributions	5.0
Total sum	**53.2**
Approximate share on nominal GDP 2022-2026	**0.25%**

Source: Bayer et al. (2023b), Table 1. Own choice of allocation to targeted transfers. GDP data are from AMECO6.

In total, these interventions account for approximately 0.25 percent of the German nominal GDP between 2022 and 2026. Hence, we calibrate the size of transfers to the respective share on GDP, distributed equally among deciles 1 to 4. In the model, we use quarterly values depending on when a single measure has been implemented and how large the fiscal costs have been in the respective year.

Solid lines represent the effects of the policy in Figures 8 and 9 compared to the dot-

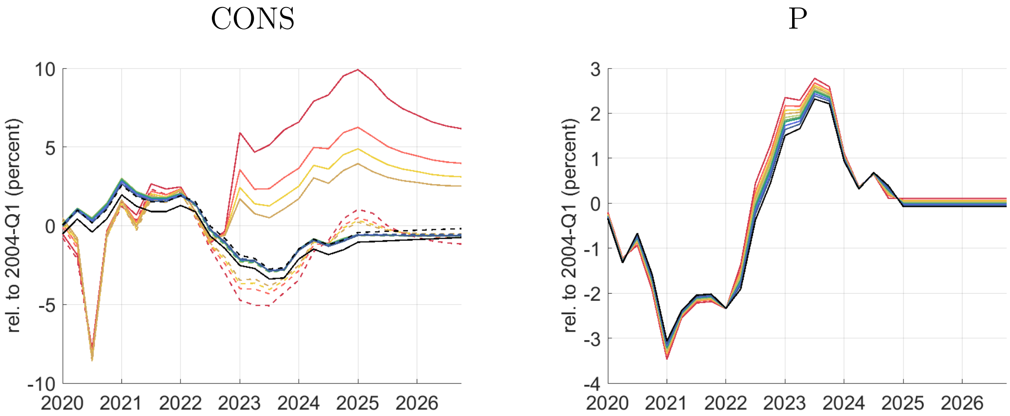
Figure 8: Dynamics on aggregate level with targeted transfers.



Note: Development of gross domestic product (GDP), consumption expenditures (CONS), energy input (EY), and energy consumption (CE) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

ted baseline without policy. An increase in aggregate total and energy consumption, as well as GDP, appears compared to baseline. Energy inputs for production do not react significantly, neither do decile-specific consumer price indices.

Figure 9: Dynamics on decile level with targeted transfers.



Note: Development of decile-specific consumption and price index for decile 1 (dark red), decile 2 (salmon red), decile 3 (yellow), decile 4 (ocher yellow), decile 5 (light green), decile 6 (green), decile 7 (turquoise), decile 8 (blue), decile 9 (dark blue), and decile 10 (black) in the fiscal policy scenario (solid lines) compared to the baseline scenario without any fiscal intervention (dotted lines). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Labor income increases relatively to the baseline, and there is a larger stock of capital with a slightly lower rental rate, furthermore, a strong reaction of public debt with a stable interest rate. Targeted households are even better off than in the pre-double-crisis state in terms of consumption, while a very small negative spillover effect can be observed on Ricardian households who have investment possibilities and are aware of potential future tax increases after costly interventions.

5.3 Untargeted Transfers

In opposite to these targeted transfers to vulnerable deciles, there have also been measures affecting all households or only the richer deciles in a direct way. As next step, we simulate a scenario with those two instruments, where again we match the quarterly cost as share on GDP in our model. Table 3 provides an overview of the single items in this basket, which in total represent around 1.21 percent of GDP.

Table 3: Untargeted instruments and measures to all households and transfers to saving households in Germany.

Lump Transfer Policy Measure	**Total Cost in Bill. euros 2022-2026**
General Transfers	
Increase employee flat rate	6.6
Increase basic allowance	15.2
Long-distance commuter allowance	0.7
Short-time working benefits	0.5
Fourth Corona tax aid act	10.9
Child bonus 100 euros	1.4
Nine euros ticket	2.5
Energy price flat rate	10.4
Inflation compensation act	119.7
Successor nine euros ticket	12.0
Prolongation short-time working benefit	0.1
Adjustments home-office flat rate	3.9
Further measures	28.3
Tax exemption for payments to employees	1.2
Financial transaction	41.0
Total sum	254.4
Approximate share on nominal GDP 2022-2026	1.19%
Transfers to Ricardians	
Tax exemption for additional payments from companies to employees	1.2
Business aids	4.0
Peak compensation for energy-intensive companies	1.7
Total sum	6.9
Approximate share on nominal GDP 2022-2026	0.032%
Total sum	**260.1**
Approximate share on nominal GDP 2022-2026	**1.21%**

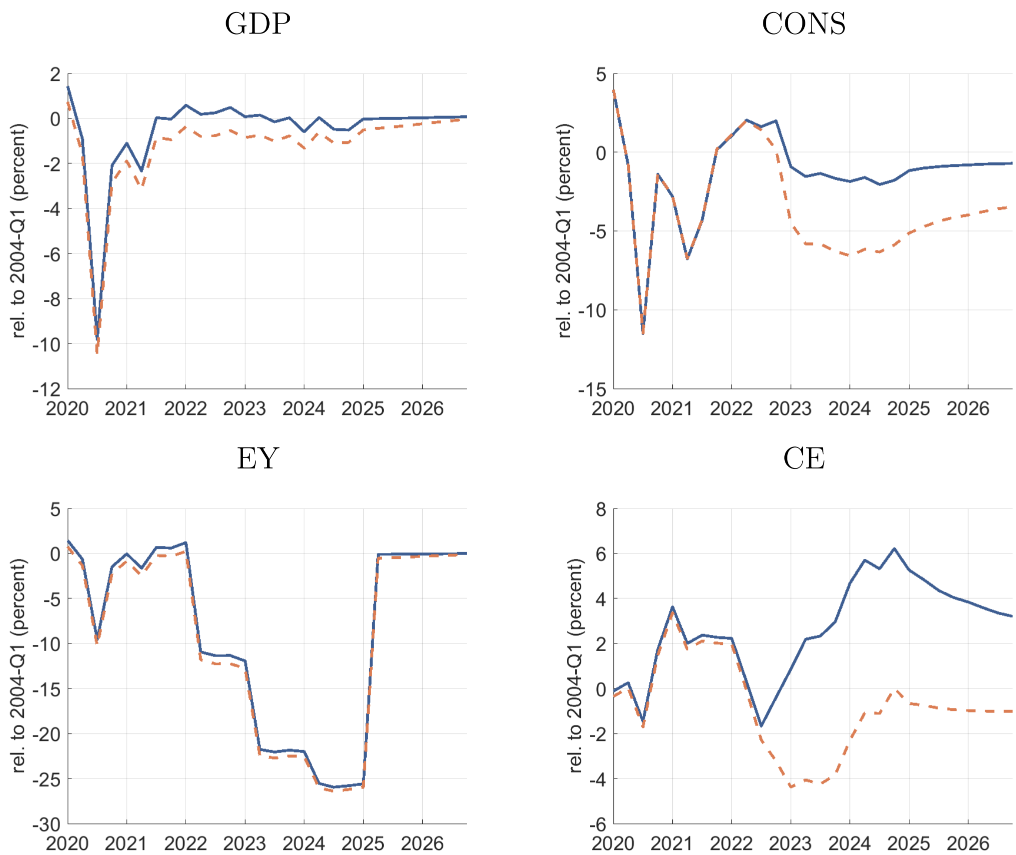
Source: Bayer et al. (2023b), Table 1. Own choice of allocation to targeted transfers. GDP data are from AMECO6.

Figures 10 and 11 present the results. These untargeted transfers have qualitatively a comparable impact on the economy, but note that the government spent a much larger amount of money for them and the effects are significantly larger. It gets clear, that also in this case, hand-to-mouth households benefit from the political intervention while wealthier deciles partly slightly reduce their consumption smoothed over time. They shift additionally available income towards capital. Given the large share in total capital stock, the richest decile prioritizes that and has a clear negative response to consumption. Again, there is no difference in individual price indices.

5.4 Value-Added Tax Reduction

A further instrument that affected all consumers has been the temporary reduction in the value-added tax rate for restaurants and catering services from 19 to 7 percent that was prolonged after the pandemic. During the double crisis, it took place from the third

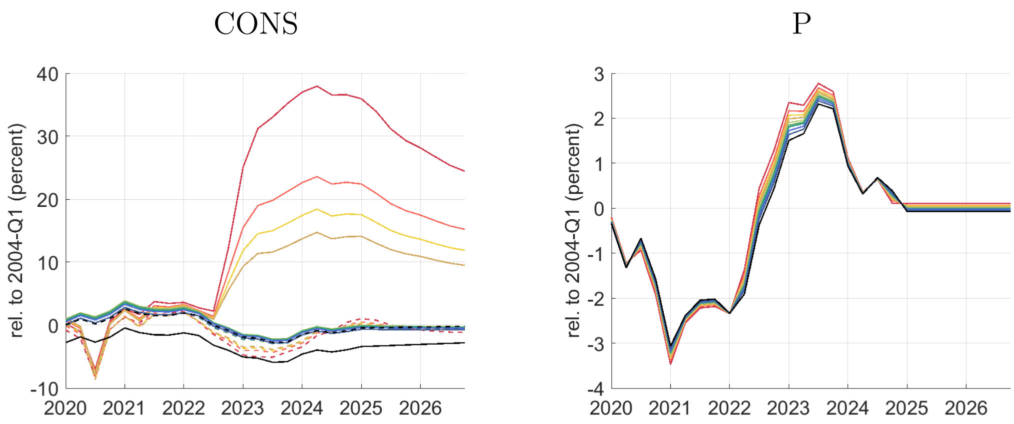
Figure 10: Dynamics on aggregate level with untargeted transfers.



Note: Development of gross domestic product (GDP), consumption expenditures (CONS), energy input (EY), and energy consumption (CE) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

quarter in 2020 to the last quarter in 2023. According to Bayer et al. (2023b), the total cost of this measure has been around 3.3 billion euros, or in other words, 0.016 percent of GDP in the respective time span, where we again take the values as well as projections from the AMECO6 database. Instead of matching the cost, we take the average share of monthly expenditures for restaurants and catering services on total private consumption purchases from the German Statical Office income and consumption survey 2018 and calculate, respectively, the decrease in the VAT rate. Quantitatively, the responses are comparable, but the effects are much smaller, as can be expected given the volume of the transfer measures (see Figure 12). Figure 13 presents the distributional impact of the tax reduction. Again, we do not see any difference in the decile-specific consumer price index.

Figure 11: Dynamics on decile level with untargeted transfers.



Note: Development of decile-specific consumption and price index for decile 1 (dark red), decile 2 (salmon red), decile 3 (yellow), decile 4 (ocher yellow), decile 5 (light green), decile 6 (green), decile 7 (turquoise), decile 8 (blue), decile 9 (dark blue), and decile 10 (black) in the fiscal policy scenario (solid lines) compared to the baseline scenario without any fiscal intervention (dotted lines).

5.5 Gas and Fuel Tax Reduction

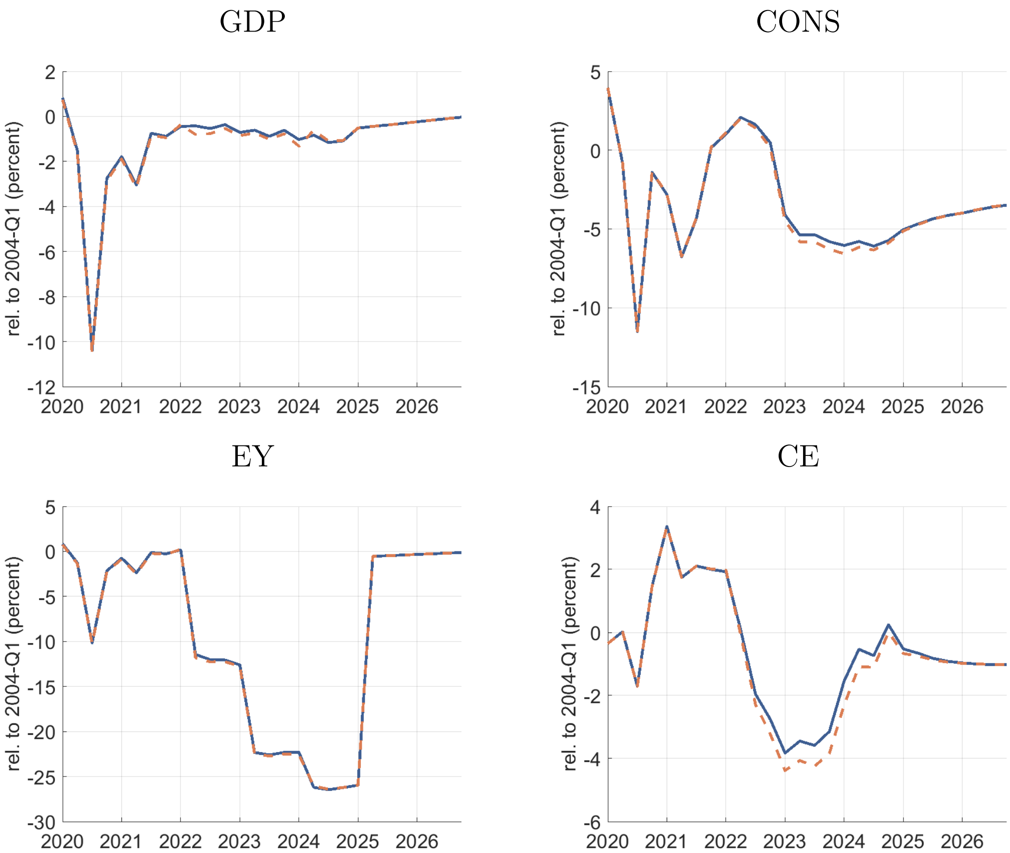
In the next step, we look at the gas and fuel tax reductions. Given the different shares of energy expenditures in the consumption basket depending on the financial situation of households, we can expect also here a distributive impact. Around 13.4 billion euros have been the cost of the gas tax reduction and 3.2 billion euros of the fuel tax cut, which makes 0.063 percent and 0.016 percent of nominal GDP, respectively. As for the other instruments, we use here Bayer et al. (2023b) and AMECO as sources. Similarly to the last scenario, we do not match the cost, but calculate the decrease in the energy tax rate based on the share of gas on total energy use as well as the usage of different mineral oils and natural gas from the AGEB Annual Reports 2022. This leads to a value of -2.8 percentage points decrease in the gas sales tax and -5.4 percentage points decrease in the fuel tax (on mineral oils and natural gas).

The observed effects are smaller than in the last scenario with value-added tax cuts, see Figure 14. The fiscal shock hits the economy in 2022-Q2 for three quarters since the tax on gas was reduced in these periods and the tax on fuels in the first shock period only. In this scenario, we can also see effects on the personal consumer price indices of deciles, which decrease slightly with this reduction in the gross price for energy, since the tax directly affects this index. The positive effects on consumption are again observable for constrained households and are smaller than in the case of direct transfers, as Figure 15 demonstrates.

5.6 Energy Cost Brake

A further scenario is the energy cost brake as it has been installed in Germany for the year 2023. For energy consumers, there have been maximum prices for electricity, gas, and district heating they have to pay if the actual market price is higher. In order to still

Figure 12: Dynamics on aggregate level with value-added tax cut.



Note: Development of gross domestic product (GDP), consumption expenditures (CONS), energy input (EY), and energy consumption (CE) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

keep the incentive to save energy, this did apply to a certain amount which has been 80 percent of the use in the previous year. Table 4 lists the conditions for private households.

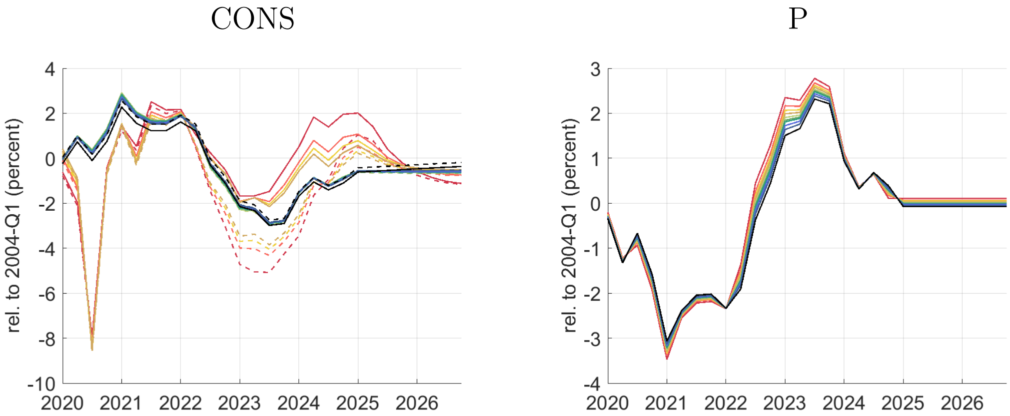
Table 4: Energy cost brake in Germany.

Energy Source	Maximum Price	Maximum Amount	Market Price
Electricity	40 ct/kWh	80% of 2022	ca. 42 ct/kWh
Gas	12 ct/kWh	80% of 2022	ca. 14 ct/kWh
District heating	9.5 ct/kWh	80% of 2022	ca. 25 ct/kWh

Source: Bundesregierung, Eurostat, FairEnergy

With average prices above the guaranteed maximum price, the cost brake has been (slightly) binding.

Figure 13: Dynamics on decile level with value-added tax cut.



Note: Development of decile-specific consumption and price index for decile 1 (dark red), decile 2 (salmon red), decile 3 (yellow), decile 4 (ocher yellow), decile 5 (light green), decile 6 (green), decile 7 (turquoise), decile 8 (blue), decile 9 (dark blue), and decile 10 (black) in the fiscal policy scenario (solid lines) compared to the baseline scenario without any fiscal intervention (dotted lines). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

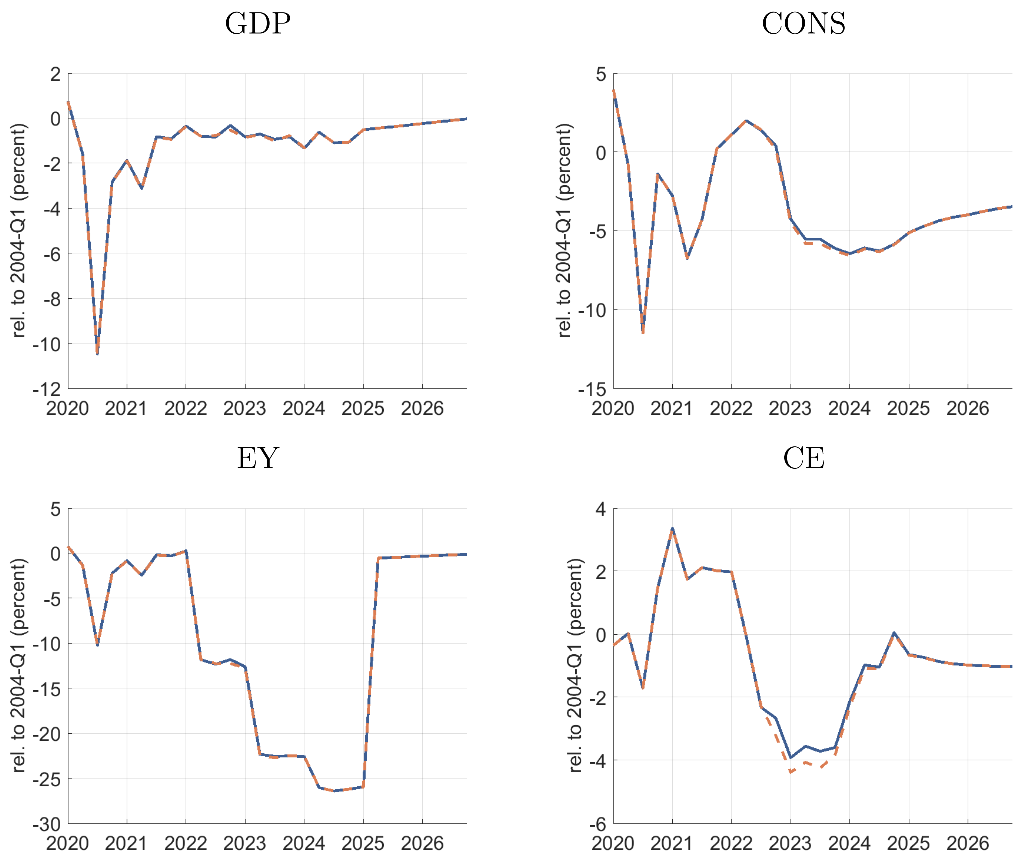
In our theoretical model we define this maximum price to pay P_E^{Max} for a certain amount of consumption $C_{E,hh}^{Max}$, where $C_{E,hh,t}^{Max} = \mu \bar{C}_{E,hh}$ is the maximum amount of consumption for which the guaranteed maximum price holds. We set $\mu = 0.8$ and $\bar{C}_{E,hh}$ as steady-state energy consumption prior to the crisis per household. There are three possible cases of consumption expenditures:

1. The brake does not bind and $P_{E,t} \leq P_E^{Max}$: In this case, consumption expenditures for energy per household can be defined in the usual way as
$$(1 + \tau_{E,t} + \tau_{CE,hh,t}) P_{E,t} C_{E,hh,t}.$$
2. The brake is binding and a household purchases less than the maximum consumption amount, i. e. $P_{E,t} > P_E^{Max}$ and $C_{E,hh,t} \leq C_{E,hh}^{Max}$: This implies consumption expenditures defined as
$$(1 + \tau_{E,t} + \tau_{CE,hh,t}) P_E^{Max} C_{E,hh,t}.$$
3. The brake is binding and a household purchases more than the maximum consumption amount, i. e. $P_{E,t} > P_E^{Max}$ and $C_{E,hh,t} > C_{E,hh}^{Max}$:
Energy consumption expenditures are then equal to
$$(1 + \tau_{E,t} + \tau_{CE,hh,t}) \left[P_E^{Max} C_{E,hh}^{Max} + P_{E,t} \left(C_{E,hh,t} - C_{E,hh}^{Max} \right) \right].$$

Bayer et al. (2023a) report cost of the energy price brake of around 106 billion euros, which is about 0.5 percent of the projected GDP of AMECO between 2022 and 2026.

The solid lines in Figure 16 show the effects with such a brake, while the dotted line

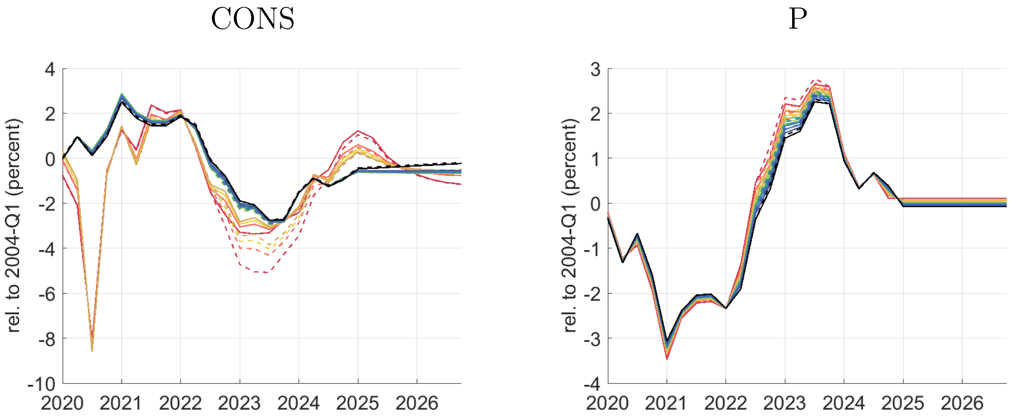
Figure 14: Dynamics on aggregate level with gas and fuel tax reduction.



Note: Development of gross domestic product (GDP), consumption expenditures (CONS), energy input (EY), and energy consumption (CE) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

again represents the baseline scenario without intervention. On the aggregate level, one can observe a slightly smaller loss in consumption relative to the steady state, but no difference in GDP. All households benefit from lower consumption expenditures with a binding-cost brake, but they react in a different way. Although liquidity constrained households react straightforwardly by consuming more than in the baseline, during the brake periods, households with saving possibilities do not react significantly. Figure 17 documents this. Decile-specific prices are not affected since this is not a price brake with direct price effect but a cost cap.

Figure 15: Dynamics on decile level with gas and fuel tax reduction.



Note: Development of decile-specific consumption and price index for decile 1 (dark red), decile 2 (salmon red), decile 3 (yellow), decile 4 (ocher yellow), decile 5 (light green), decile 6 (green), decile 7 (turquoise), decile 8 (blue), decile 9 (dark blue), and decile 10 (black) in the fiscal policy scenario (solid lines) compared to the baseline scenario without any fiscal intervention (dotted lines). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

5.7 Fiscal Package

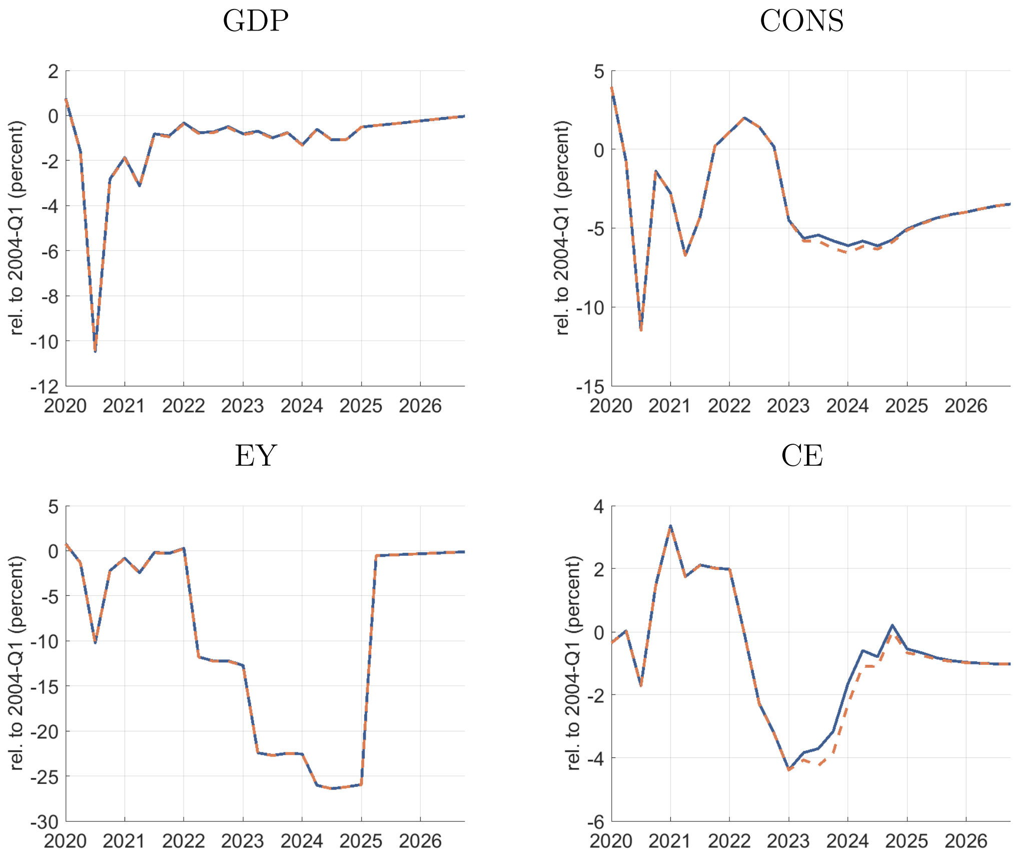
Lastly, we want to present in Figures 18 and 19 the overall effect of the fiscal package in Germany by implementing all shocks from policy scenarios in our model. The package did well in stabilizing GDP, partly almost around the pre-Covid level in 2019-Q4, but at least at the steady state in 2004-Q1, aggregate consumption could be stimulated significantly, the same counts for the use of energy. On the household level, there has not been a significant positive consumption effect on Ricardians, while lower income deciles have a strong consumption boost. Individual prices are slightly smaller than in the baseline. We see that all measures have quantitatively similar effects, with a different size and different fiscal cost. In order to make them comparable, we will analyze welfare effects in the following section and will also take a look at the cost measured by public debt of the scenarios compared to the baseline.

5.8 Welfare Analysis

In order to better compare the policy interventions, we set up a welfare measure. We specify the aggregate welfare as the sum of logarithmic functions of decile-specific utilities. This functional form is chosen because it considers the distribution among households.

$$U_t = \sum_{hh=1}^{hh=10} \ln\left(U_{hh,t}\right)$$

Figure 16: Dynamics on aggregate level with cost brake.



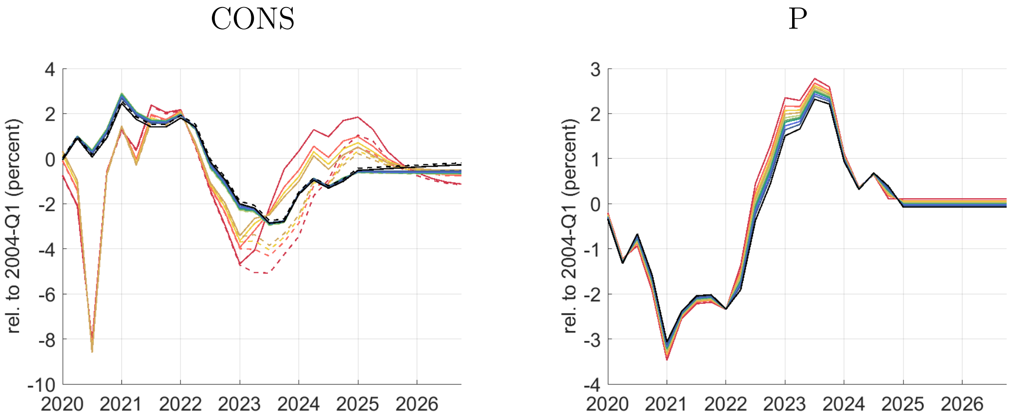
Note: Development of gross domestic product (GDP), consumption expenditures (CONS), energy input (EY), and energy consumption (CE) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line).

Aggregate discounted welfare is calculated for the first period of the energy crisis and the following years with fiscal cost:

$$W = \sum_{t=2022.00}^{2026.75} \beta^t U_t$$

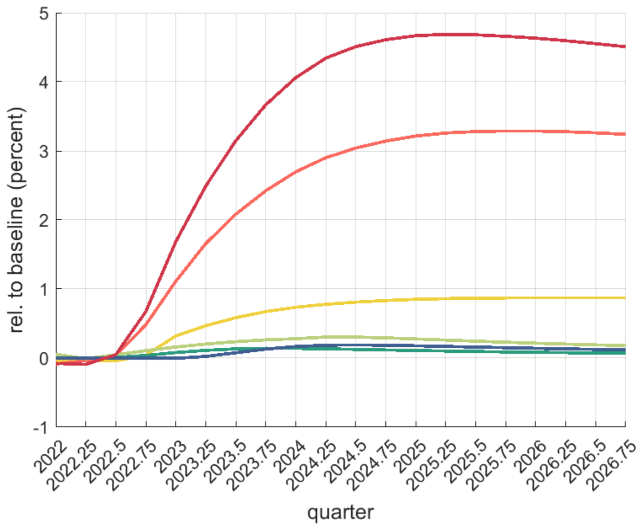
To compare several scenarios, we calculate the percentage deviations of the cumulated discounted welfare with the respective policy intervention from the cumulated discounted welfare without any measures. Figure 20 shows the welfare effects. Not surprisingly, the fiscal package has the largest welfare effects. Looking at the single measures, it turns out that the energy cost brake, and fuel and energy tax reductions contribute the least in terms of welfare while transfers are the most welfare increasing measures.

Figure 17: Dynamics on decile level with cost brake.



Note: Development of decile-specific consumption and price index for decile 1 (dark red), decile 2 (salmon red), decile 3 (yellow), decile 4 (ocher yellow), decile 5 (light green), decile 6 (green), decile 7 (turquoise), decile 8 (blue), decile 9 (dark blue), and decile 10 (black) in the fiscal policy scenario (solid lines) compared to the baseline scenario without any fiscal intervention (dotted lines). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

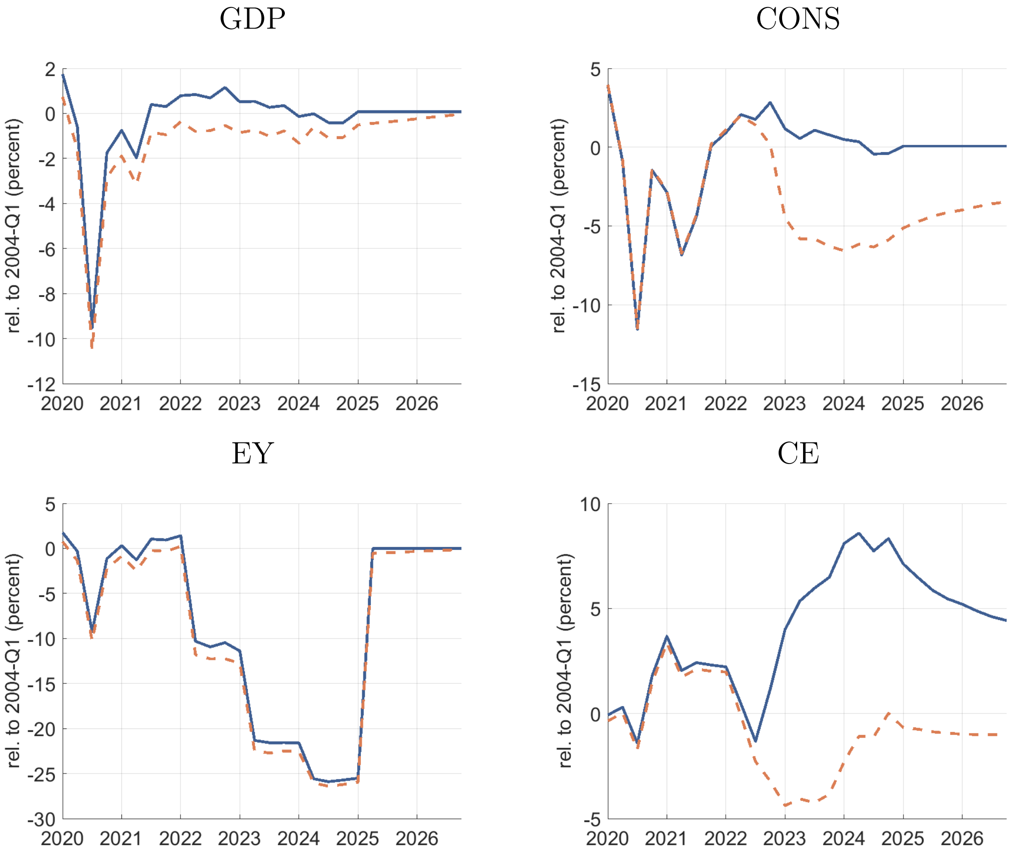
Figure 20: Welfare effects in different scenarios.



Note: Welfare effects in scenarios with targeted transfers (yellow), untargeted transfers (salmon red), value-added tax cut (light green), gas and fuel tax reductions (turquoise), energy cost brake (dark blue), and total fiscal package (dark red) compared to the baseline without intervention. For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Of course, the welfare effects depend on the costs of the respective measures, which also depend on the duration of implementation. The cost of each policy measure will

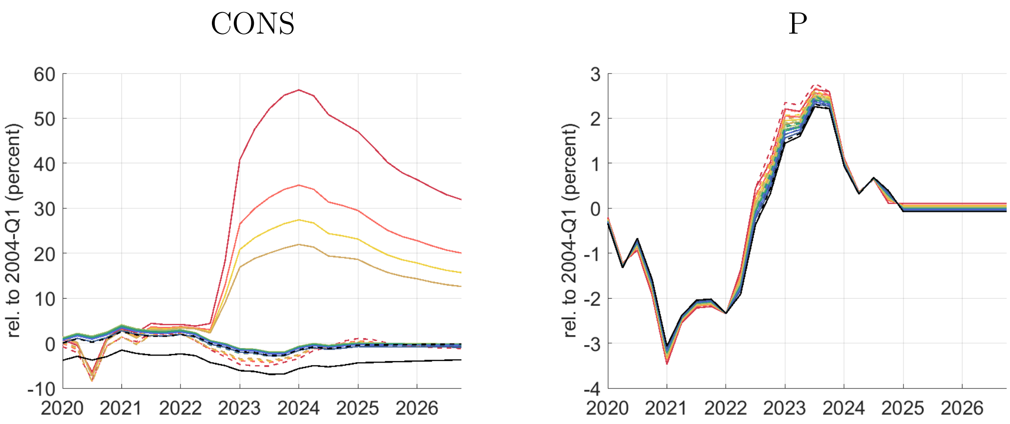
Figure 18: Dynamics on aggregate level with fiscal package.



Note: Development of gross domestic product (GDP), consumption expenditures (CONS), energy input (EY), and energy consumption (CE) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

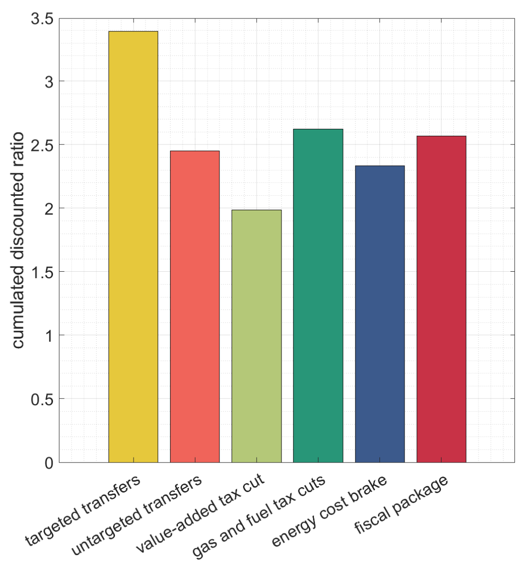
increase public debt (see Figure 21). Concerning the fiscal burden of these instruments, the smallest debt-driving effect is caused by the energy-targeted instruments, which also had the smallest welfare gains. Untargeted transfers are the instrument with the highest fiscal impact in line with the significant welfare benefit. To take a look at the cost effectiveness of the instruments and the willingness to pay given the overall impact, we compare the cumulated welfare effects to the cumulated discounted public debt in Figure 22 by calculating the ratio of deviations from baseline, reporting the cumulated value over the periods until 2026-Q3. The analysis reveals that targeted transfers and reductions in gas and fuel taxes are the most cost-effective measures, while the value-added tax reduction has proven to be the most expensive instrument relative to its implied welfare benefits. Also, the energy cost brake as well as targeted transfers show limited welfare gains compared to transfers that are solely addressing lower income deciles in a direct way.

Figure 19: Dynamics on decile level with fiscal package.



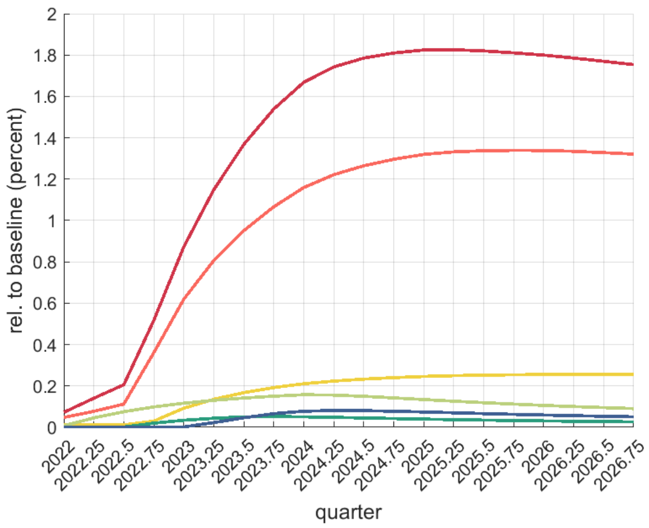
Note: Development of decile-specific consumption and price index for decile 1 (dark red), decile 2 (salmon red), decile 3 (yellow), decile 4 (ocher yellow), decile 5 (light green), decile 6 (green), decile 7 (turquoise), decile 8 (blue), decile 9 (dark blue), and decile 10 (black) in the fiscal policy scenario (solid lines) compared to the baseline scenario without any fiscal intervention (dotted lines). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Figure 22: Fiscal effectiveness in different scenarios.



Note: Fiscal effectiveness measured by the ratio between welfare and debt deviations compared to baseline in case of targeted transfers (yellow), untargeted transfers (salmon red), value-added tax cut (light green), gas and fuel tax reductions (turquoise), energy cost brake (dark blue), and total fiscal package (dark red). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Figure 21: Fiscal burden in different scenarios.



Note: Debt driving effect of targeted transfers (yellow), untargeted transfers (salmon red), value-added tax cut (light green), gas and fuel tax reductions (turquoise), energy cost brake (dark blue), and total fiscal package (dark red) compared to the baseline without intervention. For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

6 Discussion

Our findings provide detailed insights into distributional dynamics, leveraging the strengths of the TENK framework. Unlike TANK models, TENK enables a more granular examination of income distribution without the computational complexity of HANK models. Specifically, our approach accurately replicates Germany's income decile distribution and captures transition dynamics for key macroeconomic variables. This contribution bridges the gap between HANK and TANK models, circumventing the need for assumptions about idiosyncratic income or wealth risks. By utilizing decile-level data on income, wealth, and consumption, we effectively tailor the model to reflect Germany's economy.

Distinctively, our analysis aligns observed trends in GDP, consumption, and inflation with Germany's long-term trajectory, incorporating the unique policy measures enacted during the energy crisis. This approach controls for the exceptional circumstance that the energy crisis unfolded directly after the COVID-19 pandemic. By matching energy expenditure shares to total consumption per decile, we employ a streamlined methodology compared to classical HANK models, which rely on intricate micro-foundations of income distribution (Bayer et al., 2023a; Auclert et al., 2023). Our approach retains detailed heterogeneity in energy consumption, enhancing its applicability to real-world data.

Additionally, our study provides a comprehensive examination of the policy mix implemented during Germany's energy crisis. While previous research has focused on narrower interventions (Bayer et al., 2023a; Blanz et al., 2023; Gustafsson et al., 2024) or broader analyses not tied to specific countries (Auclert et al., 2023), we model Germany's unique context. By evaluating individual instruments within the relief package, we extend the literature's scope. Related studies often focus on specific energy sources, such as gas, oil, or electricity (Roeger and Welfens, 2022; Clemens and Roeger, 2023). Our broader perspective, similar to Auclert et al. (2023) and Blanz et al. (2023), considers the surge in overall energy inflation during the crisis.

One limitation of our model is the assumption of exogenous energy inflation. This precludes an analysis of potential inflationary pressures arising from fiscal interventions that increase energy demand. However, given Germany's position as a small open economy, domestic demand changes are unlikely to significantly influence global energy prices. Thus, our study focuses on the distributional and aggregate effects of fiscal measures, including their implications for government debt.

Future research should explore systematic differences in outcomes across RANK, HANK, and TENK models, as well as hypothetical policy scenarios beyond those implemented. Furthermore, the TENK framework offers considerable potential for analyzing other fiscal and monetary policy questions, particularly when investigating the interplay between aggregate and distributive effects.

7 Conclusion

We analyze the aggregate, distributive, and welfare effects of fiscal policy interventions during an energy crisis using a novel Ten-Agents New Keynesian (TENK) model. This framework incorporates ten income deciles, enabling a detailed distributional analysis. As expected, a positive exogenous energy price shock induces a recession at the aggregate level. In our simulation of a double-crisis scenario - combining the COVID-19 pandemic and energy price increases - the second crisis appears relatively milder in aggregate terms. However, its impact remains significant, as it disrupts the ongoing recovery from the pandemic. At the income decile level, consumption losses reveal notable disparities in the burden of this crisis. Lower-income households are particularly affected due to their higher share of energy expenditures relative to total consumption and their limited capacity to smooth consumption without savings. In our evaluation of fiscal policy scenarios based on measures implemented in Germany, we find qualitatively similar responses across interventions, with quantitative effects influenced by the duration of fiscal support and the magnitude of the shock. Untargeted transfers, which made up a substantial portion of the total package, proved to be more effective in stabilizing aggregate key variables and mitigating consumption losses among lower income deciles. Finally, an assessment of cumulative discounted welfare relative to public debt indicates that targeted transfers were the most cost-effective intervention.

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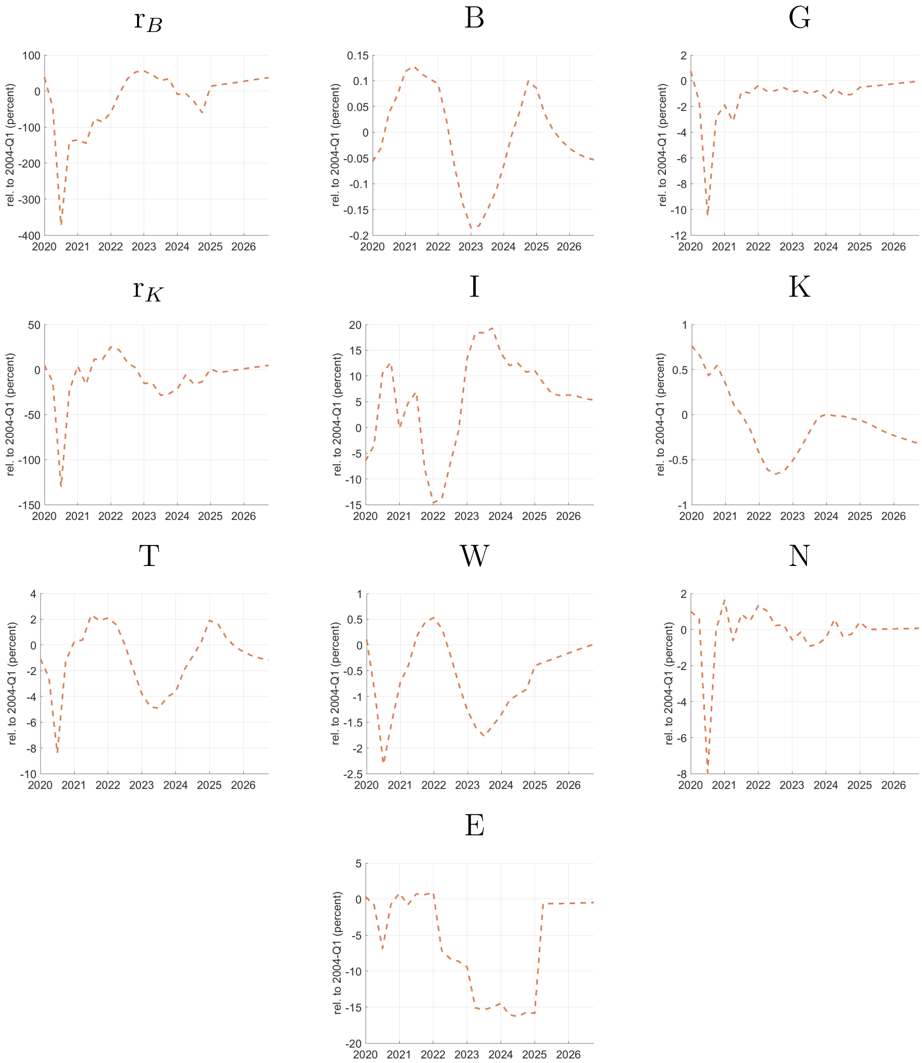
A Transition Dynamics

Energy Crisis

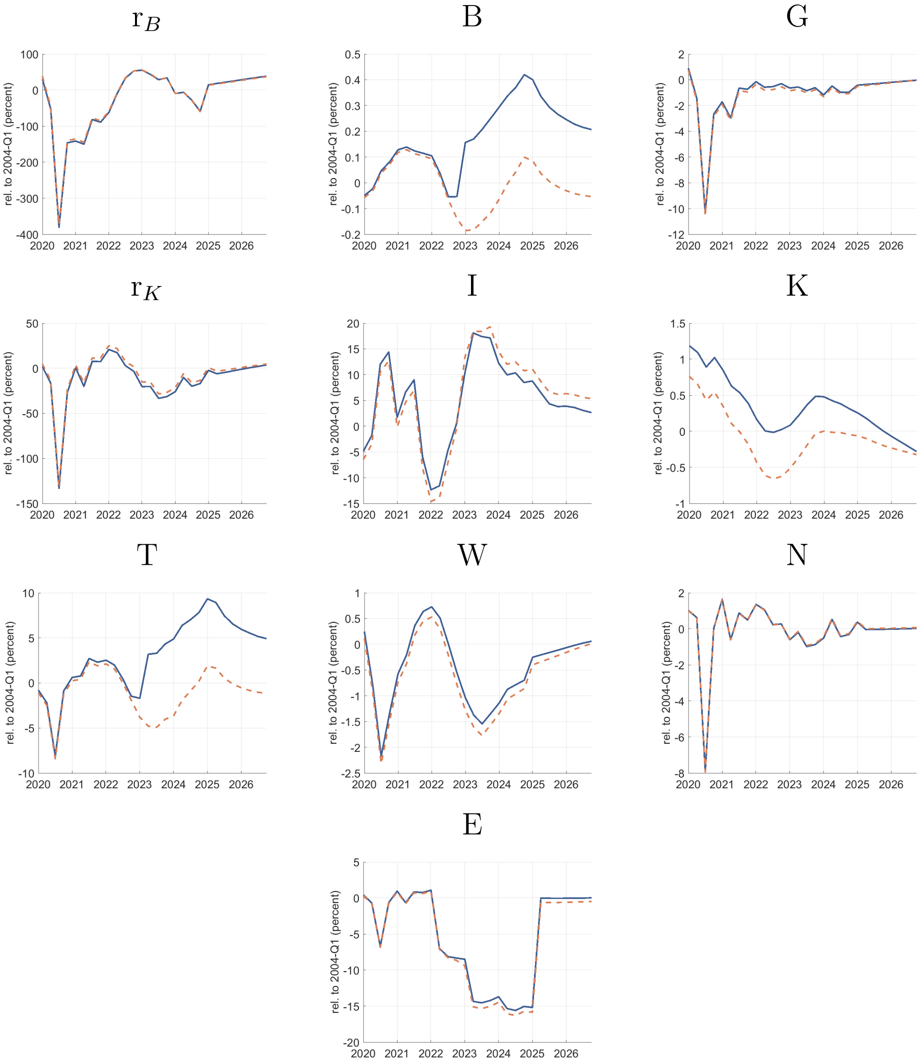
Figure 23: Dynamics on aggregate level without policy intervention.



Note: Development of nominal interest rate (r_B), debt (B), public consumption (G), rental rate of capital (r_K), investment (I), capital (K), lump-sums (T), real wage (W), hours (N), and energy use (E) in the baseline scenario without any fiscal intervention. For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Targeted Transfers

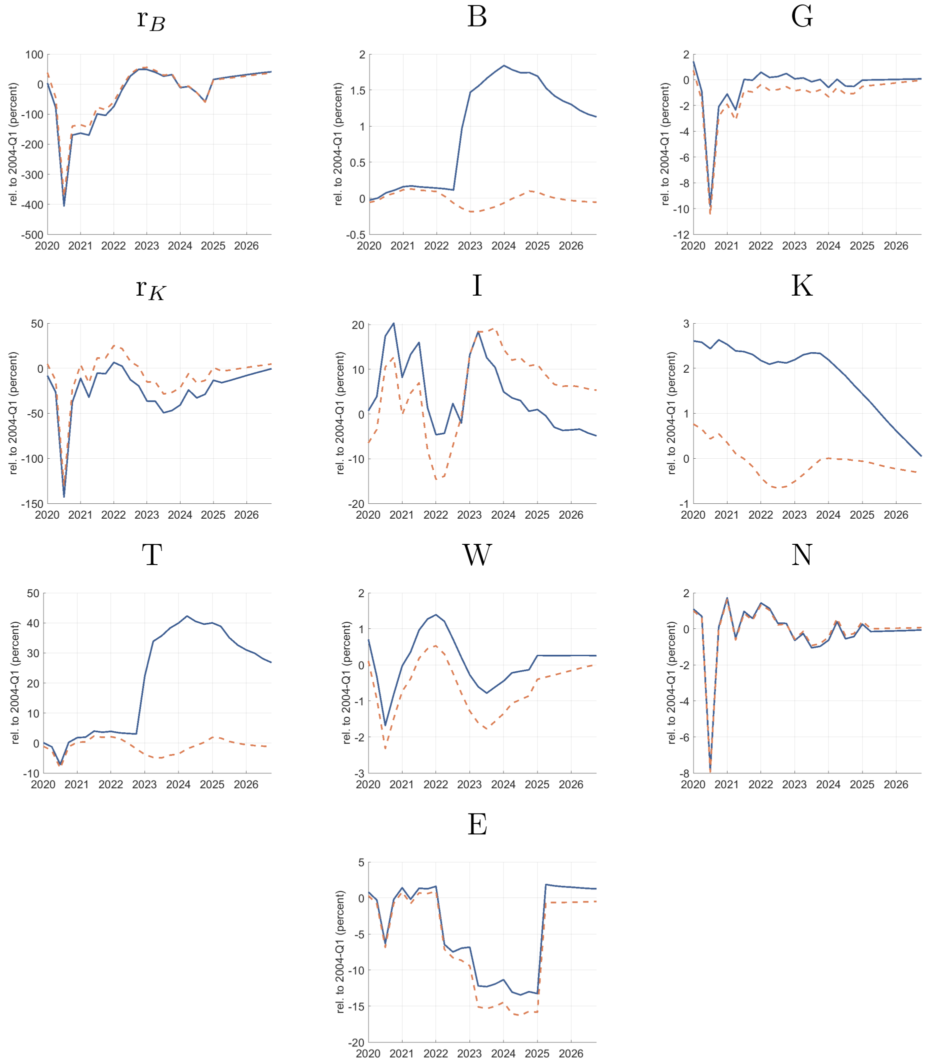
Figure 24: Dynamics of additional variables with targeted transfers.



Note: Development of nominal interest rate (r_B), debt (B), public consumption (G), rental rate of capital (r_K), investment (I), capital (K), lump-sums (T), real wage (W), and energy use (E) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Untargeted Transfers

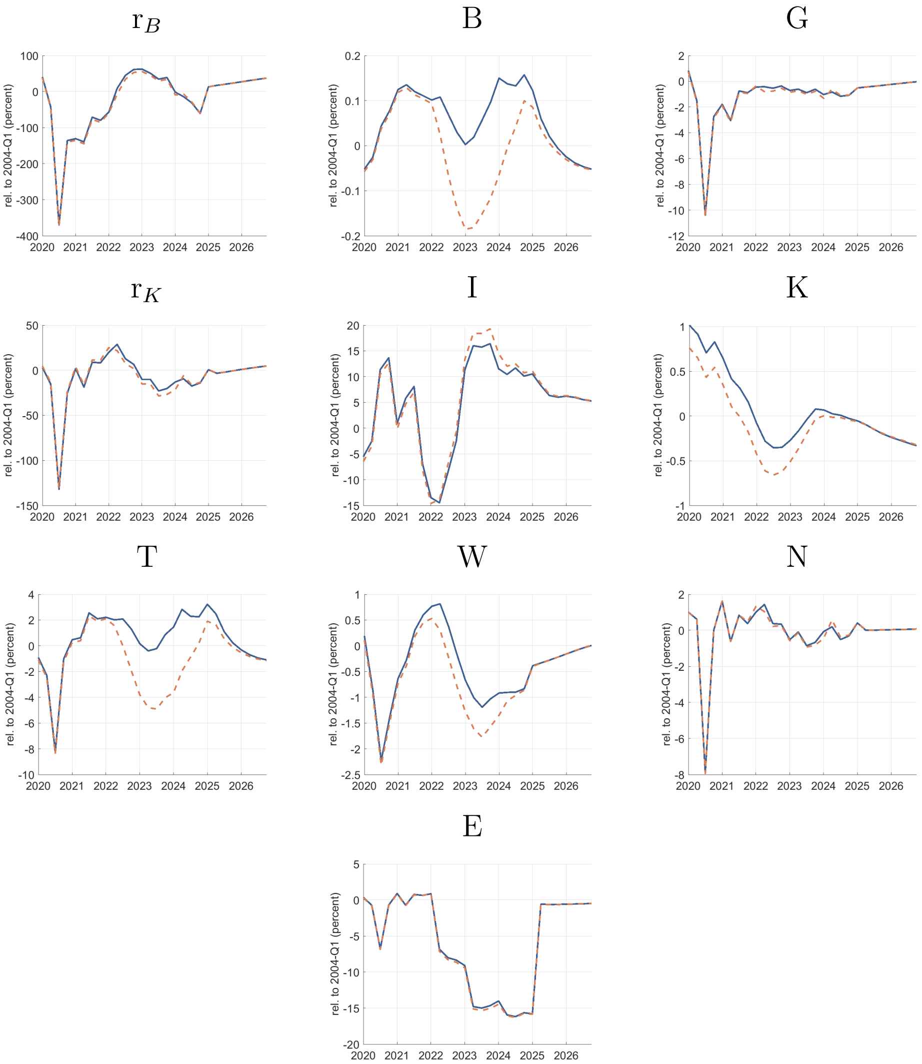
Figure 25: Dynamics of additional variables with untargeted transfers.



Note: Development of nominal interest rate (r_B), debt (B), public consumption (G), rental rate of capital (r_K), investment (I), capital (K), lump-sums (T), real wage (W), and energy use (E) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Value-Added Tax Reduction

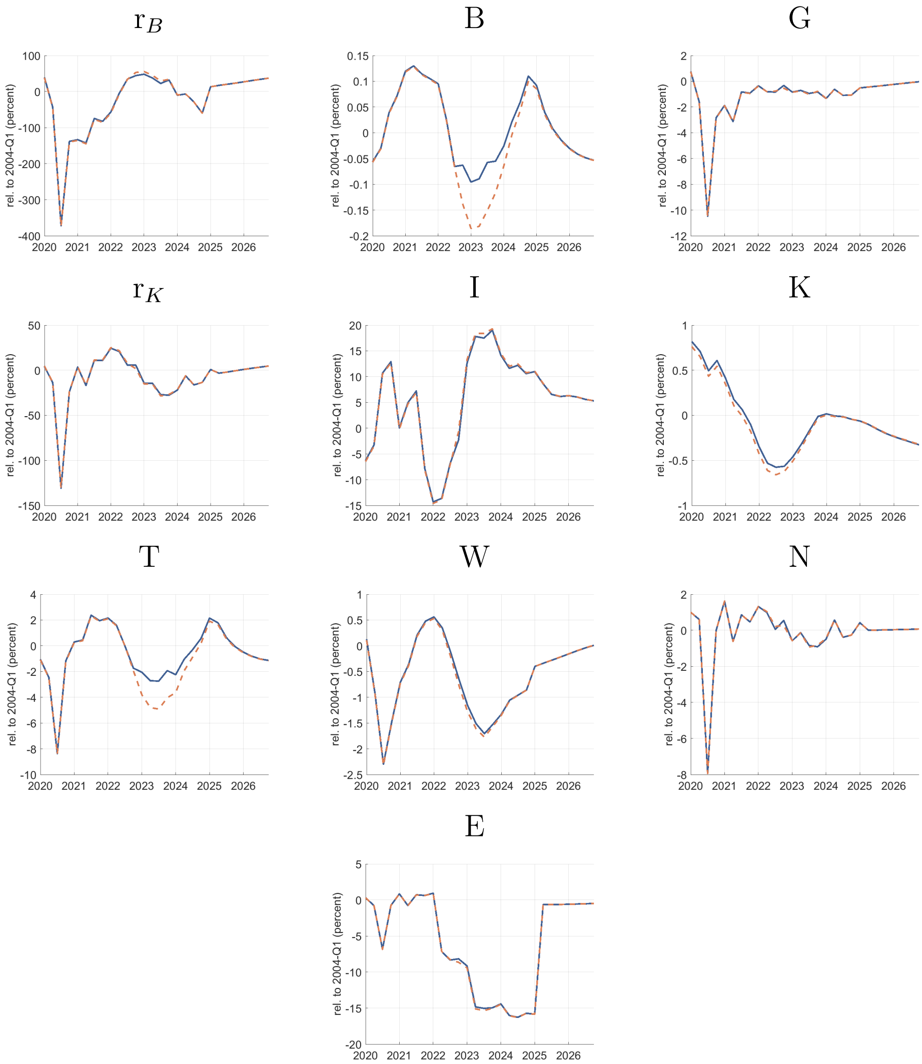
Figure 26: Dynamics of additional variables with value-added tax reduction.



Note: Development of nominal interest rate (r_B), debt (B), public consumption (G), rental rate of capital (r_K), investment (I), capital (K), lump-sums (T), real wage (W), and energy use (E) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Gas and Fuel Tax Reduction

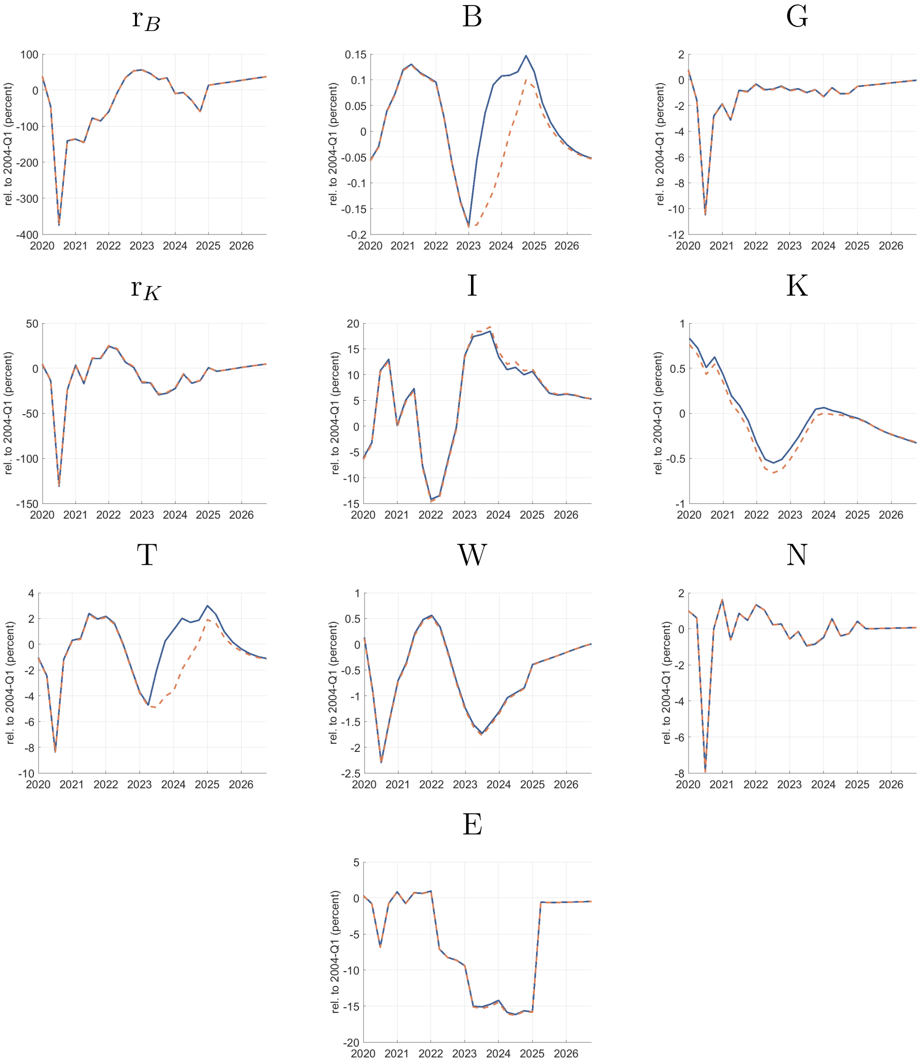
Figure 27: Dynamics of additional variables with gas and fuel tax reduction.



Note: Development of nominal interest rate (r_B), debt (B), public consumption (G), rental rate of capital (r_K), investment (I), capital (K), lump-sums (T), real wage (W), and energy use (E) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Energy Cost Brake

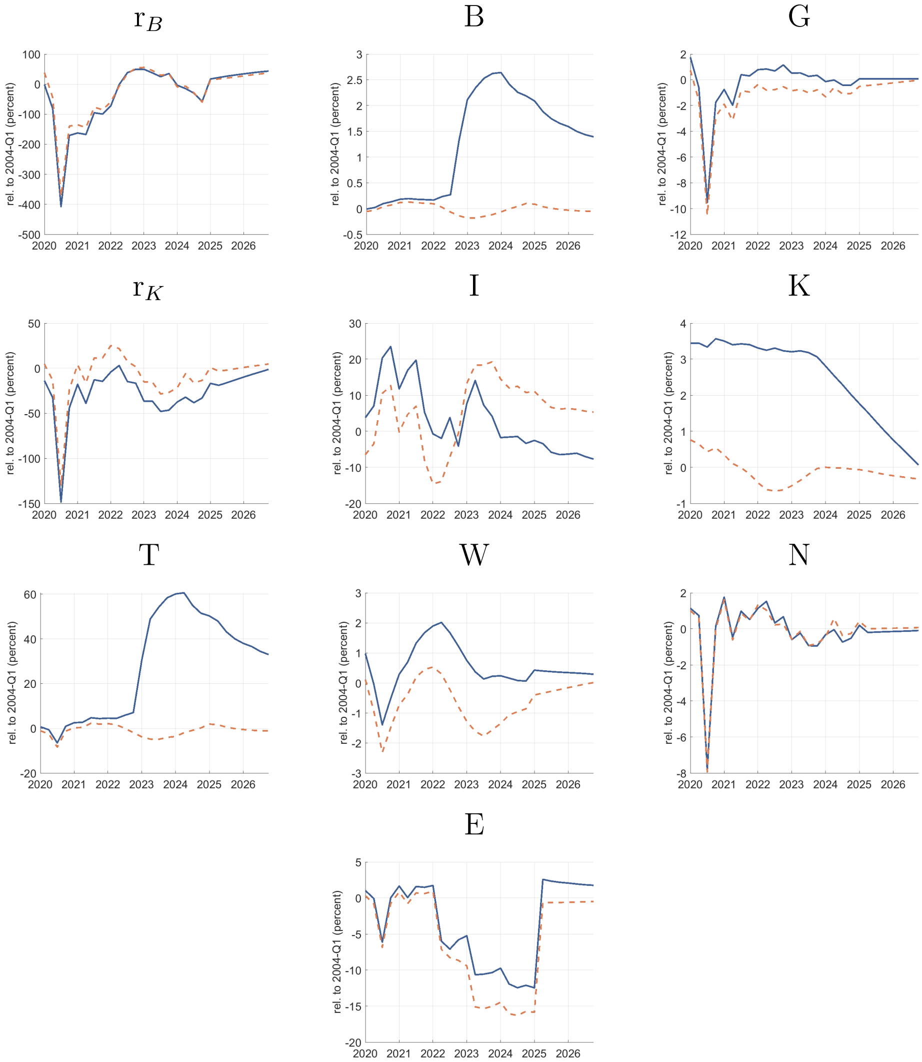
Figure 28: Dynamics of additional variables with energy cost brake.



Note: Development of nominal interest rate (r_B), debt (B), public consumption (G), rental rate of capital (r_K), investment (I), capital (K), lump-sums (T), real wage (W), and energy use (E) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

Fiscal Package

Figure 29: Dynamics of additional variables with fiscal package.



Note: Development of nominal interest rate (r_B), debt (B), public consumption (G), rental rate of capital (r_K), investment (I), capital (K), lump-sums (T), real wage (W), and energy use (E) in the fiscal policy scenario (solid line) compared to the baseline scenario without any fiscal intervention (dotted line). For simulations we use the toolkit Dynare provided by Adjemian et al. (2022) and assume perfect foresight since the duration of fiscal intervention periods is common knowledge when politicians publicly announce their actions.

B Parameter Calibration

Values of parameters are listed in Tables 5 and 6.

Calibration of Energy Tax Rates

We use individual energy tax rates $\tau_{CE,hh}$ to match the share of energy expenditures on total consumption expenditures per household $share_{CEC,hh}$ to data from the Statistical Office of Germany Income and Consumption Survey 2018. We calculate energy tax rates from given total household income

$$INC_{hh} = (1-\tau_{W,hh})W_{hh}N_{hh}+(1-\tau_K)(r_K+\delta)K_{hh}+(1-\tau_{D,hh})\frac{D_{hh}}{P_{Y,gross}}+r_B B_{hh}+r_F B_{F,hh}-T_{hh}$$

and share of energy expenditures on total consumption expenditures per household:

$$share_{CEC,hh} = \frac{(1+\tau_{CE,hh}+\tau_E)P_E/P_{Y,gross}C_{E,hh}}{EXP_{hh}},$$

where EXP_{hh} are real consumption expenditures per household; the share of non-energy expenditures can be written as:

$$1 - share_{CEC,hh} = \frac{P_{Y,gross}C_{NE,hh}}{(1+\tau_{CE,hh}+\tau_E)P_E C_{E,hh} + P_{Y,gross}C_{NE,hh}}.$$

Therefore, we can derive an expression for non-energy consumption per decile depending on decile specific energy consumption using the following relationship:

$$EXP_{hh} = \frac{(1+\tau_{CE,hh}+\tau_E)P_E/P_{Y,gross}C_{E,hh}}{share_{CEC,hh}} = \frac{C_{NE,hh}}{1-share_{CEC,hh}},$$

$$C_{NE,hh} = \frac{(1+\tau_{CE,hh}+\tau_E)P_E/P_{Y,gross}C_{E,hh}(1-share_{CEC,hh})}{share_{CEC,hh}}.$$

To obtain $\tau_{CE,hh}$, we must substitute $C_{NE,hh}$, which itself depends on $\tau_{CE,hh}$. Then we solve for $\tau_{CE,hh}$:

$$INC_{hh} = (1+\tau_{CE,hh}+\tau_E)P_E/P_{Y,gross}C_{E,hh}\left(1+\frac{1-share_{CEC,hh}}{share_{CEC,hh}}\right),$$

$$INC_{hh} = (1+\tau_{CE,hh}+\tau_E)P_E/P_{Y,gross}C_{E,hh}\frac{1}{share_{CEC,hh}},$$

$$\tau_{CE,hh} = \left(P_E C_{E,hh}\frac{1}{share_{CEC,hh}}\right)^{-1} P_{Y,gross}INC_{hh} - (1+\tau_E).$$

Calibration of Labor Income Shares

Given the share on total disposable net income $share_{INCNET,hh}$ consisting of capital and labor income, capital share per household on total capital income $share_{K,hh}$, capital share on total income $share_K$, and labor share on total income $share_{LAB} = 1 - share_K$, we calculate the capital income share per household on total net income as

$$share_{KINCNET,hh} = share_K \times share_{K,hh},$$

and the labor income share per household on total net income as

$$share_{NINCNET,hh} = share_{INCNET,hh} - share_{KINCNET,hh}.$$

Then we get share per household on total net labor income as

$$share_{NNET,hh} = share_{NINCNET,hh} / share_{LAB}.$$

Given data from SOEPv34, DIW Berlin, we get $share_{INCNET,hh}$ and data from Statistical Office of Germany data report 2021, chapter 6 (p. 247), we get $share_{K,hh}$ and are able to calculate $share_{NNET,hh}$, if we assume $share_K = 0.3$. Now, we want to calibrate $share_{NGROSS,hh}$ given labor tax rates such that $share_{NNET,hh}$ calculated from data is matched. We take average labor tax rates per decile from IAQ. The net labor income share is defined as

$$share_{NNET,hh} = \frac{(1 - \tau_{W,hh}) W_{hh} N_{hh}}{\sum_{hh} (1 - \tau_{W,hh}) W_{hh} N_{hh}} = \frac{(1 - \tau_{W,hh}) W_{hh} N_{hh}}{(1 - \tau_W) W N}$$

and the gross labor income share as

$$share_{NGROSS,hh} = \frac{W_{hh} N_{hh}}{\sum_{hh} W_{hh} N_{hh}} = \frac{W_{hh} N_{hh}}{W N}.$$

Therefore,

$$share_{NGROSS,hh} = share_{NNET,hh} \frac{1 - \tau_W}{1 - \tau_{W,hh}},$$

First, we calculate the gross labor income per household when aggregate gross income is normalised to one as

$$INCGROSS_{hh} = share_{NGROSS,hh}$$

and net income per household as

$$INCNET_{hh} = (1 - \tau_{W,hh}) INCGROSS_{hh}.$$

The average labor income tax rate can then be computed for a normalized gross income $INCGROSS = 1$ as

$$\tau_W = \sum_{hh} INCGROSS_{hh} - \sum_{hh} INCNET_{hh}.$$

Finally, we get the gross labor income share per household:

$$share_{NGROSS,hh} = share_{NNET,hh} \frac{1 - \tau_W}{(1 + \tau_{W,Y})(1 - \tau_{W,hh})}.$$

Calibration of Transfer Shares

We match the share per household on aggregate consumption expenditures by setting the share on total lump-sum taxes per household.
The budget constraint ($EXP_{hh} = INC_{hh}$) is given as

$$share_{C,hh} = \frac{EXP_{hh}}{EXP} = \frac{INC_{hh}}{INC}.$$

Total decile-specific income consists of labor, capital, dividends, and interest payments from foreign as well as domestic bonds.

$$\begin{aligned} INC_{hh} &= (1-\tau_{W,hh})W_{hh}N_{hh} + (1-\tau_K)r_K K_{hh} + (1-\tau_{D,hh})D_{hh} + r_B B_{hh} + r_F B_{F,hh} - T_{hh}, \\ T_{hh} &= share_{T,hh}T, \\ INC &= (1-\tau_W)WN + (1-\tau_K)r_K K + (1-\tau_D)D + r_B B + r_F B_F - T. \end{aligned}$$

Now we use the previous three equations to solve for the share of transfers per decile.

$$share_{T,hh} = \Omega_{1,hh} - \Omega_{2,hh},$$

where we define the following auxiliary variables $\Omega_{1,hh}$ and $\Omega_{2,hh}$ for each decile

$$\begin{aligned} \Omega_{1,hh} &= 1/T\left[(1-\tau_{W,hh})W_{hh}N_{hh} + (1-\tau_K)r_K K_{hh} + (1-\tau_{D,hh})D_{hh} + r_B B_{hh} + r_F B_{F,hh}\right], \\ \Omega_{2,hh} &= 1/T share_{C,hh}\left[(1-\tau_W)WN + (1-\tau_K)r_K K + (1-\tau_D)D + r_B B + r_F B_F - T\right]. \end{aligned}$$

Table 5: Aggregate Parameters

Parameter		Value (Source)
$share_E$	energy share on GDP	0.03 (OECD)
$share_{EY}$	energy share used for production	0.6
$share_{ED}$	domestic energy share	0.2
$share_{MD}$	domestic intermediate share	0.4 (OECD)
$share_{MF}$	foreign intermediate share	0.1 (OECD)
$share_M$	intermediate share	endogenous
$share_X$	export share	0.15
$share_K$	capital share on GDP	0.35(1-$share_M$)
$share_B$	debt share on GDP	2.4
$share_{BF}$	foreign debt share on GDP	2.4
$share_N$	labor share on GDP	endogenous
α	capital elasticity of capital-labor-bundle	$\frac{share_K}{share_N+share_K}$
δ	depreciation rate of capital	0.015 (DHK)
ρ	time preference rate	0.001
β	discount factor	$1/(1+\rho)$
φ	inverse Frisch elasticity of labor supply	1
ϵ	substitution elasticity (non-)energy consumption	0.12
γ	energy intensity of production	endogenous
γ_M	domestic intermediate intensity of production	0.0252
γ_F	foreign intermediate intensity of production	0.0252
ϵ_{PE}	price elasticity domestic energy production	0.001
σ	substitution elasticity energy and intermediates	0.05
σ_M	elasticity of substitution capital-labor and energy	0.1
σ_F	elasticity of substitution foreign and domestic intermediates	1.1
σ_N	elasticity of substitution between decile labor	1.1
$\bar{\tau}_E$	steady state energy sales tax rate	0.08
$\bar{\tau}_{NE}$	steady state non-energy VAT rate	0.1
$\bar{\tau}_K$	steady state capital revenue tax rate	0.25
$\bar{\tau}_{WF}$	steady state labor input tax rate	0
$\bar{A}, \bar{A}_E$	steady state (non-)energy productivity	1
$\bar{E}$	foreign steady state energy supply	0.1
$\bar{P}_E, \bar{P}_{Y,gross}$	steady state (non-)energy price	1
$\bar{P}_F$	steady state foreign price	1
χ	price elasticity of energy productivity	0.28
$\bar{T}$	steady state lump-sum share on GDP	-0.2
θ_p	degree of price rigidity	0.0001
θ_w	degree of wage rigidity	0.8
κ_w	wage inflation indexation parameter	1 (CWT)
ς_p	mark-up parameter production sector	1.2 (CWT)
ς_w	mark-up parameter labor markets	1.8
$\bar{\pi}$	steady state gross inflation rate	0
ϕ_π	monetary policy inflation reaction parameter	1.5
ϕ_y	monetary policy output reaction parameter	0.25
ρ_ν	monetary policy shock persistency	0.5
η_r	interest rate smoothing parameter	0.87 (CWT)
η_g	government deficit reaction	0.86
ϕ_b	fiscal rule public debt parameter	0.33 (GLV)
ϕ_g	fiscal rule public spending parameter	0.1 (GLV)

Sources: Christiano et al. (2011) (CWT), Drygalla et al. (2020) (DHK), Galí et al. (2007) (GLV), OECD input-output-tables.

Table 6: Decile Parameters

Parameter		Value (Source)
num_{hh}	total number of households	10
$share_{ROT}$	share of ROT households on total population	0.4 (DHK)
$share_{T,hh}$	share on total lump-sum transfers per decile	endogenous
$share_{K,hh}$	capital share per decile	$\in (0, 0.559)$ (Statistical Office of Germany, own computation)
$share_{B,hh}$	bond share per decile	$\in (0, 0.559)$ (Statistical Office of Germany, own computation)
$share_{BF,hh}$	foreign bond share per decile	$\in (0, 0.559)$ (Statistical Office of Germany, own computation)
$\kappa_{K,hh}$	capital adjustment cost	0.01
$\kappa_{B,hh}$	bond adjustment cost	0.01
$\kappa_{BF,hh}$	foreign bond adjustment cost	0.01
$\kappa_{BF,hh}$	foreign bond adjustment cost	0.01
$share_{N,hh}$	share on total effective labor hours per decile	$\in (0.012, 0.246)$ (SoEP, own computation)
$share_{CE,hh}$	share on aggregate energy consumption per decile	$\in (0.059, 0.139)$ (Statistical Office of Germany)
$share_{CEC,hh}$	energy share on total consumption per decile	$\in (0.038, 0.087)$ (Statistical Office of Germany)
$share_{C,hh}$	share on aggregate consumption per decile	$\in (0.037, 0.200)$ (Statistical Office of Germany)
A_{hh}	labor disutility per decile	endogenous
ψ_{hh}	basket weight of energy consumption per decile	endogenous
$\bar{\tau}_{W,hh}$	steady state labor income tax rate per decile	$\in (0, 0.232)$
$\bar{\tau}_{E,hh}$	steady state energy sales tax rate	endogenous
$\bar{\tau}_{D,hh}$	steady state energy sales tax rate	$\in (0, 0.232)$

Sources: Drygalla et al. (2020) (DHK), Statistical Office of Germany, SoEP.

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