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Redistribution within and across borders: The fiscal response to an energy shock

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Abstract

The distributional and disruptive effects of energy supply shocks are potentially large. We study the effectiveness of alternative fiscal responses in a two-country HANK model calibrated to the euro area. Subsidies can stabilize the domestic economy, but they are fiscally costly and generate negative spillovers to the rest of the monetary union: What the subsidizing country gains, other countries lose. Transfers based on historical gas consumption in the form of a Slutsky compensation are less effective domestically than subsidies, but do not harm economic activity abroad. Moreover, transfers increase domestic welfare, while subsidies decrease it.

Keywords: Energy Crisis, Subsidies, Transfers, HANK^2, Monetary Union, International Spillovers, Heterogeneity, Inequality, Households
JEL-Codes: D31, E64, F45, Q41

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1 Introduction

The Russian invasion of Ukraine in 2022 triggered a massive energy crisis in Europe that has an energy import dependency rate of 55.5%. This crisis was particularly pronounced in the market for natural gas, as it plays an important part in Europe‘s energy mix, notably when it comes to heating (Eurostat, 2023). And while the market for gas is well integrated in Europe, it is highly fragmented on a global scale: Transporting gas requires pipelines or gas liquefaction terminals, which take time to build (Pescatori and Stuermer, 2022). Hence, as gas imports from Russia to Europe collapsed in the context of the invasion, the price of natural gas in Europe went through the roof. Figure 1 shows time-series data for the price of natural gas, contrasting the developments in Europe (red dashed line) and the US (blue solid line).[1] It illustrates both the sharp increase of gas prices in Europe and the extent of market fragmentation.

The gas shortage affected firms and rendered their production more costly, but it also affected households directly and increased their cost of living. In particular, poor households were adversely effected since energy often makes up a disproportionally large share of a poor household's expenditures. This cost-of-living shock, was feared to create second round effects as the purchasing power households was curtailed, such that a further cut in household spending on other consumption goods could have amplified the recessionary impact of the shock. And since the gas crisis arrived at a time when the economic, but also political, recovery from the pandemic had just begun, policymakers quickly agreed on the need for policy interventions to soften impact of the shock. The policy response in Europe, however, were not coordinated and the three largest countries in the euro area chose different instruments, with France opting more for subsidies, Germany more for transfers, and Italy responded the least.[2]

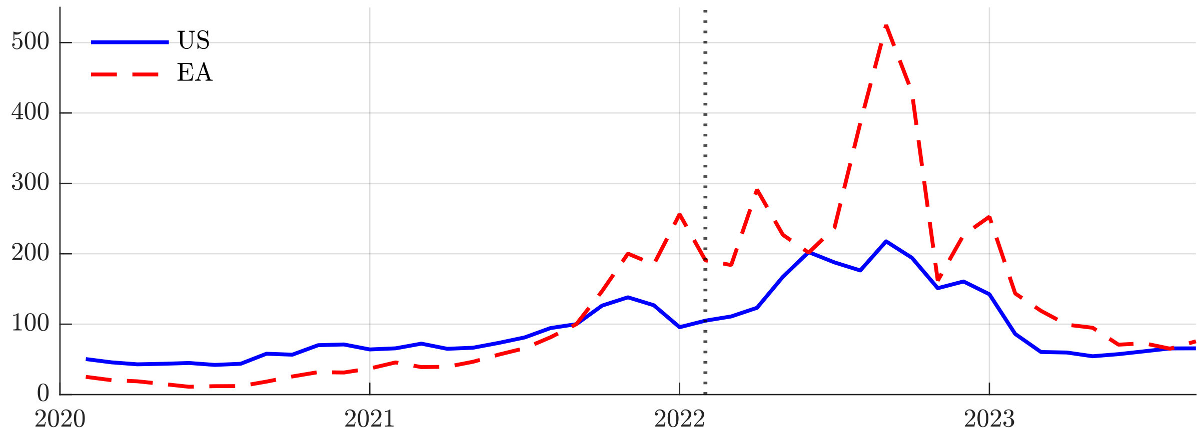
Against this background, we model the economic impact of the gas crisis and assess different policy interventions. We analyze their macroeconomic impact as well as their distributional implications—both among the households within countries, but also across countries. This is essential in the context of the gas crisis precisely because the European gas market is so highly integrated but fragmented on a global scale. Policies that are implemented in one country can, therefore, generate sizable spillovers to the other countries in the euro area.

We analyze these policies using an extended version of the HANK^2 model, that is, a two-country heterogeneous agents New Keynesian model that we developed in earlier work (Bayer et al., 2024). In this model, households face idiosyncratic income shocks, and financial markets are incomplete. Consequently, there is a non-degenerate distribution of income and wealth, and transfer policies are non-neutral. The model features two large countries in a currency union and a common energy market, which allows us to account for and analyze cross-country spillovers. We explicitly model the gas market and the gas consumption of households and firms. Importantly, we assume that the total supply of gas in the union is inelastic, reflecting a given import capacity that may not be adjusted in the short run for reasons discussed above. Gas is used in both production and consumption, and we allow for heterogeneity in the energy share of households' consumption baskets, in line with the data.

[1] The price started to rise by mid-2021 when Russia reduced its gas supply (Pescatori and Stuermer, 2022).

[2] Italy decreased gasoline/natural gas taxation for a limited period and had some, but comparably limited, means tested transfers based on heating needs.

Figure 1: The price of natural gas



Notes: Price index for Dutch TTF gas in the euro area and Henry Hub Gas in the US. August 2021 normalized to 100. Sources: FRED and Bloomberg. A vertical dotted line marks the Russian invasion of Ukraine in February 2022.

In this model, we are able to capture two other important particularities of gas consumption. First, in the data there is a large dispersion of gas consumption by households even conditional on income. We model this by assuming two types of households which differ in their energy expenditure share, reflecting that some households live in buildings that are much less insulated than others. Second, gas consumption is localized and is, because of its link to the building type, persistent. This means that measuring past and present consumption is straightforward and is part of the information set of the policymaker. These facts were exploited in Germany to make transfers based on past consumption which we also allow for in the model.[3]

We simulate the effects of an adverse gas supply shock in response to which the price of gas shoots up, the economy contracts, and inflation rises. For the baseline scenario, we assume a drop of gas supply by 20 percent which is anticipated to last for 1.5 years. In response to this shock, the energy price increases fivefold. Inflation rises by 4 percentage points and production declines by about one percent. These effects are basically identical in both countries. In addition, in both countries, the distributional impact of the shock is quite large: Consumption drops by more than 1.5 percent for the lowest income quintile, but by only about 1 percent for the highest. Moreover, the consumption drop of households with a gas-intense consumption basket is twice as large as the average.

Given the shock scenario, we analyze three policy interventions. The first two capture, in a stylized way, the actual responses, namely transfers and subsidies to both households and firms. And because actual policy interventions were implemented at the national level—even as the crisis unfolded in the entire euro area—we first study these policies under the assumption that they are implemented only in one country, say "Home." However, we also study as a third policy option a coordinated, union-wide price subsidy.

The first policy is a *price subsidy* that caps prices at the pre-crisis level in the home economy. The policy at the national level is effective in stabilizing consumption at Home: Across

[3]While these are particularities of the natural gas market we, for simplicity, use the term energy throughout the paper interchangeably with natural gas.

the income distribution, the fall in consumption is much smaller compared to the baseline without policy intervention, as is the fall in GDP. However, as the gas market is fully integrated, subsidizing energy at Home further raises its price abroad, thus amplifying the adverse effect of the shock abroad.

The second policy we consider is a *transfer* conditional on the pre-crisis level of gas consumption. This policy is feasible because gas consumption is associated with a fixed place, i.e., gas consumption is localized. Technically, the transfer represents a Slutsky compensation: the old consumption bundle remains affordable as prices go up. As with the subsidy, transfers stabilize consumption across the income distribution but to a lesser extent. Also, production falls almost as much as in the absence of the policy because the rising energy price triggers a 'Keynesian supply shock' and the expected increase in tax distortions in the future, necessary to finance the transfer, dampens the expansionary effect of the transfers. In contrast to the subsidy, the transfer policy does not harm production in Foreign, as energy demand declines and energy prices in the union do not go further up.

Both policies have sizable fiscal costs, but subsidies are about 50% more expensive than transfers. In line with the actual policies, we assume that these costs are covered by newly issued debt, which is gradually reduced over time. This requires taxes, which are assumed to be distortionary, to go up in the medium run. As a result, the welfare impact of both policies is generally negative from a European perspective—for national as well as for coordinated policies. We see this as we compute the consumption-equivalent variation of both policies. However, the subsidy generally fares much worse in this dimension. This is true both at Home and even much more for the Foreign economy. Intuitively, subsidizing energy consumption in the face of a massive supply contraction is inefficient. In case of transfers, their welfare costs are almost exclusively due to tax distortions. And because tax distortions alter through their supply side effects the terms of trade, their costs are partly borne by the Foreign economy.

While the analysis focuses on policy interventions in one country and investigates the effects on the other, we also consider union-wide price subsidies. This exercise is motivated by the observation that subsidies seem to work in the Home economy, but come with large negative spillovers on the Foreign economy. Hence, the question arises whether union-wide subsidies might be beneficial for the entire union. However, it turns out that since the energy supply is fixed, a subsidy in both countries is quasi ineffective in lowering the energy price and only burdens households and firms with future tax liabilities. Hence, demand collapses due to the anticipated future taxes. Additionally, with subsidies large enough to prevent relative price movements, the economy effectively becomes close to 'Leontief', and union-wide GDP decreases almost one-for-one with energy. This illustrates the beggar-thy-neighbor dimensions of subsidies: they only "work" if implemented in one country, because it is possible to maintain a high level of gas consumption at the expense of the other country.

The paper is structured as follows. In the remainder of this section, we discuss the related literature and clarify the contribution of our paper. Section 2 gives a summary of the model with a focus on the energy market, delegating most details to the appendix. Section 3 discusses the calibration of the model and Section 4 presents results. The final section concludes.

Related literature. Our paper relates to three strands of the literature. First, there is the recent surge of HANK models which are used to revisit the transmission of traditional business cycle shocks and economic policies starting with the influential study of Kaplan, Moll, and Violante (2018), but also, for instance, Auclert (2019) and Bayer, Luetticke, Pham-Dao, and Tjaden (2019). This framework lends itself naturally to the analysis of transfer policies such as those implemented during the pandemic and fiscal policy more broadly (Auclert, Rognlie, and Straub, 2024; Bayer, Born, Luetticke, and Müller, 2023).

Second, this class of models has also been extended to revisit open-economy issues, see Auclert, Rognlie, Souchier, and Straub (2021) or Chen, Lazarakis, and Varthalitis (2023) and Bayer, Kriwoluzky, Müller, and Seyrich (2024) for two-country models such as ours. Our contribution relative to this literature is to extend this framework to account for an energy sector in a two-country HANK model. This is particularly relevant since the distributional impact of energy shocks can be large, as we illustrate below. Closely related to our study, Langot, Malmberg, Tripier, and Hairault (2023) use a small-open HANK model to study the effects of subsidies in a scenario that is meant to represent the European energy crisis, too. In contrast to our analysis, however, they assume that energy supply is perfectly elastic and, hence, they find that a price subsidy performs well. Auclert, Monnery, Rognlie, and Straub (2024) also analyze how to manage an energy shock in a small-open economy HANK framework. They stress the negative externalities that arise if all energy-importing countries simultaneously resort to subsidizing energy ("coordination"). Our analysis corroborates this insight based on a quantitative analysis tailored to capture key aspects of the European energy crisis.

Third, there is work on the energy crisis in RANK and TANK models. Gagliardone and Gertler (2023) model oil in an otherwise conventional New Keynesian model to better understand inflation dynamics. Gornemann, Hildebrand, and Kuester (2024) discuss the role of supply elasticity of energy for monetary policy and price stability in an open economy TANK type model. Chan, Diz, and Kanngiesser (2024) analyze the optimal response of monetary policy to an energy price shock. For their TANK model they find that as incomes and consumption fall in response to the shock, optimal monetary policy should be less contractionary relative to what is optimal in a RANK version of their model.

2 A HANK model with energy

We evaluate the fiscal response to the European gas crisis based on an extension of the HANK^2 model developed in Bayer et al. (2024). Specifically, we consider the use of gas in production and directly in household consumption (heating). The model features two countries forming a monetary union, incomplete financial markets, and assets with different liquidity (bonds and capital). Thus, it captures important aspects of the European macroeconomy as well as the heterogeneity of households within countries. For these reasons, we believe it is particularly well suited to study the European gas crisis of 2022/23 and the policy options discussed to address it. The following is a brief summary of the model, with a particular focus on energy, in our case gas. While we calibrate the model to the European gas crisis in Section 3, the model is capable of capturing many aspects of energy consumption in general. We have therefore chosen a notation that refers to energy and we will use energy and gas synonymously in the model section. A full description of the model can be found in the Appendix A.

2.1 Summary of the model

The model represents a monetary union of two countries. Markets are incomplete and households face idiosyncratic, household-specific, risks, but are able to self-insure. They can do so using a liquid asset that can be traded every period on a union-wide market (nominal bonds) and an illiquid asset (physical capital) traded only within countries. As a result, households are heterogeneous in terms of income and wealth. Households with little wealth or households whose wealth consists mainly of illiquid assets (e.g. houses) have a high propensity to consume out of disposable income and transfers.

Prices and wages are sticky, as is common in the New Keynesian literature.[4] Each country comprises a firm sector and a household sector. The firm sector of each country consists of (a) perfectly competitive intermediate goods firms that produce intermediate goods using capital, labor, and energy; (b) final goods firms that operate under monopolistic competition and produce differentiated final production goods from homogeneous domestic intermediate goods; (c) a representative consumer goods firm that puts together domestic and imported foreign final production goods in order to produce consumer goods; (d) capital goods producers that transform consumer goods into capital; (e) labor intermediaries that produce labor services by combining differentiated labor from (f) unions that differentiate the raw labor provided by households. Pricing by final goods producers goods and wage setting by unions is subject to frictions à la Calvo (1983). We assume that only final production goods can be traded between the two countries.

There is a continuum of households in each country. Households in both countries consume a basket of domestic and imported final production goods and, in addition, energy. Households generate income by providing labor and capital to the national markets and by owning their national firm sector. They absorb any rents resulting from the market power of unions, final goods producers, and diminishing returns to scale in capital goods production. Additionally, we assume that households own the energy sources and that income from these sources is treated similarly to other rents. This reflects the fact that during the European energy crisis in 2022/23 the bottleneck of energy imports was mainly the import capacity of European LNG terminals and western European gas pipelines, which would then absorb the scarcity rents.[5]

The government sector comprises a common European monetary policy and national fiscal authorities. Each fiscal authority levies taxes on labor income and distributed profits, issues government bonds, and adjusts taxes to stabilize debt levels in the long run. The national fiscal authorities also operate a targeted transfer system. Monetary policy sets the nominal interest rate in the economy using a Taylor rule, that is, it adjusts the interest rate to union-wide inflation.

[4]The set up in each country is closely related to the HANK model in Bayer, Born, and Luetticke (2024).

[5]When calculating welfare, we exclude the owners of energy. In Section 4.6 we discuss a robustness exercise with an additional third country as an exporter of gas. The country is modeled with a representative household. In this case, the dynamics triggered by a gas supply shock are very similar to our two-country baseline.

2.2 Energy market

A distinct and novel feature of our analysis is to account for an energy market within an open-economy HANK framework. Hence, we provide some more details in this regard, first discussing sources of energy demand and then turning to market clearing.

Energy is important in the model for two reasons. First, energy—along with labor and capital—is an input to the production of intermediate goods in both, Home and Foreign. Countries are symmetric in production and our exposition focuses on Home. Specifically, we assume intermediate goods Y_t are produced with the (nested) CES production function:

$$Y_t = \left((1 - a_P)^{\frac{1}{\sigma_P}} \; {Y_t^P}^{\frac{\sigma_P - 1}{\sigma_P}} + {a_P}^{\frac{1}{\sigma_P}} \; \left(E_t^Y\right)^{\frac{\sigma_P - 1}{\sigma_P}} \right)^{\frac{\sigma_P}{\sigma_P - 1}}, \tag{1}$$

$$\text{where } Y_t^P = (u_t K_t^s)^{\alpha} \; {N_t}^{1-\alpha}.$$

As this expression shows, the intermediate good is composed of a physical input, Y_t^P, which, in turn, combines capital, K_t, with capacity utilization u_t, and labor, N_t, on the one hand, and energy used in production, E_t^Y, on the other hand. The coefficient α is the capital share, the coefficient σ_P captures the (short-run) substitutability of energy in the production process, and a_P is the energy share of production in normal times.

Second, energy is consumed directly by households. Since we focus on natural gas, this can be thought of as energy for heating homes. Again, our formal exposition focuses on Home (with the understanding that the same relationships hold in Foreign). Total consumption c_{it} of household i at time t consists of energy E_{it}^C and the physical consumption good c_{it}^P, again combined in a CES aggregator:

$$c_{it} = \left(\left(1 - a_{it}^C\right)^{\frac{1}{\sigma_C}} \; {c_{it}^P}^{\frac{\sigma_C - 1}{\sigma_C}} + {a_{it}^C}^{\frac{1}{\sigma_C}} \; \left(E_{it}^C\right)^{\frac{\sigma_C - 1}{\sigma_C}} \right)^{\frac{\sigma_C}{\sigma_C - 1}}. \tag{2}$$

Here σ_C represents the elasticity of substitution in consumption, that is, it measures the extent to which energy is substituted for physical consumption goods as relative prices fluctuate.

In addition, households differ in the energy intensity of their consumption, captured by a_{it}^C. We assume that the share of energy in consumption varies exogenously across households and over time. The transitions from low to high and from high to low energy intensity are random but related to the income state of the household. Concretely, we assume for the probability $\rho(h, a^C)$ to switch from one energy type to the other the following functional form:

$$\rho(h, a^C) = \bar{\rho} + (\mathbb{I}_{a^C = a_H^C} - \mathbb{I}_{a^C = a_L^C}) A(h) + \mathbb{I}_{a^C = a_L^C} B, \tag{3}$$

where $\mathbb{I}_{a^C = a_H^C}$ is 1 if the household is currently in a high-energy dwelling and 0 otherwise, and $\mathbb{I}_{a^C = a_L^C}$ is 1 if the household is currently in a low-energy dwelling and 0 otherwise. Moreover, A is a linear function of the quintile of idiosyncratic labor productivity and B is a constant that captures that it is generally more likely to remain in a low-energy dwelling.

This allows us to capture two key dimensions of heterogeneity in households' energy share in the data: First, there is a strong negative correlation between the energy share and household income. Second, there is a large dispersion in the energy shares even conditional on income. Some households live in poorly insulated homes, while others live in modern low-energy buildings. However, while we allow for transitions in energy-intensity types, we model them as rather infrequent. Thus, energy intensity of the household is very persistent—in line with the fact that people move homes rather infrequently.[6]

We assume that the energy market is fully integrated across the countries of the union, consistent with the observation that within continental Europe the market for natural gas is highly interconnected. In addition, during the energy crisis caused by the Russian invasion of Ukraine, the amount of gas available to European consumers was largely limited by import capacity rather than world market supply. For this reason, we model the amount of energy available to the euro area as fixed, with a common price clearing the market. Here our analysis differs from work on the world energy market which allows supply to respond to price movements (see, for instance, Nakov and Nuño, 2013; Känzig, 2021).

This means that in our model, prices adjust for markets to clear. Total energy consumption of households and firms equals the exogenous energy supply:

$$E_t = E_t^C + E_t^Y + E_t^{C,*} + E_t^{Y,*}. \tag{4}$$

The energy crisis is then modeled as an exogenous decrease in energy supply E_t. Following common practice, variables with a star refer to Foreign.

2.3 Policy options during an energy crisis

In this section, we examine three alternative fiscal policy responses to an energy crisis. The first policy we look at, is a direct subsidy on energy. In the German context, some economists have argued in favor of such subsidies (often mislabeled "price caps") limiting what households and firms pay for gas (see e.g. Dullien, 2022). For simplicity, we consider an extreme version of this policy where the user price of gas is fixed at the pre-crisis level. Alternatively, other economists suggested to pay a transfer that compensates for the difference in income (Slutsky compensation) caused by the shock (Bachmann et al., 2022b; Bachmann et al., 2022a). Ultimately, German policymakers opted for the latter suggestion, and the largest part of the German relief package consisted of these transfer payments. Again, we consider an extreme case of a complete (Slutsky) compensation. While neither the proposal nor the actual policy involved a transfer or subsidy to fully offset the price change, we nonetheless consider these extreme versions for the sake of illustration. In each case, and following the German debate, we focus on a scenario where the policy is implemented only at Home. This allows us to analyze potential spillovers to the rest of the monetary union. The third policy option we consider is a union-wide price subsidy. Unlike the other two policy options, this one has not been implemented by any country in the monetary union, but it could be considered as an alternative policy option to mitigate potential negative spillovers.

[6] On average, around 10% of Germans move house every year. Sources: Federal Statistical Office (Destatis) and Deutsche Post.

2.3.1 Policy option 1: subsidies

We assume the subsidy to offset entirely an increase in energy prices such that prices that households or industry pay in Home are stabilized at the pre-crisis level $\bar{p}^E$:

$$\tau_t^E = p_t^E - \bar{p}^E. \tag{5}$$

The subsidy stabilizes retail energy prices perfectly at the pre-crisis level, despite changes in the wholesale price of energy p_t^E which is expressed in terms of the physical consumption good. All else equal, the demand for energy in Home will therefore be unchanged. As a result, Foreign is faced with even higher energy prices on the common market relative to a scenario where no policy intervention takes place in Home.

While this extreme policy of offsetting any energy price increase was followed by no actual member state in the euro area, many did subsidize energy consumption quite strongly (Sgaravatti et al., 2023). And indeed, Auclert et al. (2024) and Langot et al. (2023) advocate this as a policy that helps to overcome the adverse spillovers through demand channels that emerge under incomplete markets.

2.3.2 Policy option 2: transfers

As an alternative to the subsidy, national authorities can compensate the households and firms in the economy for the rise in the costs of gas through transfers. In the German case and in our model, transfers are designed in a way that they offset the change in income (Slutsky compensation). More precisely, we model the Slutsky compensation as the transfer equal to the price increase such that the transfers to household i is:

$$tr_{it}^E = (p_t^E - \bar{p}^E)\bar{E}_i^C. \tag{6}$$

$\bar{E}_i^C$ is energy consumption of household i in steady state. Such transfers were indeed implemented in Germany in response to the energy crisis, partly because policymakers and their advisors anticipated adverse spillovers from a subsidy scheme on the rest of the euro area (ExpertInnen-Kommission Gas und Wärme, 2022). In their policy response, the German government largely followed an early proposal by Bachmann et al. (2022b) and Bachmann et al. (2022a) for transfers to households, but extended it to firms as well. The transfer was conditional on energy consumption in 2020/21 and applied to both households and firms. More precisely, when such a policy was implemented in Germany in practice, the reference quantity was only 80% the energy consumption (for heating) in 2020 of the apartment/house the household was living in and the reference retail price was roughly 1.5 times the pre-crisis price (120€/MWh and 80€/MWh, respectively). Again, we abstract from the details of the actual implementation and assume full compensation. What is more, for simplicity we condition the transfer on the steady state energy-consumption policy of a household indexed by income, energy intensity, and asset holdings.[7] This avoids the introduction of historical consumption as another state

[7] In Section 4.6 we consider the case where the information of the government is limited. Specifically, in this version of the policy transfers are based on average gas consumption conditional on income and wealth. We find results are very similar to the baseline policy.

variable to the model and is for a slow-moving variable such as energy consumption a good approximation of the actual policy.

In the model, we implement transfers to firms as transfers to entrepreneurs that increase profits, assuming that the transfers fully compensate for the increase in gas prices. In detail, the transfers to firms are defined as:

$$tr_t^f = (p_t^E - \bar{p}^E)\bar{E}^Y. \tag{7}$$

2.3.3 Policy option 3: coordinated union-wide subsidies

The policy measures in the previous sections are implemented on a national level only. A third alternative is a coordinated euro-area-wide subsidy for households and firms. While subsidies paid on a national level leads to higher prices in the other country, a union-wide policy might alleviate the consequences for Foreign.

We model this coordinated policy option as a symmetric increase in national energy subsidies to offset entirely an increase in union-wide energy prices such that prices that households or industry pay in the union are stabilized at the pre-crisis level $\bar{p}^E$:

$$\tau_t^E = \tau_t^{E,*} = p_t^E - \bar{p}^E, \tag{8}$$

where $\tau_t^{E,*}$ is the subsidy paid at foreign.

3 Calibration

The HANK^2 model is well able to capture key features of the euro area business cycle, including cross-country co-movement and, at the same time, household-level heterogeneity within countries. We show this for a calibrated version of the model in earlier work (Bayer et al., 2024). In our analysis below, we build on our earlier calibration strategy, a key aspect of which is to take seriously the differences in social transfers and steady-state government debt between the more government-based Northern European model and the more self-insurance-based Southern European model. Indeed, this aspect is central to understanding differences in the heterogeneity of household portfolios across countries. Specifically, we calibrate Home to Germany, with its minimum income benefits, and Foreign (the rest of the monetary union) to Italy, which has redistributive taxation but for long had no direct income support and thus is modeled without. Instead, the government facilitates self-insurance by issuing more government bonds. Admittedly, this is a simplistic choice in that the rest of the euro area is not identical to the Italian economy in its extreme reliance on self-insurance, but it is arguably more so on average than the German economy.

The calibration ensures that in steady state the interest rate on government bonds is the same across countries. Moreover, we set key parameter values in order to match the debt ratio, the capital ratio, the wealth Gini, the share of the 10% richest in total wealth, the share of the 50% poorest in total wealth, and the share of indebted households in Germany and Italy. Furthermore, the persistence of idiosyncratic shocks is calibrated to be equal in both Home and

Table 1: Calibration of the energy sector

	Description	Value
a_P	Share of energy in production	0.005
σ_P	Elasticity of substitution in production	0.200
σ_C	Elasticity of substitution in consumption	0.100
a_{CH}	Proportion of energy in consumption: Type "high"	0.035
a_{CN}	Proportion of energy in consumption: Type "low"	0.020
$\bar{\rho}$	Persistence of high energy state at median income	0.970
A	Slope of probability to stay in low energy state	0.005
B	Shift in probability to remain in low energy state	0.010

Foreign.[8] In addition, we set the remaining parameters to values that have been established in business cycle analyses based on New Keynesian models. Appendix B provides details on the calibration. The relative size of Home is key for the spillovers which we analyze below. Within the European integrated gas market/network (i.e. excluding the Spanish peninsula) Germany makes up for roughly one-third of the area's GDP. Consequently, also in the model, we assume that Home accounts for one-third of GDP.

In terms of the size and duration of the shock, we assume that there is a 20% decline in euro area-wide energy supply and that this decline lasts for 6 quarters. In this way, we capture the drop in net gas supply due to the interruption of pipeline imports from Russia, and the duration of this drop (the expected time to build LNG import capacity) as expected in the summer of 2022. Note that the increase of imports from Norway and through LNG terminals did not make up for this shortfall. Indeed, our assumption on the size of the shock falls in between the EU's political gas reduction target of 15% and the 25% reduction expected in Germany, as reported by Moll, Schularick, and Zachmann (2023).

Finally, we calibrate the energy sector symmetrically across countries. Table 1 reports the key parameters related to this sector. We base the calibration on German data.[9] Specifically, we select the energy share, (a^P), for the firm sector to align with the steady-state gas expenditure shares, which constitute 0.5% of production costs. We set the elasticity of substitution in production, (σ_P), to 0.2, reflecting the limited substitutability of natural gas in the short run (Bachmann et al., 2022b). For the household sector, we also follow Bachmann et al. (2022b) and set the elasticity of substitution to ($\sigma_C = 0.1$). This leaves us with five additional parameters to characterize household energy consumption: the energy share in the consumption basket of high and low energy-intensive households (a^C_H, a^C_L) and the parameters ($\bar{\rho}, B, A$), which govern the process determining the household energy type, as described in Equation (3) above. First, we set these parameters so that the average expenditure share on gas amounts to 2.5%.[10] Additionally, we ensure that the average annual probability of switching energy types is just

[8] In Section 4.6 we take up the concern that the persistence of these shocks may differ across countries (Fonseca et al., 2023). Appendix C.2 shows that our results are robust to relaxing the assumption of similar stochastic processes.

[9] From 2015-19 the average HICP expenditure weights on gas for Germany and the rest of the euro area have been similar—both roughly 2%, with Germany slightly above and the rest of the euro area slightly below.

[10] In the data, only about 50% of all German households heat with gas, while in the model, we assume that all households heat with gas. Conditional on heating with gas, the microdata show an expenditure share of 5%.

Table 2: Expenditure on gas (heating and hot water, Germany, Data/Model)

Income quintiles				Expenditure quartiles					
		Mean		p25		p50		p75	
		D	M	D	M	D	M	D	M
I:	0-20%	0.79	0.88	0.44	0.48	0.65	0.66	0.99	1.01
II:	20-40%	0.92	0.89	0.50	0.49	0.79	0.67	1.19	1.03
III:	40-60%	1.04	0.95	0.60	0.55	0.89	0.75	1.29	1.12
VI:	60-80%	1.09	1.03	0.64	0.63	0.93	0.81	1.32	1.23
V:	80-100%	1.12	1.23	0.67	0.73	0.96	0.90	1.35	1.45
Targets: relative moment by income quintile									
Mean(I)/Mean(V)		**0.70**	**0.71**		p25(V)/p75(V)			**0.50**	**0.50**
					p25(I)/p75(V)			**0.33**	**0.33**

Source: German Einkommens- und Verbrauchsstichprobe (EVS) 2018, own calculations. Income quintiles refer to household net incomes. Expenditure quartiles refer to the within-income-quintile gas consumption. The table displays expenditures relative to the economy-wide average (€ 281 per household and quarter). Columns D refer to the data, M to the model. Targeted moments in bold. Only households with gas as the predominant energy source are included.

over 10%, and that the dispersion of energy expenditures within and across incomes matches three targets shown in Table 2: (i) the average increase in energy expenditures across income quintiles, (ii) the interquartile range within the top income quintile, and (iii) the bottom quartile of energy consumption in the bottom income quintile relative to the top quartile of energy consumption in the top income quintile. Since we calibrate both countries to the same values, a natural question arises whether the same pattern is also present in Italian data. Table 6 in the Appendix B compares the Italian microdata to the German data. We find a similar pattern: poor households consume on average more than 30% less gas than rich households (conditional on heating with gas at all). The within-income group dispersion is even somewhat larger in Italy than in Germany, but similar once we control for regional fixed effects to account for the fact that, in Italy's south, often heating is much less of an issue.

With our modeling setup and the calibration, we are in the position to capture a low gradient of gas expenditures with income, that is, some non-homotheticity in gas expenditures on average, without resorting to non-homothetic preferences. At the same time, we capture the large dispersion in gas consumption even conditional on income. In fact, Table 2 also shows that the non-targeted energy expenditures (relative to the average) of the different groups in the energy expenditure and income distribution are relatively well matched, despite the very coarse parametrization. In contrast, Pieroni (2023) and Langot et al. (2023) only match the low-income gradient by assuming non-homothetic preferences. Labrousse and Perdereau (2023) achieve heterogeneity in energy consumption conditional on income by introducing persistent differences between rural and urban households and, additionally, match the low gradient through the introduction of non-homothetic preferences. However, our specification is based on fewer parameters, and thus more parsimonious. In addition, even conditional on living in a rural or urban county, there is a large dispersion in energy consumption within income group in the data; see Appendix B.3.[11]

4 Results

In what follows, we first study the effects of energy scarcity through the lens of the calibrated model. We compute a linearized state-space solution using the toolkit provided by Bayer, Born, and Luetticke (2024).[12] We then run three policy experiments and analyze the effect of policies that respond to the increase in energy prices with either i) subsidies at Home, ii) transfers at Home, or iii) coordinated union-wide subsidies. For all experiments, we assume that households fully anticipate the policy and expect it to last for as long as the energy shortage. The policies are modeled as a news shock in period 1, where the news is then accurate and realized.

In a next step, we zoom in on the mechanism and consider the effects of subsidies and transfers on households and firms separately. To further isolate the direct effect of the policy, we assume non-distortionary taxes instead of distortionary taxes. The effect of the tax distortion is then calculated as a residual. To compare the welfare effects of the policies, we also study the welfare impact of transfers and subsidies at Home in terms of consumption equivalent variations. Finally, we investigate the robustness of the results.

4.1 Energy crisis scenario

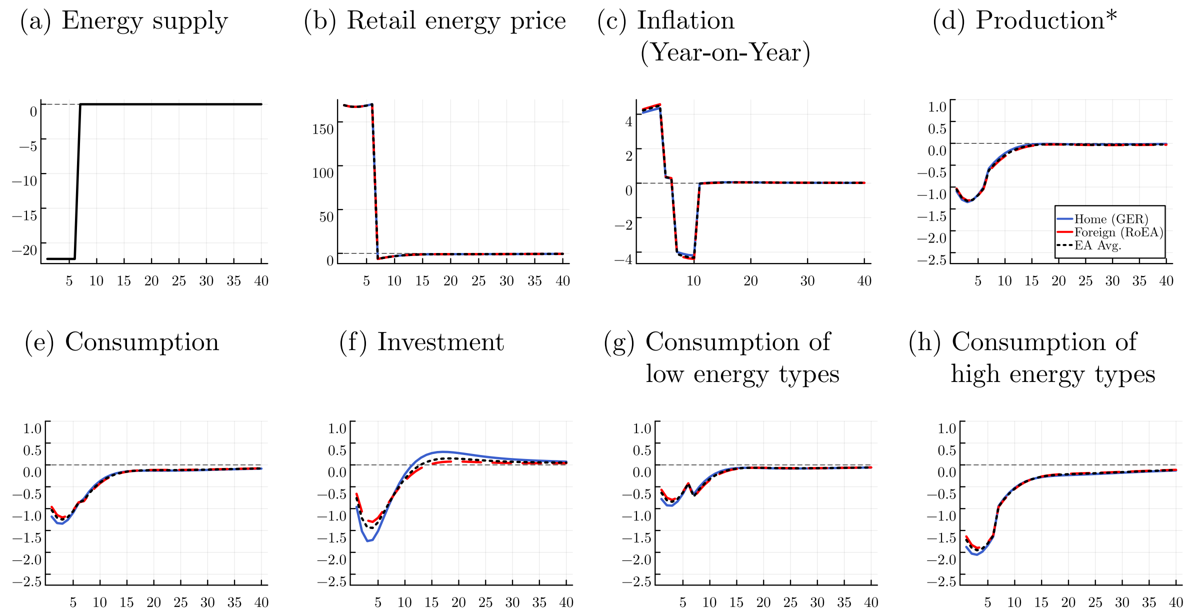
Figure 2 shows how the economy adjusts to the energy shortage in the absence of a discretionary fiscal response, both at Home (blue solid line), at Foreign (red solid line), and for the euro area as a whole (black dashed line). In the first period, energy supply in the euro area drops by 20 percent (panel a) and is known to remain depressed for 6 quarters (from Summer 2022 to Winter 2023/24). As a result of the shock, energy prices rise dramatically (panel b), to about five times their pre-crisis level (a 175 log-point increase), consistent with the data shown in Figure 1 above. We note, however, that the actual evolution was somewhat more slowly and started already prior to the invasion; see Footnote 1. Also, the duration of the price increase turned out to be shorter. Nevertheless, we assume the energy crisis lasts six quarters in line with what market participants expected in the spring/summer of 2022 as reflected by prices of futures for natural gas deliveries for the year 2023.

As a result of this cost-push, inflation rises significantly by about 4 percentage points per year (panel c). Measures of aggregate activity decline in sync: production, consumption, and investment, all by about 1% to 1.75%, as shown in panels d) to f). This reflects that energy is modeled as a complement to other factors of production and as a complement to goods

[11] See Table 8. In Appendix B.3 we also provide evidence that the large dispersion of energy expenditures across the income quintiles is also present once we control for the year of construction of the dwelling (Table 9).

[12] The linearization somewhat understates the adverse impact of the shock, as marginal output losses increase with the size of the shock, and a 20% energy reduction is clearly not marginal. We therefore perform a robustness exercise and solve a second-order perturbation of the one-country version of the model (see Section 4.6 and Appendix C.1). We find that the effects are somewhat smaller under the first-order perturbation, but adjustment dynamics are very similar. Given that the focus of this paper is on the policy measures, we report results for the first-order perturbation in what follows.

Figure 2: Macroeconomic impact of the energy crisis without policy intervention



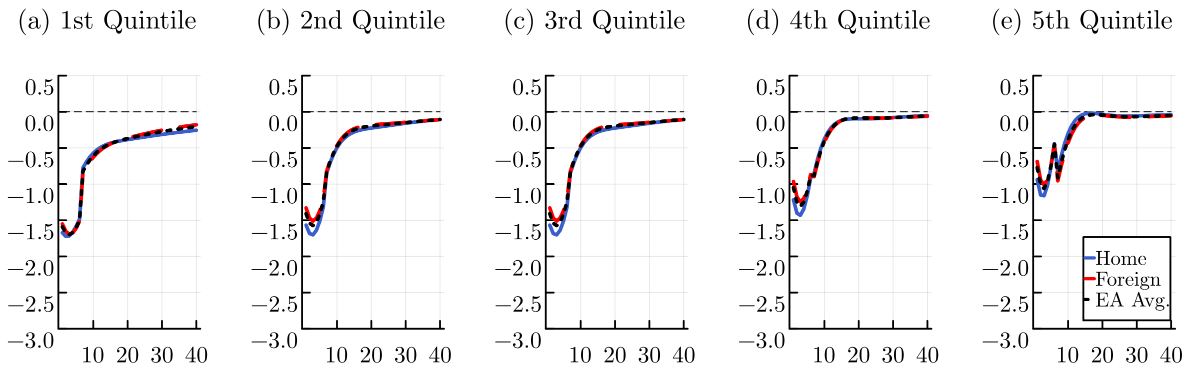
Notes: Impulse responses to a 20% reduction in energy (natural gas) supply to the Euro Area (log-linearized solution). The blue solid lines show the impact on the Home economy (GER), the red dashed line shows the response of the Foreign (rest of Euro Area) response, and the black dashed-dotted line shows the euro-area-wide response. Retail energy price is the energy price minus the subsidy, $p_t^E - \tau_t^E$. Production is in terms of each country's final output, Y_t. Y-axis: In log-point deviations (log deviations multiplied by 100) from the steady state. Inflation percentage points year-on-year. X-axis: quarters.

consumption in the utility of households. This implies in particular falling factor returns when energy inputs decrease, which amplify the decline in output compared to what the expenditure share on energy alone (the micro elasticity) would suggest. The differences between Home and Foreign are small, despite some differences in the welfare state and outstanding government debt. Given the lower level of self-insurance in Home and the greater reliance on transfers instead, the Home economy experiences a somewhat sharper contraction in consumption and investment.

The rise in consumer prices erodes the purchasing power of household incomes and, because some households are unable to borrow, leads to a fall in demand that exceeds the fall in production possibilities, further exacerbating the crisis. But even households that can borrow reduce consumption because they foresee a normalization of energy prices after 6 quarters and, therefore, expect deflation then. Panels g) and h) of Figure 2 show that the drop in consumption is particularly strong for households living in energy-intensive dwellings ("h-type")—for them, the drop is more than twice as large as for the low-energy type. They are also on average poorer in income and wealth, with correspondingly higher marginal propensities to consume.

To see this, turn to Figure 3 which zooms in on the distributional impact of the shock: It shows the response of consumption to the shock across the income distribution. The consumption response of income-poor households shown in panel a) is the strongest and about 60 percentage points higher than for the richest quintile (panel e). For the poor, the share of energy expenditure is particularly high, so they see a particularly sharp erosion of their real income. In addition, they are more dependent on labor income and therefore exposed to indirect effects,

Figure 3: The crisis along the income distribution: impact on consumption



Notes: See Figure 2. Consumption response by income quintile, log point deviations.

because changes in the real wage and employment are stronger than the effects on the real rate, in line with the evidence presented by Känzig (2023). Given the strong welfare state at Home, even the median household has little savings. In the Foreign economy, households hold more assets to insure themselves. Therefore, their consumption decline is somewhat weaker.

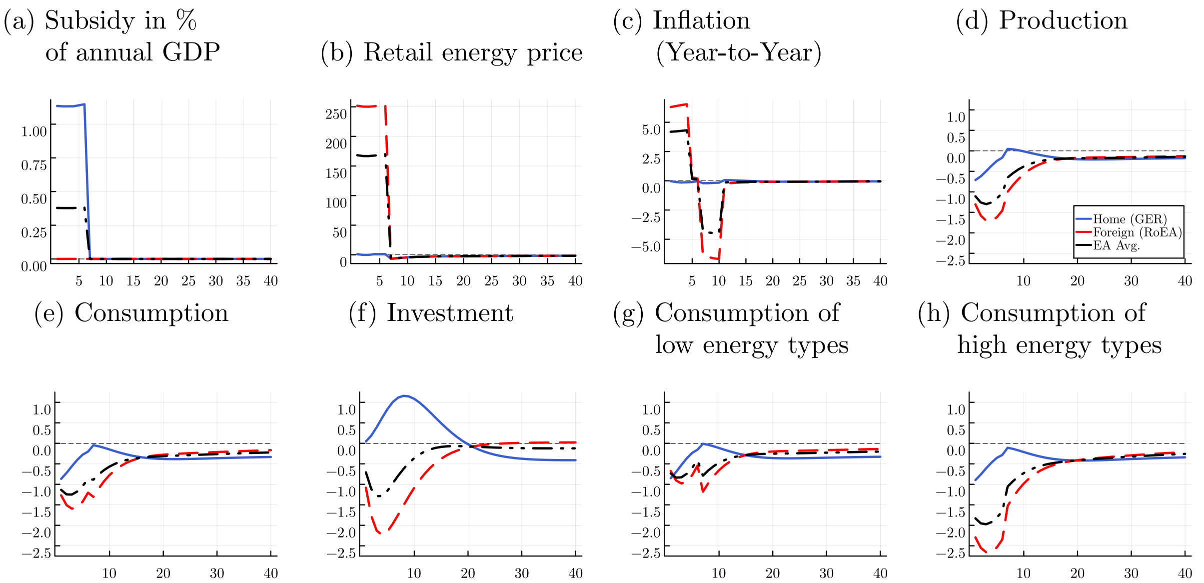
4.2 Policy option 1: subsidies

We now turn to the policy experiments and first consider the subsidy, which is only implemented at Home. It turns out that an energy subsidy is quite effective in shielding the domestic economy from the adverse aggregate impact of the shock in terms of output. Figure 4 illustrates this. It is organized in the same way as Figure 2 above and shows the adjustment to the shock when the subsidy is put in place. The drop of output in Home (panel d) is only about half as large as in the baseline. The same holds for consumption (panel e); domestic investment actually increases (panel f).

However, much of this comes at the expense of Foreign. If Home puts a subsidy in place, the adverse impact of the shock on Foreign gets amplified. The main reason for this is the response of energy prices. As panel b) of Figure 4 shows, energy prices in Foreign are much higher if Home subsidizes energy prices—simply because, as stressed above, the energy market is fully integrated across countries. This leads the subsidy to prevent inflation from rising at Home, but simultaneously to increase inflation at Foreign. Since the effect on Foreign weighted by country size is larger, euro area inflation is larger, not smaller, than what it would be in the baseline without a policy response (see panel c). Importantly, this implies that the subsidy has close to no effect on how monetary policy responds to the shock via an adjustment of short rates (not shown).

While consumers and firms in the domestic economy benefit from energy prices at pre-crisis levels, the increase in wholesale gas prices results in significant fiscal costs for the subsidy that exceed what one would have expected by just looking at the retail prices under the no-policy baseline. Expressed differently, the subsidy leads to a higher gas price and this feedback renders the subsidy particularly expensive. Over the six quarters of the intervention, the domestic economy spends around seven percent of its annual GDP on energy subsidies, which is more

Figure 4: Macroeconomic effects of energy subsidies at Home



Notes: See Figure 2. Impulse response to the energy crisis when the Home country keeps the retail price of energy at the steady state level by means of a subsidy.

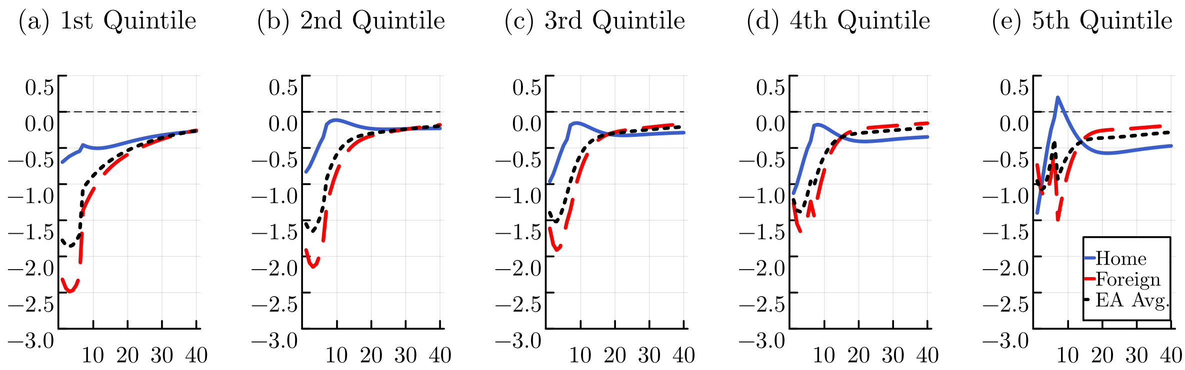
than twice the total annual energy bill to which we calibrated the model. This leads to a significant increase in distortionary taxes, causing a decline in output and consumption in the medium run (see panels d) and c) of Figure 4). These adverse medium-run effects are not confined to the domestic economy but also appear at Foreign, as the short-run amplification of the crisis via the subsidy increases the fiscal costs of the crisis there as well.

The subsidy is very effective, however, in undoing the distributional impact of the shock at Home. In fact, it shifts the burden of adjustment from the income-poor to the rich. Figure 5 illustrates the consumption response by income group, showing that the consumption of the lowest quintile now decreases less than that of the highest quintile. This effectively reverses the order of the baseline response without fiscal intervention.[13] This reversal reflects the unequal change in the tax burden over time. At Foreign, by contrast, the poor suffer even more because they are particularly exposed to the energy price increase. However, as the domestic subsidy amplifies the crisis at Foreign economy, the wealthy at Foreign country also expect to pay higher taxes in the future and also larger deflation after the crisis (i.e., even higher real rates going forward; see the discussion below). Consequently, they reduce their consumption more significantly than in the baseline.

Figure 6 offers a breakdown of the total effect of the subsidy in the effect of subsidies to households and firms, respectively. It also isolates the effect of distortionary taxes by showing results for a scenario where the subsidy is financed by a non-distortionary tax proportional to the income tax. The top row illustrates the overall effect of the policy, showing the change in adjustment dynamics relative to the baseline without policy intervention. The second row presents results when only households receive the energy subsidy, funded by a hypothetical

[13]The response of the 5th quintile shows some volatile behavior between the 4th and the 6th periods. See Appendix D.4 for further discussion of the underlying mechanism.

Figure 5: Effects of energy subsidies on household consumption along the income distribution



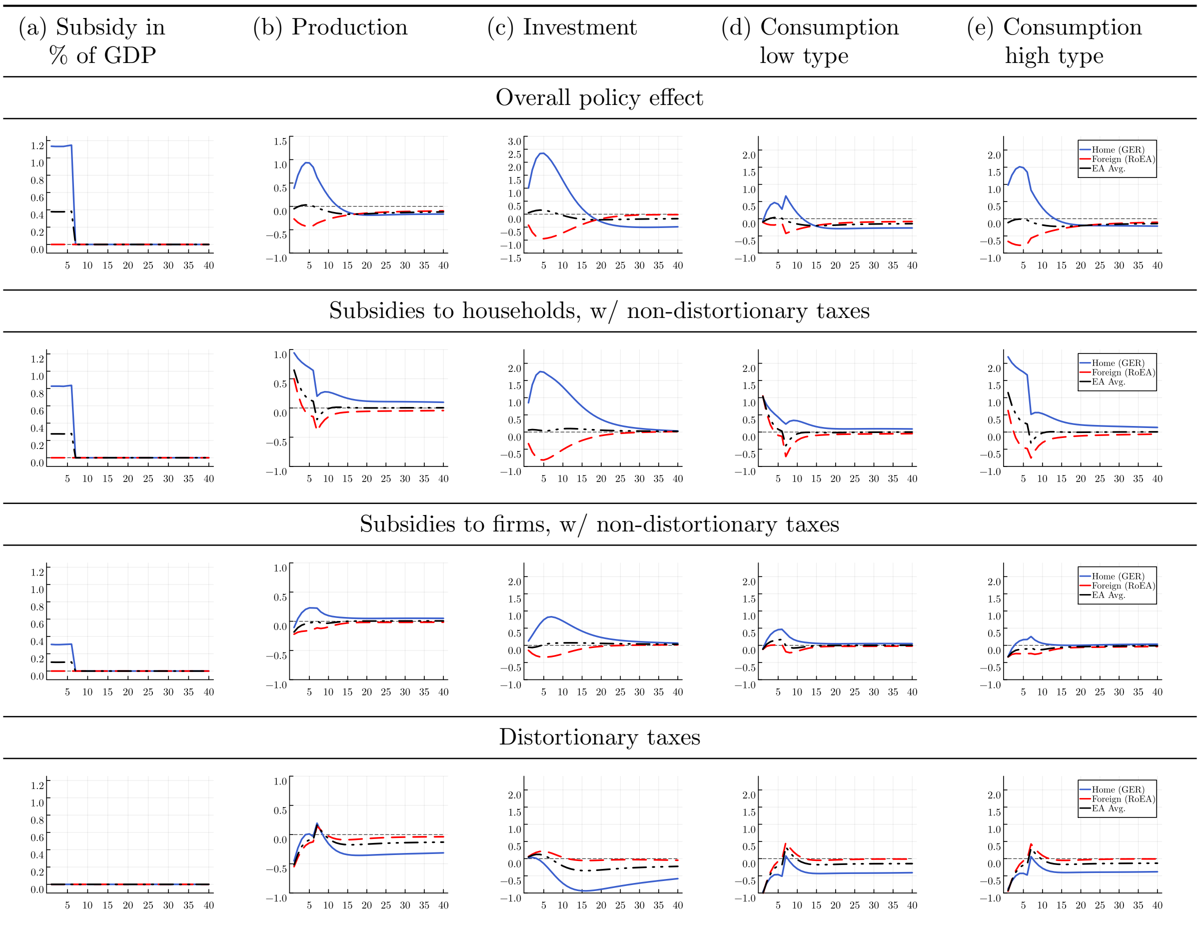
Notes: See Figure 2. Consumption response by income quintile when the Home country keeps the retail price of energy at the steady state level by means of a subsidy.

non-distortionary surcharge on labor taxes. Subsidizing household energy demand boosts consumption and, since output is demand-determined, also increases production. This occurs for two main reasons: First, household income effectively increases, which is more pronounced in poorer households with a high marginal propensity to consume. Secondly, there is a more subtle effect: an energy subsidy not only influences intratemporal substitution between energy and goods consumption but also has an intertemporal effect. This effect, highlighted by Guerrieri et al. (2022) in their analysis of the pandemic, occurs when the price of energy is flexible and complementary to goods consumption. An increase in energy prices raises the current price of the composite consumption basket, increasing the ex-ante real rate and putting downward pressure on overall consumption.[14] In equilibrium, households' attempts to reduce consumption and increase savings result in lower incomes, known as the Keynesian paradox of thrift. The energy subsidy for households mitigates this 'Keynesian supply shock' aspect of the energy crisis, making it effective. At Foreign, where no subsidy takes place, the reverse happens: as energy prices rise further, the subsidy at Home amplifies the crisis. However, because in this setting only households receive a subsidy at Home, the firm sector at Home provides a part of the required union-wide energy consumption cut. Additionally, the increased demand from Home results in a positive spillover effect of the subsidy on Foreign production.

The effect of subsidizing energy only in production, as shown in the third row, generally has an adverse impact on production initially, even if taxes are non-distortionary. Intuitively, the subsidy raises energy prices in non-subsidized markets, which, all else being equal, crowds out production at Foreign as well as union-wide household energy consumption. This exacerbates the 'Keynesian supply shock' aspect. Consequently, subsidizing energy in production generates a negative effect on demand at Home. Only when lower energy prices lead to lower goods prices at Home do we observe a positive effect on consumption and production. These positive effects are concentrated among low energy-intensive households. The last row of Figure 6 isolates the effect of distortionary taxes. It demonstrates that approximately half of the expansionary effects of the subsidy at Home, and all of the expansionary effects at Foreign that would occur under lump-sum taxes, are negated by the significant negative distortionary effects of the future

[14] See Appendix D.4 for a detailed discussion

Figure 6: Macroeconomic effects of energy subsidies: Decomposition



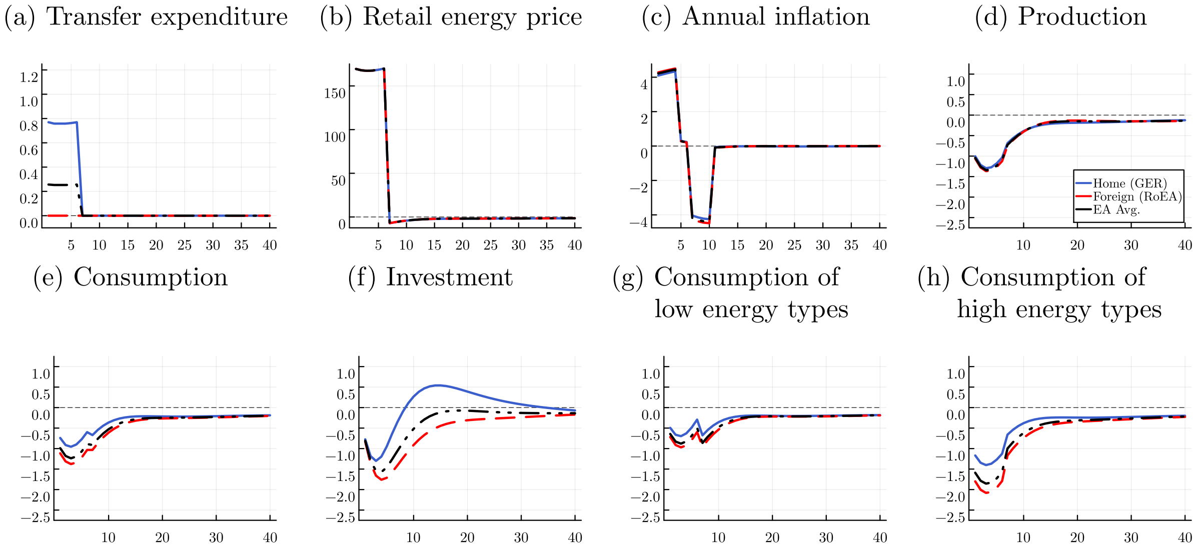
Notes: See Figure 2. Difference to baseline (as in Figure 4) when the Home country keeps the retail price of energy at the steady state level by means of a subsidy. *Top row:* overall effect. *Second row:* the effect of only a subsidy for households. *Third row:* the effect of a subsidy for firms. *Fourth row:* effect of the change in distortionary taxes.

distortionary taxation required to finance the subsidy.

4.3 Policy option 2: transfers

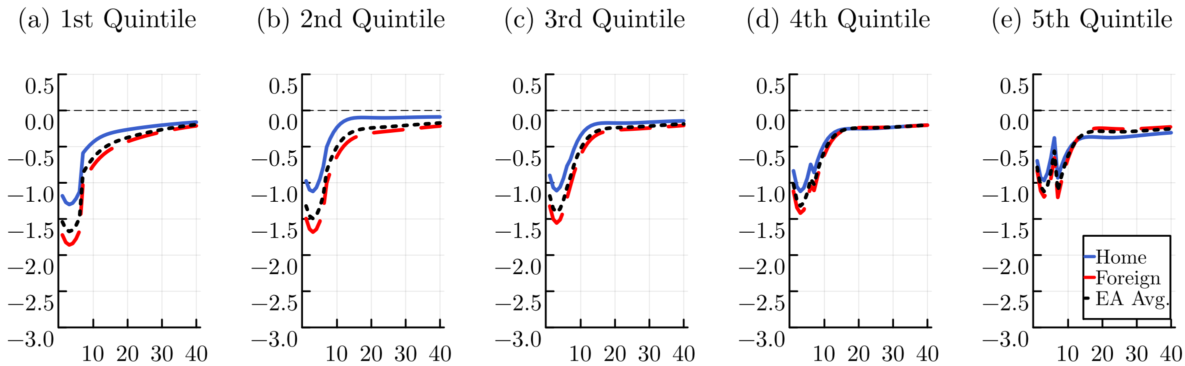
The second policy experiment that we consider involves transfers to firms and households. Figure 7 shows the aggregate effects of the crisis once the transfer scheme is implemented. The figure is organized in the same way as Figures 2 and 4 before. Comparing aggregate dynamics with transfers to the baseline without fiscal response, we find that the effect of transfers on aggregate dynamics is moderate. Cumulatively within the first six periods, the transfers reduce the output loss (panel d) at Home by about 0.05 percent of annual GDP. Household consumption at Home (panel e) increases compared to the crisis scenario, but not as much as it does with the subsidy. Importantly, the policy does not generate large international spillovers. The dynamics at Foreign are almost unchanged relative to the crisis scenario and the same holds for the retail price of energy (panel b). Compared to subsidies, the transfer policy is fiscally much cheaper, with expenditures of less than 5% of annual GDP over the six quarters of crisis.

Figure 7: Macroeconomic effects of targeted transfer payments for energy consumption in Germany



Notes: See Figure 2. Impulse response to the energy crisis when the Home country provides households and firms with transfers to compensate for the energy price increase.

Figure 8: Effects of transfer payments for energy consumption along the income distribution

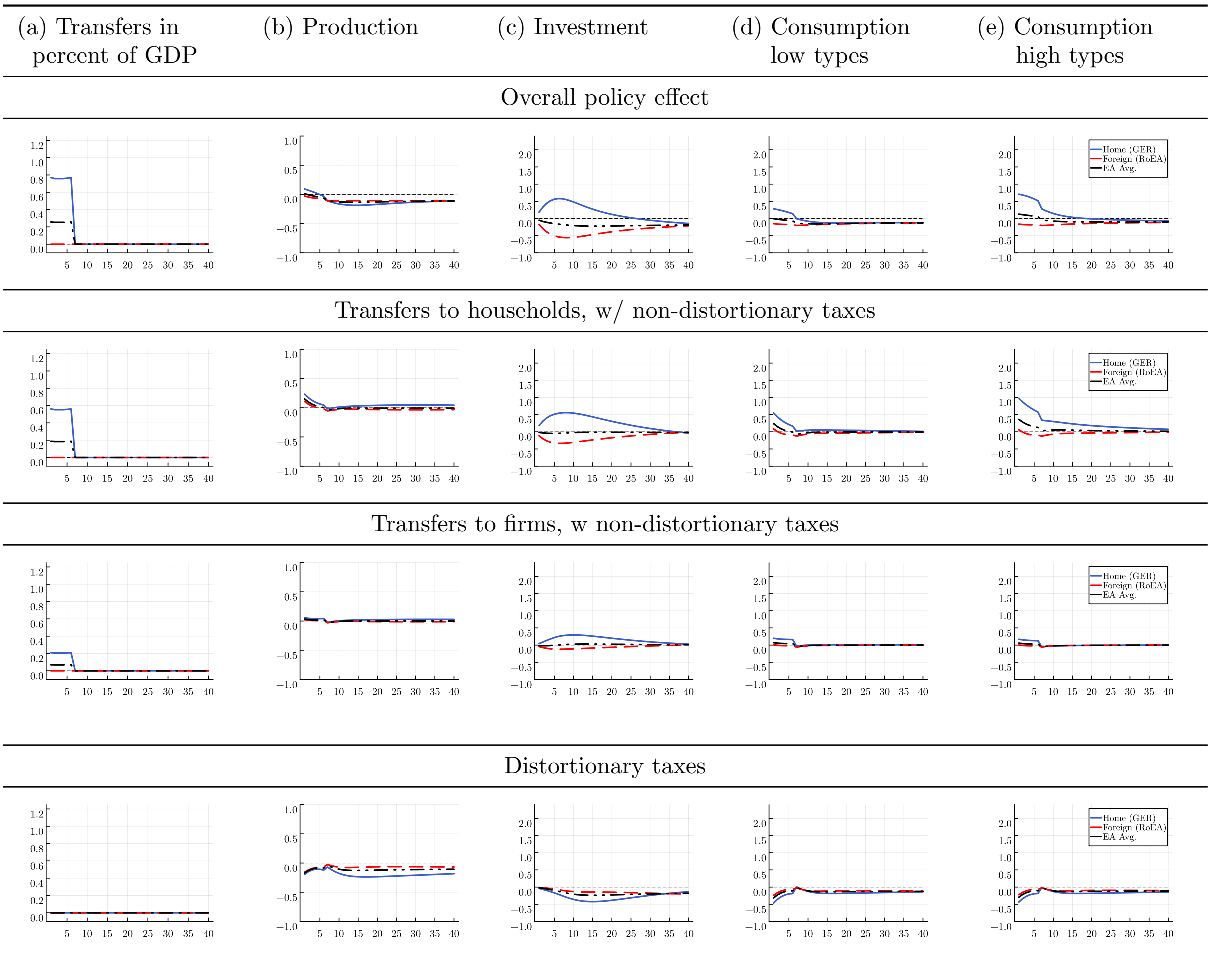


Notes: See Figure 2. Consumption response by income quintile when the Home country provides transfers to compensate for the energy price increase.

Figure 8 shows the response of consumption along the income distribution with the transfer in place. Compared to the baseline results shown in Figure 3, it is evident that transfers substantially mitigate the adverse distributional impact of the shock, particularly by reducing the decline in consumption among the poor. However, when comparing the responses under transfers in Figure 8 with those under the subsidy in Figure 5, we observe that the distributional impact of the shock remains greater with transfers. This is because, unlike energy subsidies, high-energy type households—who are on average lower income—still have a higher incentive to postpone their consumption as higher energy prices more strongly affect their consumption bundle.

As before, we decompose the effect of the transfer policy into the components received by households and firms and examine the role of distortionary taxes. Figure 9 presents the results,

Figure 9: Macroeconomic effects of energy transfers: Decomposition



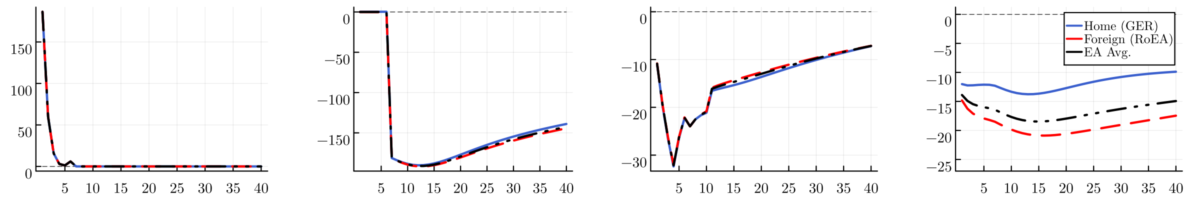
Notes: See Figure 6. The policy replaces the energy subsidies by transfers to households and firms according to their pre-crisis energy consumption and the price increase during the crisis. Difference to baseline (as in Figure 4) when the Home country pays transfers to households and firms according to their pre-crisis energy consumption and the price increase during the crisis. *Top row:* overall effect. *Second row:* the effect of only a subsidy for households. *Third row:* the effect of a subsidy for firms. *Fourth row:* effect of the change in distortionary taxes.

organized similarly to Figure 6, but provides the decomposition for the transfers. We observe that, compared to subsidies, transfers boost consumption to a lesser extent. Since transfers do not stabilize energy prices for households and firms, they reduce their energy use as in the baseline without policy intervention, which is the desired effect, but they also continue to postpone goods consumption. Unlike subsidies, transfers do not eliminate the 'Keynesian supply' channel. Consequently, we see a lower response in goods consumption as households try to save more due to the complementarity. This explains why the consumption response in panel e) of Figure 9 is considerably more muted than its counterpart for subsidies shown in Figure 6.

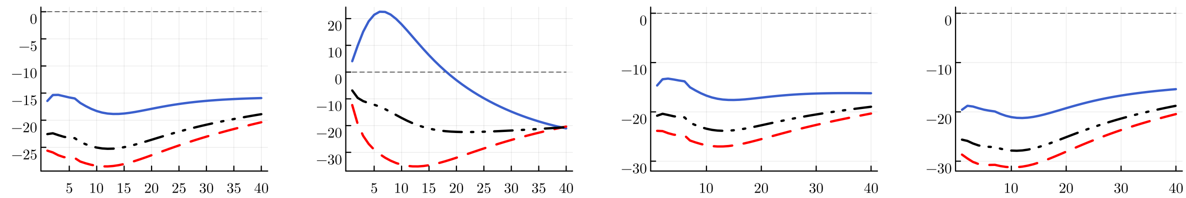
The second row illustrates how transfers in this model work by focusing solely on transfers to households. Liquidity-constrained households, which exhibit a high marginal propensity to consume, particularly increase their consumption, thus stabilizing the economy. This contrasts with models featuring a representative agent, where transfers would have no positive aggregate effect due to Ricardian equivalence. We explore the role of heterogeneity in the transmission of policy interventions by implementing the RANK version of our model and comparing impulse

Figure 10: Macroeconomic effects of energy subsidies union-wide that stabilizes energy prices

(a) Subsidy in % of annual GDP | (b) Retail energy price | (c) Inflation (Year-to-Year) | (d) Production



(e) Consumption | (f) Investment | (g) Consumption of low energy types | (h) Consumption of high energy types



Notes: See Figure 2. Impulse response to the energy crisis when the both countries keep the retail price of energy at the steady state level by means of a subsidy.

response functions in Appendix D.1. We find that while the results for the subsidy are similar in magnitude in both RANK^2 and HANK^2, the results for transfers differ. In the RANK version of the model, lump-sum payments are ineffective in stimulating demand due to the negligible marginal propensity to consume of the representative households. Additionally, since they are financed by distortionary taxes, they are even recessionary. Only in a model where many households have a high marginal propensity to consume can the transfer scheme generate a positive demand effect. The importance of targeting transfers is further illustrated by the results shown in the third row of the figure, which focuses on transfers to firms. Transfers to entrepreneurs, a group of wealthy households with low marginal propensities to consume, do not generate much of an effect. However, it should be noted that we abstract from financing frictions that entrepreneurs might face and which then could alter results. Lastly, the bottom row of Figure 9 shows the effects of higher distortionary taxation in isolation. These taxes will eventually increase to fund the costs of the fiscal intervention. All else being equal, these taxes have adverse effects on the economy, but less so than in the case of the subsidy, simply because the fiscal costs of the transfers are smaller.

4.4 Policy option 3: coordinated union-wide subsidies

So far, the analysis has focused on policies implemented at Home. One of the main differences between subsidies and transfers is that Foreign is affected differently. In particular, in the case of subsidies, Foreign is affected very negatively. This raises the question of the effects of policies that are coordinated within the monetary union in the sense that they are implemented in both countries.

Figure 10 illustrates the results of a union-wide subsidy large enough to offset the increase in energy prices. If energy prices for consumers and firms are fixed at pre-crisis levels, the only way the energy market can clear is if overall demand falls sufficiently to reduce energy demand in line with the reduced supply. Essentially, subsidies prevent gas from being substituted by other factors of production and consumer goods. In this sense, the coordinated subsidies transform an economy with a positive elasticity of substitution almost into a 'Leontief' economy, where activity must fall in direct proportion to energy supply. This necessary reduction in income is a natural consequence of the subsidy policy: Future tax distortions increase drastically, resulting in poorer households that demand fewer goods and less energy. Inflation and interest rates (not shown) fall. Thus, for the union as a whole, coordinated subsidies do not stabilize the economy in a gas crisis but worsen the crisis. This result highlights a key difference in our analysis compared to Langot et al. (2023), namely the assumption that the energy supply is fixed for the euro area. This is the key reason why subsidies at a euro-area level are ineffective: National subsidies shrink the size of the "pie" but redistribute it towards the subsidizing country. If both countries subsidize, only the size of the "pie" declines.

From a country perspective, coordinated subsidies do not harm economies uniformly. They affect the Foreign economy more adversely than the Home economy. The key difference between the two countries lies in their welfare states. Strong minimum income benefits in the domestic economy not only provide an automatic stabilizer but also make households more willing to accept the illiquidity of physical assets compared to households at Foreign. This results in different interest rate elasticities of illiquid savings in the two economies. Illiquid savings respond more to the interest rate cuts by the central bank that responds to the worsened euro-area wide recession. As a result, investment at Home actually increases initially. This rise in investment stabilizes aggregate demand at Home relative to Foreign in the short term and potential output in the medium term.

Consequently, the contractionary effect of the coordinated subsidy is smaller at Home than at Foreign. Notably, the coordinated subsidy does not stabilize the consumption of households with high energy consumption relative to those with low energy consumption. Since high-energy households are poorer on average, their consumption depends more on income than on wealth, as they have a higher marginal propensity to consume out of income.

Overall, the negative impact and fiscal costs of a coordinated subsidy are extremely large. The subsidies initially amount to 150% of GDP, significantly affecting the government budget. Given the magnitude of these negative effects on top of the energy crisis itself, our first-order approximation should be taken with a grain of salt. For this reason, Appendix D.3 provides the results for a smaller euro-area-wide subsidy, where the size of the subsidy payments in both countries is fixed to the amount that the domestic economy paid in Figure 4. In this scenario, output and consumption of all households fall more than in the case without policy intervention across the euro area, while the effect on energy prices is barely noticeable. Hence, we conclude that with a fixed energy supply, coordinated subsidies are bound to fail their purpose regardless of their size. Therefore, we will not consider this policy in the following section, which investigates the welfare consequences of each policy.

4.5 Welfare comparison

So far we have focused on the extent to which the fiscal responses to the crisis are successful in terms of macroeconomic stabilization. In what follows, we take up a related but distinct issue, namely the role of the policy response in insuring households in the cross section and hence, for welfare. We do this by calculating the consumption equivalents of avoiding the energy crisis for each household with and without the two alternative fiscal policies. Figure 11 shows the results of this exercise for policy options conducted at Home only. On average, households at Home would be willing to give up 0.40% of lifetime consumption to avoid going through the 6 expected quarters of energy scarcity.[15]

The blue bars in the first row of Figure 11 show the effect of the crisis itself, the red bars show the effect of the crisis with active subsidies, and the black bars show the effect of the crisis with active transfers. The top left panel shows the effects at Home split by income Quintile, the top right panel shows the effects in Home, in Foreign, and euro-area wide ('Avg.') split by energy type of household.

Looking at the overall euro-area wide effects first (last two blocks of columns in the top row right panel), we see that subsidies produce additional welfare losses for both energy types, while transfers produce welfare losses only for the low-energy-consumption type. For the high type, on average there are small welfare gains. However, overall (not shown) transfers as a crisis measure reduce welfare.

The subsidy policy (see left panel, top row of Figure 11) even produces additional welfare losses for the 40% income-richest households at Home, while the transfers improve welfare at Home in all income groups (comparing blue and red / blue and black bars).[16] The largest welfare gains from both policies are observed for high-energy-consumption type of households at Home. Conversely, subsidies particularly harm households with high energy consumption in the Foreign economy.

The bottom part (rows two to four) of Figure 11 provide a decomposition of the welfare effects both for the Home economy (left column) and for the Foreign economy (right column). We separate the effects of subsidies/transfers to households (row 2) and firms (row 3) from their distortionary effects (row 4).

Overall, subsidies to households, if they could be financed through non-distortionary taxation, would eliminate 91% of the welfare loss from the energy crisis at Home (compare the

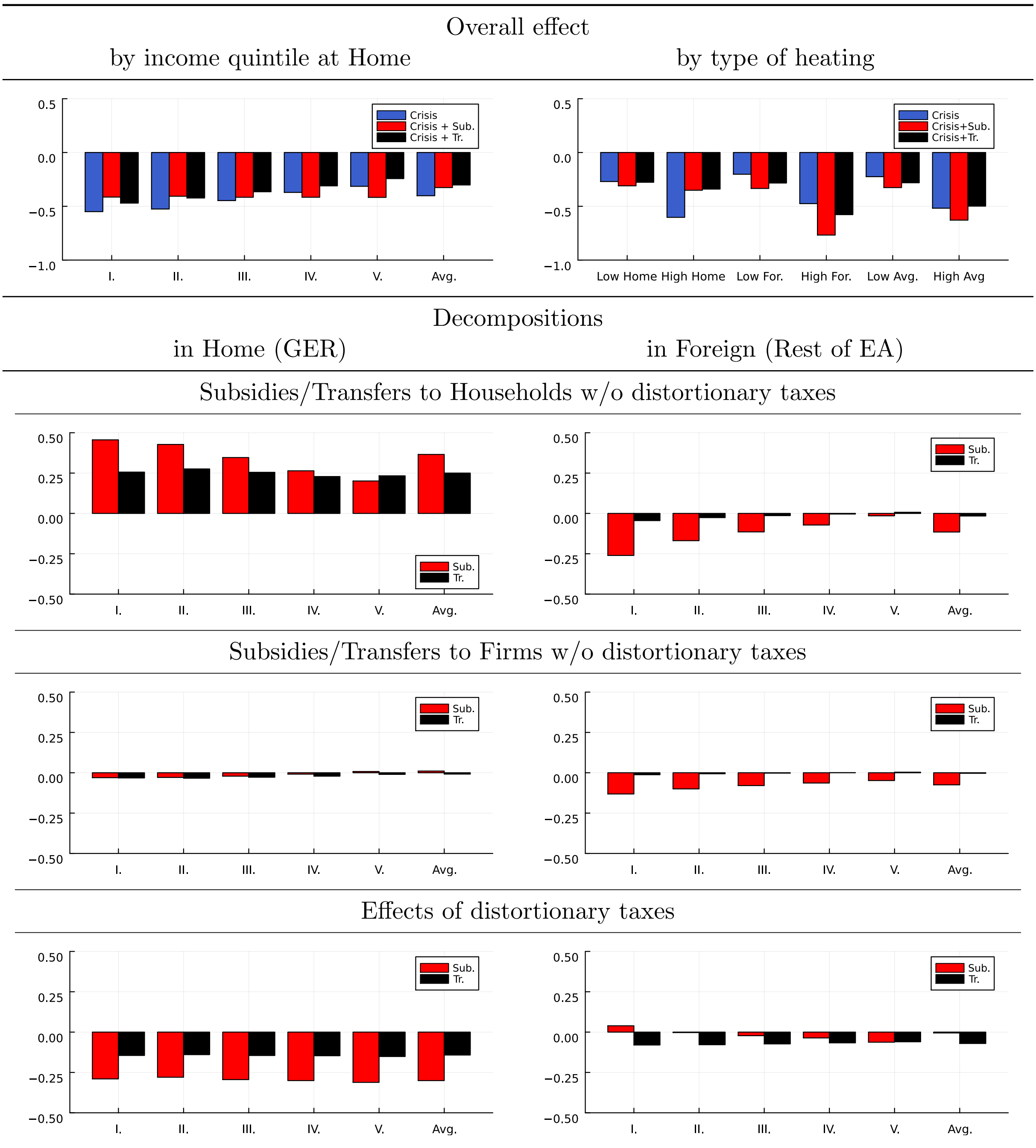
[15] We first calculate the change in utility of a household as

$$\sum_t \frac{\partial V(b,k,h,a)}{\partial P_t} \mathbf{d}P_t = \mathbf{d}V(b,k,h,a), \tag{9}$$

where $\mathbf{d}P_t$ is the impulse response of all prices that appear in the household problem, and $\frac{\partial V(b,k,h,a)}{\partial P_t}$ is the gradient of the value function with respect to those prices. This gradient can be computed efficiently using the envelope theorem as in Auclert, Rognlie, and Straub (2024). With this change in the utility of a household in state (b,k,h,a), we compute the consumption equivalent variation for that household as $\frac{\mathbf{d}V(b,k,h,a)}{V(b,k,h,a)(1-\xi)}$. When reporting the consumption equivalents of groups of households, we report the unweighted average of their consumption equivalents.

[16] Comparing the welfare gains of subsidies relative to transfers by income groups in the Home economy, one finds that the top 60% of households in terms of income prefer transfers over subsidies. A difficulty in this comparison is that the subsidies are fiscally more expensive. If we rescale the subsidies to only cover a fraction of the price increase, such that the costs of the program are as high as for the transfers, the top 80% prefer the transfer program over subsidies, see Appendix D.

Figure 11: Welfare impact of energy subsidies and transfers



Notes: The top row shows the average (within-group) welfare effect in terms of the energy crisis in terms of consumption equivalents. Left: only in Home, by income. Right: by energy intensity, both Home and Foreign. Next two rows: partial effects on welfare of subsidies/transfers to households and firms separately (financed through non-distortionary taxes). Last row: effect of distortionary taxes. Left: in Home, by income. Right: in Foreign, by income.

red bar in "Avg." in the left panel of row 2 to the corresponding blue bar in the left panel of row 1). However, this is largely at the expense of poor foreign households (right panel, row 2). Transfers provide a slightly smaller boost in welfare at home of 63% of the loss of welfare from the crisis (compare the black bar in "Avg." in the left panel of row 2 to the corresponding blue bar in the left panel of row 1), while barely affecting the welfare of the foreign economy.

Subsidies to firms (third row, red bars) and transfers to firms (third row, black bars) do not have a sizable impact at welfare at Home. Transfers to firms also do create an international spillover while energy subsidies for firms have a noticeably negative welfare impact in the rest of the euro area. They raise consumer prices for energy.

The last row of Figure 11 shows that the welfare costs of the necessary increase in distortionary taxation to finance subsidies or transfers are sizable. Expressed differently, it is important to take them into account. On average, the necessary tax distortions eliminate more than three quarters of the welfare gain of subsidies at Home and roughly half of the welfare gain from transfers. As the Home economy levies higher taxes, its output falls but this externalized the tax distortion somewhat, because it improves Home's terms of trade. Therefore, the distortionary effects of higher taxes also spill over to the Foreign economy.

4.6 Robustness

To assess the robustness of our findings, we conduct a series of additional experiments, which we summarize in what follows, delegating a more detailed analysis, along with the corresponding figures to Appendix C.

First, we use a second-order perturbation to solve a one-country version of the model to assess the quality of the first-order approximation of the model dynamics studied so far (see Section B.4). The impulse responses in Appendix C.1 indicate that, while there are differences between the two solutions, these differences primarily affect the amplification of the shock, not the shape of the impulse responses. Therefore, once we adjust for the lack of amplification in the first-order solution by increasing the size of the shock, the impulse responses are almost perfectly superimposed. Since our baseline solution is linear, this finding suggests that all our baseline results are fairly accurate up to the size of the shock.[17]

Second, we revisit the calibration of the idiosyncratic risk process (see Appendix C.2). In one robustness exercise, we set the variance of idiosyncratic income shocks at Foreign equal to the one at Home, ensuring the same parametrization in both countries. Additionally, we increase the persistence of the idiosyncratic risk, extending the half-life of the shock by 10%. We then adjust the discount rates in both countries to match the debt levels in our baseline. These variations have virtually no effect on our findings. While, under the alternative calibration, the recession is slightly less severe at Home and slightly more severe at Foreign, the quantitative differences are minimal.

Third, we consider an alternative calibration for the fiscal policy rule with slower debt repayment, setting the repayment parameter γ_B to 0.01 instead of 0.02 (Appendix C.3) . This

[17] As subsidies at Home effectively increase the size of the energy shock in Foreign and reduce it at Home, the second-order approximation suggests that this might come with an additional euro-area-wide dead weight loss from which our first-order approximation abstracts

increases the expansionary effect of the policy measures, but it increases in particular the effectiveness of transfers in stimulating output, consumption, and investment at Home. With a later repayment, the non-Ricardian nature of the transfers plays out more strongly, and because this is their main effect, boosts their effectiveness comparably more relative to the subsidies which, as explained, work partly through effectively changing expected real rates.

Fourth, we consider a more dovish monetary policy, with $\gamma_\pi = 1.25$ instead of 1.5 and $\rho_R = 0.9$ instead of 0.85 (again see Appendix C.3). This policy stance slightly dampens the effectiveness of subsidies and transfers. This is because both policies are contractionary in the monetary union as a whole. The more hawkish the central bank, the more it eliminates the negative euro-area demand effects by lowering interest rates. A more dovish monetary policy means that interest rates are cut less.

Fifth, we include a third country in the analysis (see Appendix C.4). This additional country exports gas and captures the profits. Specifically, we model the gas-exporting country as a simple representative agent. If we assume that the representative household in the gas-exporting country has the same preferences as the entrepreneurs in our baseline model, and thus purchases the same amount of consumer goods and capital in response to changes in gas prices, the impulse responses to the gas crisis remain unchanged. However, recognizing that this could be a strong assumption, we also consider an alternative behavior for the gas exporter. In this scenario, the gas exporter follows a simple demand rule, accumulating liquid assets in the euro area when income from gas sales exceeds the steady state. Subsequently, it gradually reduces its accumulated liquid asset position by increasing consumption above the steady state in the future. The results indicate that the difference between the two scenarios is negligible.

Sixth, we examine the consequences of a potential limited information set for the policy maker. Throughout the paper, we assumed that the energy consumption of each household is known to the policy maker. In Appendix C.5, we conduct a robustness exercise where this is not the case. Instead, households receive transfers based on average gas consumption, conditional on income and wealth. Specifically, households receive a transfer equal to the average gas consumption for households with a given level of income and wealth. From a macroeconomic perspective, this approach has the same effect as directly targeting gas consumption. This is because the marginal propensity to consume of a household is only a function of its wealth and income, not its energy type. Thus, the incidence of the transfer multiplied with the recipients marginal propensity to consume is identical to our baseline. However, at the micro level, such a policy means the government is less able to shield high energy consumers from the impact of the energy shock. Consequently, the consumption of high energy consumers is less stabilized compared to the baseline scenario.

Seventh, we further decompose the effects of tax distortions required to finance the subsidy and transfer policies, as reported in the last rows of Figure 6 and Figure 9. In Appendix C.6, we break down the total tax distortion effects into the portions needed to finance subsidy/transfer payments to households and those needed to finance subsidy/transfer payments to firms. In both cases, the distortionary effects of the policies paid out to households have larger negative impacts. This is because payments to households are fiscally more expansive than payments to firms, simply due to the higher steady-state share of gas in consumption compared to production (see Table 1).

5 Conclusion

In response to the European energy crisis of 2022/23, many countries have adopted discretionary fiscal policies to mitigate the impact of the sharp rise in natural gas prices. For instance, France has implemented subsidies, while Germany has opted for transfers. In this paper, we use a two-country HANK model, incorporating energy in both private consumption and production, to evaluate these policies across various dimensions. We examine not only their business cycle impact on macroeconomic aggregates but also their effects across the income distribution. Importantly, our two-country framework allows us to study the spillovers of these policies, assuming they are implemented in the domestic economy but may extend to the rest of the union.

We conduct our analysis in a quantitative model calibrated to the euro area. The domestic economy is calibrated to German data and represents one third of the euro area. A key result of our analysis is that while energy subsidies stabilize the domestic economy, they raise energy prices in the rest of the union. This, in turn, generates negative spillovers to the rest of the euro area—making them a zero-sum game, a beggar-thy-neighbor policy. Next, we examine the effect of targeted transfers conditional on pre-crisis levels of energy consumption—similar in spirit to a Slutsky compensation. These targeted transfers are less effective than subsidies in stabilizing national output. Yet, they do not harm production in the rest of the union and perform better in terms of welfare. In addition, such transfers do not prevent substitution effects when energy supply collapses. We also demonstrate that union-wide subsidy policies, as an alternative to subsidies in a single country, do not prevent negative spillovers. With a fixed energy supply, energy subsidies hinder the substitution of energy with other factors of production and consumer goods. This shifts the entire union's economy from having a positive elasticity of substitution to one that is nearly 'Leontief'. Consequently, output across the union declines almost one-for-one with energy.

As in all HANK models, heterogeneity is a recurring theme in our analysis, with a high marginal propensity to consume playing a crucial role in the effectiveness of policy measures. Additionally, we demonstrate that shielding households with high energy consumption is essential during an energy crisis. While subsidies are effective in one country, they come at the expense of another. On the other hand, transfers also support these households but at a lower cost and with minimal negative spillovers to other countries. These effects are reflected in the welfare analysis. High-income households, low-energy consumption households at Home, and all households at Foreign lose out with a subsidy implemented at Home. The first two groups receive no benefits but bear the costs, while the latter faces higher energy prices. Transfers in one country result in households in the other country being worse off, but to a much lesser extent than with a subsidy. This suggests that policymakers should employ targeted transfers during an energy crisis rather than subsidies.

In sum, our research illustrates the potential of (open-economy) HANK models to address first-order policy issues, as they allow for the simultaneous treatment of within- and between-country heterogeneity and their interaction.

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A A HANK2-model with energy

The model in the paper is based on the two-asset, medium-scale HANK^2 model in Bayer et al. (2024). We extend the model to cover energy use in production and in household consumption (heating).

Each country consists of a firm sector and a household sector. The firm sector of each country comprises (a) perfectly competitive intermediate goods producers, who produce intermediate goods using capital, labor, and energy; (b) final goods producers that face monopolistic competition when selling differentiated final goods, in turn, produced on the basis of homogeneous domestic intermediate inputs; (c) a representative consumption good bundler bundling domestic and imported foreign final goods to consumption goods; (d) producers of capital goods that turn consumption goods into capital subject to adjustment costs; (e) labor packers that produce labor services combining differentiated labor from (f) unions that differentiate raw labor rented out from households. Price setting for the final goods, as well as wage setting by unions, is subject to a pricing friction à la Calvo (1983). Only final goods are traded across countries.

In each country, there is a continuum of households of size $n \in (0, 1)$ and $1 - n$, respectively, such that the total population is 1. Households in both countries consume a bundle that consists of domestically produced and imported goods. Households earn income from supplying (raw) labor and capital to the national labor and the national capital markets and from owning firms in their respective country. Households absorb all rents that stem from the market power of unions and final good producers, and decreasing returns to scale in capital goods production. Furthermore, we assume that the profits of the energy suppliers go to the entrepreneurs.

There is a common monetary authority and the exchange rate is permanently fixed. Fiscal policy is run at the country level. It levies taxes on labor income and profits, issues bonds, pays transfers, and adjusts taxes to stabilize the level of outstanding debt in the long run. Public debt is risk-free and thus yields the same return in both countries, in turn, determined by monetary policy by means of a simple interest rate feedback rule. We assume that countries are perfectly symmetric and differ only because of asymmetric shocks and different parameterizations. In what follows, our exposition thus focuses on the domestic economy and uses an asterisk to denote foreign variables whenever they are relevant.

A.1 Households

The household sector is subdivided into two types of agents: workers and entrepreneurs. The transition between both types is stochastic. Both rent out physical capital, but only workers supply labor. The efficiency of a worker's labor evolves randomly exposing worker-households to labor-income risk. Entrepreneurs do not work but earn all pure rents in the economy except for the rents of unions which are equally distributed across workers. It is worth stressing that the entrepreneurs earn profits from selling energy, i.e., the deviations from the steady state energy prices move "entrepreneurial" incomes. The assumption is made because during the European energy crisis European gas liquefication terminals and gas transport ships earned the scarcity rents of gas. Moreover it reflects the fact that gas profits by, say Norway, typically get reinvested.

All households self-insure against the income risks they face by saving in a liquid nominal asset (bonds) and a less liquid asset (capital). Trading illiquid assets is subject to random participation in the capital market. To be specific, there is a continuum of ex-ante identical households of measure n, indexed by i. Households are infinitely lived, have time-separable preferences with time discount factor β, and derive felicity from consumption and leisure. Total consumption c_{it} consists of energy E_{it}^C and the physical consumption good c_{it}^P. Households obtain income from supplying labor, n_{it}, from renting out capital, k_{it}, and from earning interest on bonds, b_{it}, and potentially from profits or union transfers. Households pay taxes on labor and profit income and receive minimum income benefits as well as other transfers.

A.1.1 Productivity, labor supply, and labor income

A household's gross labor income $w_t n_{it} h_{it}$ is composed of the aggregate wage rate on raw labor, w_t, the household's hours worked, n_{it}, and its idiosyncratic labor productivity, h_{it}. We assume that productivity evolves according to a log-AR(1) process with time-varying volatility and a fixed probability of transition between the worker and the entrepreneur state:

$$\tilde{h}_{it} = \begin{cases} \exp(\rho_h \log \tilde{h}_{it-1} + \epsilon_{it}^h) & \text{with probability } 1-\zeta \text{ if } h_{it-1} \neq 0, \\ 1 & \text{with probability } \iota \text{ if } h_{it-1} = 0, \\ 0 & \text{else.} \end{cases} \tag{10}$$

with individual productivity $h_{it} = \frac{\tilde{h}_{it}}{\int \tilde{h}_{it} di}$ such that $\tilde{h}_{it}$ is scaled by its cross-sectional average, $\tilde{h}_{it} di$, to make sure that average worker productivity is constant. The shocks ϵ_{it}^h to productivity are normally distributed with variance $\sigma_{h,t}^2$. With probability ζ households become entrepreneurs ($h = 0$). With probability ι an entrepreneur returns to the labor force with median productivity. In our baseline specification, an entrepreneur obtains a share of the pure rents (aside from union rents), Π_t^F, in the economy (from monopolistic competition in the goods sector and the creation of capital). These rents include profits due to an increase in energy prices. We assume that the claim to the pure rent cannot be traded as an asset. Union rents, Π_t^U are distributed lump sum across workers, leading to labor-income compression. For tractability, we assume union profits to be taxed at a fixed rate independent of the recipient's labor income.[18]

With respect to leisure and consumption, households have Greenwood, Hercowitz, and Huff-

[18] This modeling strategy serves two purposes. First and foremost, it generally solves the problem of the allocation of pure rents without distorting factor returns and without introducing another tradable asset. Second, we use the entrepreneur state in particular – a transitory state in which incomes are very high – to match the income and wealth distribution following the idea by Castaneda, Dıaz-Giménez, and Rıos-Rull (1998). The entrepreneur state does not change the asset returns or investment opportunities available to households.

man (1988) (GHH) preferences and maximize the discounted sum of felicity:[19]

$$E_0 \max_{\{c_{it}, n_{it}\}} \sum_{t=0}^{\infty} \beta^t u[c_{it} - G(h_{it}, n_{it})] \tag{11}$$

Total consumption c_{it} of household i at time t consists of energy E_{it}^C and the physical consumption good c_{it}^P, again combined in a CES aggregator:

$$c_{it} = \left(\left(1 - a_{it}^C\right)^{\frac{1}{\sigma_C}} \; c_{it}^{P\,\frac{\sigma_C - 1}{\sigma_C}} + a_{it}^{C\,\frac{1}{\sigma_C}} \; \left(E_{it}^C\right)^{\frac{\sigma_C - 1}{\sigma_C}} \right)^{\frac{\sigma_C}{\sigma_C - 1}}. \tag{12}$$

Here σ_C represents the elasticity of substitution in consumption, which determines how much utility the household loses by substituting energy for physical consumption goods. a_{it}^C determines the share of the energy in the consumption good. The parameter follows a Markov chain to capture households with relatively high energy consumption as well as households with relatively low energy consumption. Since energy consumption is mostly related to heating, we calibrate the Markov chain such that it is highly persistent. The switching probability $\rho(h, a^C)$ from one type to the other is a function of the current productivity level, h, and the current energy intensity, a^C. We specify

$$\rho(h, a^C) = \bar{\rho} + (\mathbb{I}_{a^C = a_H^C} - \mathbb{I}_{a^C = a_L^C}) A(h) + \mathbb{I}_{a^C = a_L^C} B,$$

where A is a linear function of the idiosyncratic productivity quintile. With idiosyncratic productivity capital the household is more likely to remain in a low energy intense dwelling and more likely to move out of a high energy intense one. B is a constant that captures that it is in general more likely to remain in a low-energy dwelling.

The maximization is subject to the budget constraints described further below. The felicity function u exhibits a constant relative risk aversion (CRRA) with risk aversion parameter $\xi > 0$,

$$u(x_{it}) = \frac{1}{1 - \xi} x_{it}^{1-\xi}, \tag{13}$$

where $x_{it} = c_{it} - G(h_{it}, n_{it})$ is household i's composite demand for (energy and physical composite) goods consumption c_{it} and leisure and G measures the dis-utility from work. The consumption good c is a bundle consisting of energy directly consumed by the household and a physical good, which itself is a bundle of domestic and imported foreign final goods as described in Section A.2.2.

The household's labor income gets taxed at rate τ_t, such that its net labor income, expressed

[19] The assumption of GHH preferences is mainly motivated by the fact that many estimated DSGE models of business cycles find small aggregate wealth effects in labor supply; see, e.g., Schmitt-Grohé and Uribe (2012) and Born and Pfeifer (2014). Bayer, Born, and Luetticke (2023, 2024) provide a robustness check of their main results assuming King, Plosser, and Rebelo (1988) (KPR) preferences instead of GHH preferences, which transfers to our exercise. In particular, they show that a particular criticism regarding the preferences is not valid: fiscal multipliers in their estimated model are of reasonable size both in the short and in the long run. Bayer et al. (2023) provide additional and similar evidence for transfer multiplier.

in physical consumption units (i.e. without energy consumption), is given by

$$y_{it} := (1-\tau_t)w_t h_{it} n_{it}, \tag{14}$$

where w_t is the aggregate real wage rate (in physical consumption units). Given net labor income, the first-order condition for labor supply is

$$\frac{\partial G(h_{it}, n_{it})}{\partial n_{it}} = (1-\tau_t)\frac{w_t}{p_t^c(a_{it}^C)} h_{it} = \frac{y_{it}}{n_{it}} / p_t^c(a_{it}^C). \tag{15}$$

Here $p_t^c(a_{it}^C)$ is the cost in terms of physical goods at which household i buys its energy-physical consumption bundle. This price depends on the energy intensity of the household and is given by

$$p_t^c(a_{it}^C) = \left[(1-a_{it}^C) + a_{it}^C(p_t^E - \tau_t^E)^{1-\sigma_C}\right]^{\frac{1}{1-\sigma_C}}.$$

Assuming that G has a constant elasticity w.r.t. n, $\frac{\partial G(h_{it},n_{it})}{n_{it}} = (1+\gamma)\frac{G(h_{it},n_{it})}{n_{it}}$ with $\gamma > 0$, we can simplify the expression for the composite consumption good, x_{it}, making use of this first-order condition (15), and substitute $G(h_{it}, n_{it})$ out of the individual planning problem:

$$x_{it} = c_{it} - G(h_{it}, n_{it}) = c_{it} - \frac{1}{1+\gamma} y_{it}/p_t^c(a_{it}^C). \tag{16}$$

When the Frisch elasticity of labor supply is constant and the tax schedule has the form (14), the dis-utility of labor is always a fraction of labor income and constant across households. Therefore, in both the household's budget constraint and felicity function, only after-tax income enters and neither hours worked nor productivity appears separately.

What remains to be determined is individual and aggregate effective labor supply. Without further loss of generality, we assume $G(h_{it}, n_{it}) = h_{it}\frac{n_{it}^{1+\gamma}}{1+\gamma}$. This functional form simplifies the household problem in the stationary equilibrium as h_{it} drops out from the first-order condition and all households supply the same number of hours $n_{it} = N(w_t)$. Total effective labor input, $\int n_{it}h_{it}di$, is hence also equal to $N(w_t)$ because we normalized $\int h_{it}di = 1$.[20]

Households also receive profit income from union profits Π_t^U or firms profits Π_t^{fi} as workers or entrepreneurs, respectively. Both profits get taxed at rate τ_t. What is more, households may receive *non-distortionary* targeted transfer as minimum income benefits tr_{it} or transfers related to their energy consumption tr_{it}^E. The latter are given by:

$$tr_{it}^E = (p_t^E - \bar{p}^E)\bar{E}_i^C, \tag{17}$$

where p_t^E are the price of energy in terms of the consumption good c, and $\bar{E^C}_i$ is the consumption of energy a household with the characteristics of household i has in steady state. All together, after-tax non-capital income, plugging in the optimal supply of hours, is then:

$$y_{it} = \left[(1-\tau_t)w_t/p_t^c(a_{it}^C)\right]^{\frac{1+\gamma}{\gamma}} h_{it} + \mathbb{I}_{h_{it}\neq 0}(1-\tau_t)\Pi_t^U + \mathbb{I}_{h_{it}=0}(1-\tau_t)\Pi_t^{fi} + tr_{it} + tr_{it}^E. \tag{18}$$

[20]This means that we can read off average productivity risk from the estimated income risk series in the literature. Without scaling the labor dis-utility by productivity, we would need to translate productivity risk to income risk through the endogenous hour response.

A.1.2 Consumption, savings, and portfolio choice

Given this labor income, households optimize inter-temporally subject to their budget constraint expressed in terms of physical consumption goods:

$$p_t^c(a_{it}^C)c_{it} + b_{it+1} + q_t k_{it+1} = y_{it} + b_{it}\frac{R(b_{it}, R_t^b)}{\pi_t^{core}} + (q_t + r_t)k_{it}, \quad k_{it+1} \geq 0,\, b_{it+1} \geq \underline{B} \tag{19}$$

b_{it} is real bond holdings, k_{it} is the amount of illiquid assets, q_t is the price of these assets, r_t is their dividend, $\pi_t^{core} = \frac{P_t}{P_{t-1}}$ is realized average domestic core inflation (inflation of physical goods, i.e., without energy), and R is the gross nominal interest rate on bonds, which depends on the portfolio position of the household and the central bank's interest rate R_t^b, which is set one period before.

All households that do not participate in the capital market ($k_{it+1} = k_{it}$) still obtain dividends and can adjust their bond holdings. Depreciated capital has to be replaced for maintenance, such that the dividend, r_t, is the net return on capital. Holdings of bonds have to be above an exogenous debt limit $\underline{B}$, and holdings of capital have to be non-negative.

Substituting the expression $c_{it} = x_{it} + \frac{1}{1+\gamma}\left[(1-\tau_t)w_t/p_t^c(a_{it}^C)\right]^{\frac{1+\gamma}{\gamma}} h_{it}$ for consumption, we obtain the budget constraint for the composite leisure-consumption good:

$$p_t^c(a_{it}^C)x_{it} + b_{it+1} + q_t k_{it+1} = b_{it}\frac{R(b_{it}, R_t^b)}{\pi_t^{core}} + (q_t + r_t)k_{it} + z_{it}, \quad k_{it+1} \geq 0,\, b_{it+1} \geq \underline{B}, \tag{20}$$

where $z_{it} = \frac{\gamma}{1+\gamma}\left[(1-\tau_t)w_t/p_t^c(a_{it}^C)\right]^{\frac{1+\gamma}{\gamma}} h_{it} + \mathbb{I}_{h_{it}\neq 0}(1-\tau_t)\Pi_t^U + \mathbb{I}_{h_{it}=0}(1-\tau_t)\Pi_t^{fi} + tr_{it} + tr_{it}^E$ is income corrected for the dis-utility of labor.

Households make their savings choices and their portfolio choice between liquid bonds and illiquid capital in light of a capital market friction that renders capital illiquid because participation in the capital market is random and i.i.d. in the sense that only a fraction, λ, of households are selected to be able to adjust their capital holdings in a given period. This means that we specify:

$$R(b_{it}, R_t^b) = \begin{cases} R_t^b & \text{if } b_{it} \geq 0 \\ R_t^b + \bar{R} & \text{if } b_{it} < 0 \end{cases}. \tag{21}$$

The extra wedge for unsecured borrowing, $\bar{R}$, creates a mass of households with zero unsecured credit but with the possibility to borrow, though at a penalty rate.

Since a household's saving decision—(b'_a, k') for the case of adjustment and (b'_n, k') for non-adjustment—will be some non-linear function of that household's wealth and productivity, inflation and all other prices will be functions of the domestic joint distribution, Θ_t, of (b, k, h) in t and the foreign joint distribution, Θ_t^*. This makes Θ and Θ^* state variables of the household's planning problem and these distributions evolve as a result of the economy's reaction to aggregate shocks. For simplicity, we summarize all effects of aggregate state variables, including the distributions of wealth and income, by writing the dynamic planning problem with time-dependent continuation values.

This leaves us with three functions that characterize the household's problem: value function

V^a for the case where the household adjusts its capital holdings, the function V^n for the case in which it does not adjust, and the expected continuation value, $\mathbb{W}$, over both:

$$\begin{aligned} V^a_t(b,k,h,a^C) &= \max_{k',b'_a} u[x(b,b'_a,k,k',h,a^C)] + \beta \mathbb{E}_t \mathbb{W}_{t+1}(b'_a,k',h,a^C) \\ V^n_t(b,k,h,a^C) &= \max_{b'_n} u[x(b,b'_n,k,k,h,a^C)] + \beta \mathbb{E}_t \mathbb{W}_{t+1}(b'_n,k,h,a^C) \\ \mathbb{W}_{t+1}(b',k',h,a^C) &= \lambda V^a_{t+1}(b',k',h,a^C) + (1-\lambda) V^n_{t+1}(b',k,h,a^C). \end{aligned} \tag{22}$$

Expectations about the continuation value are taken with respect to all stochastic processes conditional on the current states, i.e., over both idiosyncratic productivity, h, and energy intensity, a^C, of the dwelling. Maximization is subject to the corresponding budget constraint.

A.2 Firm sector

The firm sector of each country consists of five sub-sectors: (a) a labor sector composed of unions that differentiate raw labor and labor packers who buy differentiated labor and then sell labor services to intermediate goods producers, (b) intermediate goods producers who hire labor services and rent out capital and buy energy to produce goods, (c) final goods producers who differentiate intermediate goods and then sell them to (d) goods bundlers who bundle them with foreign final goods and finally sell them as consumption goods to households and to (e) capital goods producers, who turn bundled goods into capital goods. None of these products and goods can be traded between both countries, except for the differentiated final goods.

When profit maximization decisions in the firm sector require inter-temporal decisions (i.e. in price and wage setting and in producing capital goods), we assume for tractability that they are delegated to a mass-zero group of households (managers) that are risk-neutral and compensated by a share in profits. They do not participate in any asset market and have the same discount factor as all other households. Since managers are a mass-zero group in the economy, their consumption does not show up in any resource constraint, and all but the unions' profits go to the entrepreneur households (whose $h = 0$). Union profits go lump-sum to worker households.

A.2.1 Labor packers and unions

Worker households sell their labor services to a mass-n_A continuum of unions indexed by j, each of whom offers a different variety of labor to labor packers who then provide labor services to intermediate goods producers. Labor packers produce final labor services according to the production function

$$N_t = \left(\int_0^{n_A} \hat{n}_{jt}^{\frac{\eta_W - 1}{\eta_W}} \, dj \right)^{\frac{\eta_W}{\eta_W - 1}}. \tag{23}$$

out of labor varieties $\hat{n}_{jt}$. Cost minimization by labor packers implies that each variety of labor, each union j, faces a downward-sloping demand curve

$$\hat{n}_{jt} = \left(\frac{W_{jt}}{W_t^{fi}} \right)^{-\eta_W} N_t \tag{24}$$

where W_{jt} is the nominal wage set by union j and W_t^{fi} is the nominal wage at which labor packers sell labor services to final goods producers. Since unions have market power, they pay the households a wage lower than the price at which they sell labor to labor packers. Given the nominal wage W_t at which they buy labor from households and given the nominal wage index W_t^{fi}, unions seek to maximize their discounted stream of profits. However, they face a Calvo (1983) type adjustment friction with indexation with the probability λ_w to keep wages constant. They therefore maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_w^t \frac{W_t^{fi}}{P_t} N_t \left\{ \left(\frac{W_{jt}(\bar{\pi}_W)^t}{W_t^{fi}} - \frac{W_t}{W_t^{fi}} \right) \left(\frac{W_{jt}(\bar{\pi}_W)^t}{W_t^{fi}} \right)^{-\eta_W} \right\}. \tag{25}$$

by setting W_{jt} in period t and keeping it constant except for indexation to π_W, the steady state wage inflation rate.

Since all unions are symmetric, we focus on a symmetric equilibrium and obtain the linearized wage Phillips curve from the corresponding first-order condition as follows, leaving out all terms irrelevant at a first-order approximation around the stationary equilibrium:

$$\log \left(\frac{\pi_t^W}{\bar{\pi}^W} \right) = \beta \mathbb{E}_t \log \left(\frac{\pi_{t+1}^W}{\bar{\pi}^W} \right) + \kappa_w \left(mc_t^w - \frac{1}{\mu^W} \right), \tag{26}$$

with $\pi_t^W := \frac{W_t^{fi}}{W_{t-1}^{fi}} = \frac{w_t^{fi}}{w_{t-1}^{fi}} \pi_t^{CPI}$ being domestic wage inflation, w_t and w_t^{fi} being the respective *real* wages for households and firms, $mc_t^w = \frac{w_t}{w_t^{fi}}$ is the mark-down of wages the unions pay to households, W_t, relative to the wages charged to firms, W_t^{fi} and $\kappa_w = \frac{(1-\lambda_w)(1-\lambda_w \beta)}{\lambda_w}$. Union profits paid to workers therefore are $\Pi_t^U = (w_t^{fi} - w_t) N_t$.

A.2.2 Consumption Good Bundler

The consumption goods are bundles of domestically produced and imported final goods and are not traded across countries. Letting F_t denote the consumption good and A_t and B_t bundles of domestically and imported final goods, we assume the following aggregation technology

$$F_t = \left\{ (1-(1-n)\omega_A)^{\frac{1}{\sigma}} A_t^{\frac{\sigma-1}{\sigma}} + ((1-n)\omega_A)^{\frac{1}{\sigma}} B_t^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{1-\sigma}}, \tag{27}$$

$$F_t^* = \left\{ (n\omega_B)^{\frac{1}{\sigma}} A_t^{\frac{\sigma-1}{\sigma}} + (1-n\omega_B)^{\frac{1}{\sigma}} B_t^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{1-\sigma}}. \tag{28}$$

Here σ measures the terms of trade elasticity of the relative demand for domestically produced goods. $\omega_A \in [0,1]$ provides a measure for the home bias, in the sense that with $\omega_A = 1$, Country A has no home bias. The bundles of domestically and imported final goods are defined as follows:

$$A_t = \left[\left(\frac{1}{n_A}^{\frac{1}{\sigma}} \int_0^{n_A} A_t(j)^{\frac{\epsilon-1}{\epsilon}} dj\right)\right]^{\frac{\epsilon}{\epsilon-1}}, B_t = \left[\left(\frac{1}{1-n_A}^{\frac{1}{\sigma}} \int_{n_A}^{1} B_t(j)^{\frac{\epsilon-1}{\epsilon}} dj\right)\right]^{\frac{\epsilon}{\epsilon-1}}, \tag{29}$$

where $A_t(j)$ and $B_t(j)$ denote final goods produced in Home and Foreign, respectively, and ϵ measures the elasticity of substitution between final goods produced within the same country. Let $P(j)$ denote the price of a final good expressed in domestic currency. Then, letting $\mathcal{E}_t$ denote the nominal exchange rate (the price of domestic currency in terms of foreign currency) and assuming that the law of one price holds, we have

$$P_t^*(j) = \mathcal{E}_t P_t(j), \tag{30}$$

with $\mathcal{E}_t = 1\ \forall t$ since both countries form a monetary union.

The optimization problem of the good bundler is to minimize expenditures subject to $F_t = C_t + I_t$, and the aggregation technologies (27) and (29). Assuming that government consumption, G_t, is a bundle that is isomorphic to consumption goods, but consists of domestically produced goods only, global demand for a generic final good produced in Country A and B are given, respectively, by

$$Y_t^d(j) = \left(\frac{P_t(j)}{P_{At}}\right)^{-\epsilon} \left\{\left(\frac{P_{At}}{P_t}\right)^{\sigma} (1-(1-n)\omega_A)(C_t+I_t) + (1-n)\omega_B Q_t^{-\sigma}(I_t^* + C_t^*) + G_t\right\}, \tag{31}$$

$$Y_t^d(j)^* = \left(\frac{P_t(j)^*}{P_{Bt}^*}\right)^{-\epsilon} \left\{\left(\frac{P_{Bt}^*}{P_t^*}\right)^{\sigma} (n\omega_A) Q_t^{\sigma}(C_t+I_t) + (1-n\omega_B)(I_t^* + C_t^*) + G_t^*\right\}, \tag{32}$$

where the price indices are given by

$$P_{At} = \left[\frac{1}{n}\int_0^{n_A} P_t(j)^{1-\epsilon} dj\right]^{\frac{1}{1-\epsilon}}, P_{Bt} = \left[\frac{1}{1-n}\int_{n_A}^{1} P_t(j)^{1-\epsilon} dj\right]^{\frac{1}{1-\epsilon}} \tag{33}$$

and

$$P_t = [(1-(1-n)\omega_A)P_{At}^{1-\sigma} + ((1-n)\omega_A)P_{Bt}^{1-\sigma}]^{\frac{1}{1-\sigma}}, \tag{34}$$

$$P_t^* = [(n\omega_B)(P_{At}^*)^{1-\sigma} + (1-n\omega_B)(P_{Bt}^*)^{1-\sigma}]^{\frac{1}{1-\sigma}}. \tag{35}$$

The real exchange rate is given by

$$Q_t = \frac{P_t \mathcal{E}_t}{P_t^*}. \tag{36}$$

A.2.3 Final goods producers

Similar to unions, final goods producers in the home country differentiate the homogeneous home intermediate goods and set prices. They face the global demand (31) for each good $j \in [0, n]$ and buy the intermediate good at the national nominal price, MC_t. As we do for unions, we assume price adjustment frictions à la Calvo (1983) with indexation.

Under this assumption, the firms' managers maximize the present value of real profits given this price adjustment friction, i.e., they maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_Y^t (1 - \tau_t) \left(\frac{p_{jt} (\bar{\pi})^t}{P_t} - \frac{MC_t}{P_t} \right) Y_t^d(j) \tag{37}$$

with a time-constant discount factor.

The corresponding first-order condition for price setting implies a domestic Phillips curve

$$\log \left(\frac{\pi_{At}}{\bar{\pi}} \right) = \beta \mathbb{E}_t \log \left(\frac{\pi_{At+1}}{\bar{\pi}} \right) + \kappa_Y \left(mc_t - \frac{1}{\mu^Y} \right) \tag{38}$$

where we again dropped all terms irrelevant for a first-order approximation and have $\kappa_Y = \frac{(1-\lambda_Y)(1-\lambda_Y \beta)}{\lambda_Y}$. Here, $\pi_{At} := \frac{P_{At}}{P_{At-1}}$, is the gross domestic producer price inflation rate, i.e., the gross inflation rate of domestic final goods, $mc_t := \frac{MC_t}{P_t}$ are the domestic real marginal costs, $\bar{\pi}$ is steady-state inflation, and $\frac{1}{\mu^Y} = \frac{\eta - 1}{\eta}$ is the target markup. National profits paid to domestic entrepreneurs therefore are $\Pi_t^F = (1 - mc_t) Y_t + Tr_t^{E,F} + (1-n)/n\omega \Pi_t^E$, where $\Pi_t^E = n p_t^E (E_t^C + E_t^Y) + p_t^{E,*}/Q_t (1-n)(E_t^{C,*} + E_t^{Y,*})$ is the union wide energy profit.

A.2.4 Intermediate goods producers

Intermediate goods are produced with a constant returns to scale production function:

$$Y_t = \left((1 - a_P)^{\frac{1}{\sigma_P}} \; {Y_t^P}^{\frac{\sigma_P - 1}{\sigma_P}} + a_P{}^{\frac{1}{\sigma_P}} \; \left(E_t^Y \right)^{\frac{\sigma_P - 1}{\sigma_P}} \right)^{\frac{\sigma_P}{\sigma_P - 1}}, \text{ where } Y_t^P = (u_t K_t^s)^{\alpha} \; {N_t}^{1-\alpha}. \tag{39}$$

Production combines physical production Y_t^P using capital K_t with capacity utilization u_t, labor N_t, and energy E_t^Y. The coefficient α is the capital share, the coefficient σ_P captures the (short-run) substitutability of energy in the production process, and a_P is the energy share of production in normal times. Using capital with an intensity higher than normal increases depreciation of capital according to $\delta(u_t) = \delta_0 + \delta_1(u_t - 1) + \delta_2/2(u_t - 1)^2$, which, assuming $\delta_1, \delta_2 > 0$, is an increasing and convex function of utilization. Without loss of generality, capital utilization in the steady state is normalized to 1, so that δ_0 denotes the steady-state depreciation rate of capital goods.

Let mc_t be the relative price at which the intermediate good is sold to final goods producers. The intermediate goods producer maximizes profits,

$$mc_t Y_t - w_t^{fi} N_t - [r_t^F + q_t \delta(u_t)] K_t - (p_t^E - \tau_t^E) E_t^Y, \tag{40}$$

where r_t^F and q_t are the rental rate of firms and the (producer) price of capital goods, respectively. The intermediate goods producer operates in perfectly competitive national markets, such that the real wage and the user costs of capital are determined by the following equations:

$$MPK_t = p_{At}mc_t\left(1-a_P\right)^{\left(\frac{1}{\sigma_p}\right)}\alpha\left(\frac{K_t}{N_t}\right)^{(\alpha-1)}\left(\frac{Y_t}{Y_t^p}\right)^{\left(\frac{1}{\sigma_p}\right)}, \tag{41}$$

$$r_t = 1 + MPK_t u_t - q_t\delta(u_t), \tag{42}$$

$$w_t^{fi} = p_{At}mc_t\left(1-a_P\right)^{\left(\frac{1}{\sigma_p}\right)}(1-\alpha)\left(\frac{u_tK_t}{N_t}\right)^{\alpha}\left(\frac{Y_t}{Y_t^p}\right)^{\left(\frac{1}{\sigma_p}\right)}, \tag{43}$$

$$p_t^E - \tau_t^E = p_{At}mc_t a_P^{\left(\frac{1}{\sigma_p}\right)}\left(\frac{Y_t}{E_t^Y}\right)^{\left(\frac{1}{\sigma_p}\right)}. \tag{44}$$

Here MPK is the marginal product of capital services and $p_{At} = \frac{P_{At}}{P_t}$. We assume that utilization is decided by the owners of the capital goods, taking the aggregate national supply of capital services as given. The optimality condition for utilization is given by

$$MPK_t = q_t[\delta_1 + \delta_2(u_t - 1)] \tag{45}$$

i.e., capital owners increase utilization until the marginal maintenance costs equal the marginal product of capital services.

A.2.5 Capital goods producers

Capital goods producers transform the physical good (a composite of the two country's goods), investment I_t, into capital. They take the relative price of capital goods, q_t, as given in deciding about their output, i.e., they maximize[21]

$$\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t I_t\left\{q_t\left[1-\frac{\phi}{2}\left(\log\frac{I_t}{I_{t-1}}\right)^2\right]-1\right\}. \tag{46}$$

Optimality of the capital goods production requires (again dropping all terms irrelevant up to first order)

$$q_t\left[1-\phi\log\frac{I_t}{I_{t-1}}\right] = 1-\beta\mathbb{E}_t\left[q_{t+1}\psi\log\left(\frac{I_{t+1}}{I_t}\right)\right], \tag{47}$$

and each capital goods producer will adjust its production until (47) is fulfilled.

Since all capital goods producers within a country are symmetric, we obtain the law for

[21] As we use a first order approximation changes in the stochastic discount factor are irrelevant. So are changes in the relative price $p_t(a^C)$ of the physical to the final consumption good.

motion for domestic aggregate capital as

$$K_t - (1-\delta(u_t))K_{t-1} = \left[1 - \frac{\phi}{2}\left(\log \frac{I_t}{I_{t-1}}\right)^2\right] I_t \tag{48}$$

The functional form assumption implies that investment adjustment costs are minimized and equal to 0 in the steady state.

A.3 Government Sector

The two countries form a monetary union such that they run a common monetary authority. In addition, each country runs a national fiscal authority. The monetary authority controls the nominal interest rate on liquid assets in both countries, while the national fiscal authorities issue government bonds in a union-wide bond market to finance deficits, choose both the average tax rate and the tax progressivity in their country, and make expenditures for government consumption and their national transfer system. The latter includes energy-related transfers and subsidies.

A.3.1 Monetary Union

We assume that monetary policy sets the nominal interest rate, which is the same in both countries, following a Taylor (1993)-type rule with interest rate smoothing:

$$\frac{R^b_{t+1}}{\bar{R}^b} = \left(\frac{R^b_t}{\bar{R}^b}\right)^{\rho_R} \left(\frac{n\pi_{At} + (1-n)(\pi_{Bt})}{\bar{\pi}}\right)^{(1-\rho_R)\theta_\pi} \left(n\frac{Y_t}{Y_{t-1}} + (1-n)\frac{Y^*_t}{Y^*_{t-1}}\right)^{(1-\rho_R)\theta_Y} \epsilon^R_t. \tag{49}$$

The coefficient $\bar{R}^b \geq 0$ determines the nominal interest rate in the steady state, Y^*_t determines output in Country B, and π_{Bt} is the producer price inflation in Country B. The coefficients $\theta_\pi, \theta_Y \geq 0$ govern the extent to which the central bank attempts to stabilize producer price inflation and the output growth in the monetary union. $\rho_R \geq 0$ captures interest rate smoothing and ϵ^R_t is an i.i.d. monetary policy shock.

A.3.2 Fiscal Policy

The budget constraint of the national fiscal policy reads

$$G_t + Tr_t + TP_t = B_{t+1} + T_t - \frac{R^b_t}{\pi^{CPI}_t} B_t. \tag{50}$$

Hence, the government has expenditure for government spending, G_t, aggregate spending on its transfer system specified below, Tr_t, repaying its debt, B_t, and total expenditure for its energy crisis-related policies, TP_t, specified below. It finances its expenditures by issuing new debt and tax revenue, T_t. Tax revenue is

$$T_t = \tau_t(w_t N_t + \mathbb{I}_{h_{it}=0}\Pi^{fi}_t + \mathbb{I}_{h_{it}\neq 0}\Pi^U_t). \tag{51}$$

We assume that the average tax rate is a feedback function of government debt:

$$\frac{\tau_t}{\bar{\tau}} = \left(\frac{B_{t+1}}{\bar{B}}\right)^{\gamma_B^\tau}, \tag{52}$$

where γ_B^τ governs the speed with which debt returns to its target.

A.3.3 Targeted Transfer System

The targeted transfer system provides additional resources if net labor income $w_t n_t h_{it}$ falls short of some target level. For simplicity, we assume that these transfers are non-distortionary for the labor supply decision. In particular, we assume that transfers are paid to households according to the following scheme:

$$tr_i t = tr(h_{it}) = \max\{0, a_1 \bar{y} - a_2(1-\tau_t) w_t h_{it} N_t\}, \tag{53}$$

where $\bar{y}$ is the median income and $0 \leq a_1, a_2 \leq 1$. Thus, from the perspective of the household, transfers are lump-sum in the sense that they depend only on idiosyncratic productivity and not on the household's actual hours. Since this does not distort labor incentives, it remains that all households work the same number of hours, and transfers thus effectively decrease individual income at a transfer withdrawal rate of a_2, and no transfers are paid to households whose net labor income is $(1-\tau_t) w_t h_{it} N_t \geq \frac{a_1}{a_2}\bar{y}$. Total transfer payments of the government in Country A are then

$$Tr_t = \mathbb{E}_t tr_{it}, \tag{54}$$

where again, the expectation operator is the cross-sectional average.

A.3.4 Energy-related transfers and subsidies

The energy-related transfers to household i are equal to the price increase:

$$tr_{it}^E = (p_t^E - \bar{p}^E)\bar{E}_i^C \tag{55}$$

where $\bar{p}^E$ is the steady state price of energy, $\bar{E^C}_i$ is the consumption of energy a household with the characteristics of household i has in steady state. Total energy-related transfers are aggregated over all households in country A.

Total expenditure for the energy crisis-related policies $(TP_t)$is then:

$$TP_t = T_t^{E,C} + T_t^{E,Y} + Tr_t^{E,C} + Tr_t^{E,F}, \tag{56}$$

i.e., the sum of all expenditures on energy subsidies for consumption, $T_t^{E,C} = \tau_t^E E_t^C$, energy subsidy for production, $T_t^{E,Y} = \tau_t^E E_t^Y$, energy transfers for households $Tr_t^{E,C} = (p_t^E - \bar{p}^E)\bar{E^C}$ and for firms $Tr_t^{E,F} = (p_t^E - \bar{p}^E)\bar{E^Y}$.

A.4 Energy, goods, bonds, capital, and labor market clearing

The union-wide energy market clears, when total energy consumption in Europe, consisting of household and firm energy consumption in both countries, equals the exogenous energy supply:

$$E_t = E_t^C + E_t^Y + E_t^{C,*} + E_t^{Y,*}. \tag{57}$$

The national labor market in Country A clears at the competitive wage given in (43). A symmetric labor market clearing condition is in place in Country B. The bond markets clear whenever the following equations hold:

$$\begin{aligned}
B_{t+1} &= B^d(p_t^E, Tr_t^{E,C}, Tr_t^{E,Y}, R_t^b, r_t, q_t, \Pi_t^{fi}, \Pi_t^U, w_t, \pi_t, \tau_t, \Theta_t, \Theta_t^*, \mathbb{W}_{t+1}) - \frac{B_{Bt+1}}{Q_t} \\
&:= \mathbb{E}_t[\lambda \mathbb{B}_{a,t} + (1-\lambda)\mathbb{B}_{n,t}] - \frac{B_{Bt+1}}{Q_t}, \\
B_{t+1}^* &= B^{d,*}(p_t^{E,*}, R_t^b, r_t^*, q_t^*, \Pi_t^{fi,*}, \Pi_t^{U,*} w_t^*, \pi_t^*, \tau_t^*, \Theta_t, \Theta_t^*, \mathbb{W}_{t+1}^*) + \frac{n_A}{1-n_A} B_{Bt+1} \\
&:= \mathbb{E}_t[\lambda \mathbb{B}_{a,t}^* + (1-\lambda)\mathbb{B}_{n,t}^*] + \frac{n_A}{1-n_A} B_{Bt+1}, \\
B_{t+1}^d + B_{t+1}^{d,*} &= B_{t+1} + B_{t+1}^*
\end{aligned} \tag{58}$$

where $\mathbb{B}_{a,t}$, $\mathbb{B}_{n,t}$ are functions of the states (b, k, h, a^c), and depend on how the households in the Country A value asset holdings in the future, $\mathbb{W}_{t+1}$, and the current set of prices (and tax rates) $(p_t^E, Tr_t^{E,C}, Tr_t^{E,Y}, R_t^b, r_t, q_t, \Pi_t^{fi}, \Pi_t^U, w_t, \pi_t^{CPI}, \tau_t)$.[22] Future prices do not show up because we can express the value functions such that they summarize all relevant information on the expected future price paths. Expectations in the right-hand-side expression are taken w.r.t. the distributions in both countries $\Theta_t(b, k, h, a^c)$ and $\Theta_t^*(b, k, h, a^c)$. The total net amount of foreign bond holdings in Country A, B_{Bt}, is given by the aggregation over the households' budget constraint:

$$\begin{aligned}
(1-\tau_t)(w_t N_t + \Pi_t^U + \Pi_t^{fi}) + (P_{At} Y_t - w_t N_t - (\Pi_t^U + \Pi_t^{fi})) + Tr_t + Tr_t^E + B_t R_t^b / \pi_t \\
+ B_{Bt} R_t^b / (\pi_t^* Q_t)) = C_t + I_t + \bar{R}\ BD_t + B_{t+1} + B_{Bt+1}/Q_t,
\end{aligned} \tag{59}$$

where BD_t is the total amount of borrowing in Country A. Since both government bonds pay the same interest rate, we do not need to take track of the share of domestic vs. foreign bond holdings in each household's portfolio. Equilibrium requires the total *net* amount of bonds the household sectors in both countries demand to equal the supply of government bonds. In gross terms, there are more liquid assets in circulation as some households borrow up to $\underline{B}$.

In addition, the national markets for capital have to clear. In Country A, we have:

$$\begin{aligned}
K_{t+1} &= K^d(p_t^E, Tr_t^{E,C}, Tr_t^{E,Y}, R_t^b, r_t, q_t, \Pi_t^{fi}, \Pi_t^U, w_t, \pi_t^{CPI}, \tau_t, \Theta_t, \Theta_t^*, \mathbb{W}_{t+1}) \\
&:= \mathbb{E}_t[\lambda(\mathbb{K}_t) + (1-\lambda)(k)]
\end{aligned} \tag{60}$$

where the first equation stems from competition in the production of capital goods, and the

[22] The same logic applies for $\mathbb{B}_{a,t}^*$, $\mathbb{B}_{n,t}^*$ in Country B.

second equation defines the aggregate supply of funds from households in Country A - both those that trade capital, $\lambda(\mathbb{K}_t)$ and those that do not, $(1-\lambda)(k)$. Again $\mathbb{K}_t$ is a function of the current prices and continuation values. In Country B, the capital market clearing condition is symmetric.

Finally, goods market clearing requires:

$$\begin{aligned} Y_t &= ((1-(1-n)\omega_A)\left(\frac{P_{At}}{P_t}\right)^{-\sigma}\left[C_t + I_t + BD_t\bar{R}\right] \\ &\quad + (1-n_A)\omega_B Q_t^{-\sigma}\left[C_t^* + I_t^* + BD_t^*\bar{R})\right] + G_t \\ Y_t^* &= n\omega_A Q_t^{\sigma}\left(\frac{P_{Bt}^*}{P_t^*}\right)^{-\sigma}\left[C_t + I_t + BD_t\bar{R}\right] \\ &\quad + (1-n_A\omega_B)\left[C_t^* + I_t^* + BD_t^*\bar{R})\right] + G_t^*. \end{aligned} \tag{61}$$

A.5 Equilibrium

A sequential equilibrium with recursive planning in our two-country model is a sequence of policy functions $\{\mathbb{X}_{at}, \mathbb{X}_{nt}, \mathbb{B}_{at}, \mathbb{B}_{nt}, \mathbb{K}_t\}$ in Country A and $\{\mathbb{X}_{at}^*, \mathbb{X}_{nt}^*, \mathbb{B}_{at}^*, \mathbb{B}_{nt}^*, \mathbb{K}_t^*\}$ in Country B, a sequence of value functions $\{V_t^a, V_t^n\}$ in Country A and $\{V_t^{a,*}, V_t^{n,*}\}$ in Country B, a sequence of prices $\{p_t^E, \tau_t^E, Tr_t^{E,C}, Tr_t^{E,Y}, w_t, w_t^{fi}, \Pi_t^U, \Pi_t^{fi}, q_t, r_t, R_t^b, \pi_t^{CPI}, \pi_{At}, \pi_t^W, \frac{P_{At}}{P_t}, \tau_t, Q_t\}$ in Country A and $\{p_t^{E,*}, w_t^*, w_t^{fi,*}, \Pi_t^{U,*}, \Pi_t^{fi,*}, q_t^*, r_t^*, \pi_t^*, \pi_{Bt}, \pi_t^{W,*}, \frac{P_{Bt}^*}{P_t^*}, \tau_t^*\}$ in Country B, a sequence of energy endowments, $\{E_t\}$, aggregate capital, labor supply, and foreign bond holdings $\{K_t, N_t, B_{Bt}\}$ in Country A and $\{K_t^*, N_t^*\}$ in Country B, distributions Θ_t in Country A and Θ_t^* in Country B over individual asset holdings and productivity, and expectations for the distribution of future prices, Γ, such that

1. Given the functionals $\mathbb{E}_t\mathbb{W}_{t+1}$ and $\mathbb{E}_t\mathbb{W}_{t+1}^*$ for the continuation value and period-t prices, policy functions $\{\mathbb{X}_{at}, \mathbb{X}_{nt}, \mathbb{B}_{at}, \mathbb{B}_{nt}, \mathbb{K}_t\}$ and $\{\mathbb{X}_{at}^*, \mathbb{X}_{nt}^*, \mathbb{B}_{at}^*, \mathbb{B}_{nt}^*, \mathbb{K}_t^*\}$ solve the households' planning problem; and given the policy functions $\{\mathbb{X}_{at}, \mathbb{X}_{nt}, \mathbb{B}_{at}, \mathbb{B}_{nt}, \mathbb{K}_t\}$ and $\{\mathbb{X}_{at}^*, \mathbb{X}_{nt}^*, \mathbb{B}_{at}^*, \mathbb{B}_{nt}^*, \mathbb{K}_t^*\}$ and prices, the value functions $\{V_t^a, V_t^n\}$ and $\{V_t^{a,*}, V_t^{n,*}\}$ are a solution to the Bellman equation.

2. Distributions of wealth and income evolve according to households' policy functions.

3. All markets clear in every period, interest rates on bonds are set according to the central bank's Taylor rule, fiscal policies are set according to the fiscal rules, and stochastic processes evolve according to their law of motion.

4. Expectations are model consistent.

We solve the model by using the perturbation method in Bayer, Born, and Luetticke (2024).

B Calibration

We calibrate the two countries in our model the following way: Country A, the Home country, is calibrated to match German data. Country B captures the rest of the area within the European

Table 3: Calibration—Asymmetric Parameters

	Description	**Country B: Italy**	**Country A: Germany**
a_1	Transfer level	0	0.5
a_2	Transfer withdrawal rate	0	0.8
G/Y	Gov. cons. share	0.21	0.20
σ_h	STD labor inc.	0.123	0.135
β	Discount factor	0.9854	0.9823
λ	Portfolio adj. prob.	0.038	0.071
ζ	Trans. prob. from W to E	0.0007	0.001
ι	Trans prob. E to W	0.0625	0.0625
$\bar{R}$	Borrowing penalty	0.018	0.029

gas network. As this is not a single country but consists of many, and among those Italy is large and with its reliance on natural gas instead of electricity strongly exposed to the shock, we choose to calibrate Country B, or the Foreign country, to Italy. For each country, we match the wealth distributions. This requires asymmetric calibration choices regarding the households. Table 3 shows the calibration choices required for our calibration strategy which is described in Section 3.

B.1 Calibration of asymmetric parameters

In order to match the data, the model requires German households to be slightly less patient, asset markets (this means housing markets for most households) to be less liquid, and borrowing penalties to be higher. The mass of entrepreneurs is larger such that pure profit incomes are smaller. The level of competition (in a monopolistic competition sense) is higher.

B.2 Calibration of symmetric parameters

We keep the rest of the calibration symmetric. We calibrate the parameters by matching long-run averages and using standard parameters from the literature. Table 4 summarizes our calibration of those parameters. We calibrate to quarterly frequency.

The labor share in production, $(1 - \alpha)$, is 68% corresponding to a labor income share of 62%, given a markup of 10% due to an elasticity of substitution between differentiated goods of 11. The elasticity of substitution between labor varieties is also set to 11, yielding a wage markup of 10%. The parameter δ_1 that governs the cyclicality of utilization is set to 5.0. The investment adjustment cost parameter is set to 4.0. We set the Calvo parameters for price and wage adjustment probability both to 0.25. All these parameter choices are standard values in the literature.

We set relative risk aversion, ξ, to 4, following Kaplan and Violante (2014) and the Frisch elasticity, γ to 0.5 following Chetty et al. (2011). The persistence of idiosyncratic income shocks is set to $\rho_h = 0.9815$. The stationary equilibrium real rate(-growth difference) is set to a net rate of zero.

The steady-state tax level is set to 0.3. We assume that monetary policy only targets inflation, as this is the primary mandate of the ECB, and set the Taylor coefficient to 1.5 and

Table 4: Calibration—Symmetric Parameters

	Description	Value	Source/Target
Firms			
$1-\alpha$	Share of labor	0.68	62% lab. income
η	Elast. of substitution	11	10% Price markup
η_W	Elast. of substitution	11	10% Wage markup
κ	Price adj. prob.	0.25	1 year avg. price duration
κ_W	Wage adj. prob.	0.25	1 year avg. wage duration
ϕ	Inv. adj. cost	4.0	Bayer, Born, and Luetticke (2024)
δ_0	Depreciation rate	0.018	Wealth Gini = 0.61
δ_1	Depr. rate increase	5.0	Bayer, Born, and Luetticke (2024)
Households			
ξ	Risk aversion	4	Kaplan and Violante (2014)
γ	Inv. Frisch elast.	2	Chetty et al. (2011)
ρ_h	Pers. labor inc.	0.98	Bayer, Born, and Luetticke (2024)
Open economy			
σ	Trade-price elasticity	0.66	Corsetti, Meier, and Müller (2012)
ω	Home bias	0.66	German import share
n	Country size	1/3	Size of GER in European gas market
Government			
$\bar{\tau}$	Tax rate	0.3	Bayer et al. (2024)
$\bar{R}^b$	Gross interest rate	1.00	Zero interest-growth difference
ρ_R	Pers. in Taylor rule	0.85	Auclert, Rognlie, and Straub (2020)
θ_π	Reaction to Infl.	1.5	Auclert, Rognlie, and Straub (2020)
θ_Y	Reaction to Output	0	ECB mandate

Table 5: Calibrated Model v Data

			Model		Data	
			F	**H**	**ITA**	**GER**
Steady state	Assets	Debt (% of output)	132	71	132	71
		Capital-Output-Ratio	3.3	3.2	3.3	3.2
(targeted)	Distribution	Wealth gini	0.60	0.72	0.61	0.73
		Top-10% wealth share	0.43	0.55	0.44	0.52
		Bottom-50% wealth share	0.10	0.01	0.09	0.02
		Borrowers	0.08	0.18	0.08	0.18

Notes: Model predictions based on baseline calibration, see Appendix B for details. Microdata based on the 2017 wave of the Household Finance and Consumption survey of the ECB. Macro data from Eurostat. Quantities are measured in real per capita terms, yoy changes; sample: 1999Q1-2022Q2.

Table 6: Expenditure on gas (heating and hot water, Germany (GER) and Italy (ITA))

Income quintiles				Expenditure quartiles					
		Mean		p25		p50		p75	
		GER	ITA	GER	ITA	GER	ITA	GER	ITA
I:	0-20%	222	218	124	118	183	186	278	279
II:	20-40%	259	231	141	128	222	201	334	299
III:	40-60%	292	248	169	141	250	211	362	321
VI:	60-80%	306	274	180	151	261	231	371	346
V:	80-100%	315	289	188	161	270	238	379	387

Source: For German data German Einkommens- und Verbrauchsstichprobe (EVS) 2018, own calculations. Income quintiles refer to household net incomes. Expenditure quartiles refer to the within-income-quintile gas consumption. For Italian data source is Indagine sulle spese delle famiglie 2022. Income quintiles refer to household net incomes. Expenditure quartiles in EUR are conditional on the income quintile. Data cleaned for regional and month effects. Observations with more than € 1350 spending and less than € 30 spending have been dropped. In both countries, only households with gas as the predominant energy source are included.

Table 7: Calibration of the energy model

	Description	Value
σ_P	Elasticity of substitution in production	0.200
σ_C	Elasticity of substitution in consumption	0.100
a_P	Share of energy in production	0.005
a_{CH}	Proportion of energy in consumption: Type "high"	0.035
a_{CN}	Proportion of energy in consumption: Type "low"	0.020
$\bar{\rho}$	Persistence of high energy state at median income	0.970
A	Slope of probability to stay in low energy state	0.005
B	Shift in probability to remain in low energy state	0.010

the smoothing parameter to 0.85 close to the values found in Auclert, Rognlie, and Straub (2020). The steady-state inflation is zero. We assume $n = 1/3$ representing the German size in the European gas market. The home bias parameter, $\omega = 0.66$, is calibrated to match the German import share and the terms of trade elasticity, σ is set as in Corsetti, Meier, and Müller (2012).

For the sake of completeness, Table 7 repeats the energy-related parameters, which are also presented in Section 3. And non-normalized distribution of energy expenditures in Germany are given in Table 6. This table contrasts the expenditures in Germany with this in Italy. More precisely, we repeat the exercise using Italian microdata from 2022, when detailed gas expenditures are available. Given the large monthly price fluctuations and the larger prevalence of flex price natural gas delivery contracts in Italy, we take out time effects for the date of the interview in the Italian data and also control for the region of the households given the larger geographical/climatical dispersion. Still the spread of energy expenditures is similar to the German one.

Table 8: Expenditure on gas (heating and hot water, Germany, urban vs. rural area)

Income quintiles		Mean		Expenditure quartiles					
				p25		p50		p75	
		urban	rural	urban	rural	urban	rural	urban	rural
I:	0-20%	210	221	102	114	179	195	276	312
II:	20-40%	247	284	123	150	210	243	324	381
III:	40-60%	291	305	162	174	252	267	378	396
VI:	60-80%	310	313	171	192	267	270	393	390
V:	80-100%	323	315	186	190	282	276	406	390

Source: German Einkommens- und Verbrauchsstichprobe (EVS) 2018, own calculations. Income quintiles refer to household net incomes. Expenditure quartiles refer to the within-income-quintile gas consumption conditioning living in an urban/rural area.

B.3 Further evidence for calibration of household energy consumption

An important reason for the way how we model the energy share in households' consumption is to capture the wide dispersion of energy expenditures across income groups, i.e., the fact that the highest expenditures of the lowest income group are higher than the expenditures of some of the richest households. In the following, we provide evidence that this dispersion is also present when we control for the year of construction of the dwelling and whether the dwelling is located in an urban or rural area. First, Table 8 shows the expenditure quartiles for households living in urban and rural areas. Indeed, we find the large dispersion for energy expenditures in both areas, i.e. that the lowest income quintile can have higher expenditures than the richest households. Nevertheless, there is a strong difference between energy expenditures in rural and urban areas. Except for the higher expenditures (above 50%) of the highest income quintile, expenditures are much lower in urban than in rural areas.

Second, Table 9 provides energy expenditures when we control for the year of construction. More specifically, the table reports expenditures for houses built before and after 1990. Here we find similar results to the difference between urban and rural areas. First, households living in newer and therefore probably better insulated houses pay less for energy. However, there is still dispersion across households, and households with lower incomes have some probability of paying more for energy than households with the highest incomes.

B.4 Closed-economy version

We also consider a closed-economy version of our model representing the dynamics of the union-wide aggregates. Analyzing a closed-economy drastically reduces the state-space of the solution. This allows us to solve a second-order perturbation of the model, checking for potential important non-linear dynamics that our first-order solution misses. In Bayer et al. (2024), we show that up to first order the dynamics of union-wide aggregates can be represented by a closed economy if both countries are symmetric. Given that both countries react almost perfectly

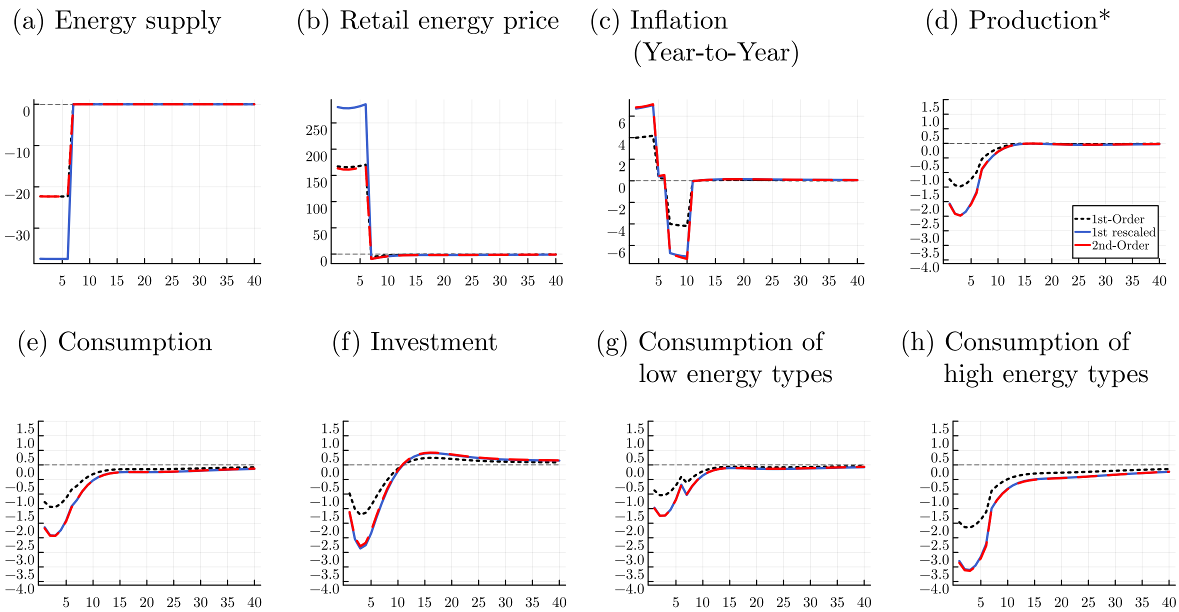
Table 9: Expenditure on gas (heating and hot water, Germany, built before/after 1990)

Income quintiles				Expenditure quartiles					
		Mean		p25		p50		p75	
		pre 90	post 90	pre 90	post 90	pre 90	post 90	pre 90	post 90
I:	0-20%	211	214	105	91	180	171	286	276
II:	20-40%	256	248	135	120	219	210	333	348
III:	40-60%	303	264	168	144	270	228	390	336
VI:	60-80%	321	290	183	159	284	240	408	360
V:	80-100%	351	280	210	171	312	246	445	348

Source: German Einkommens- und Verbrauchsstichprobe (EVS) 2018, own calculations. Income quintiles refer to household net incomes. Expenditure quartiles refer to the within-income-quintile gas consumption. Only households with gas as the predominant energy source are included.

symmetrically to the energy shock (see Figure 2), the one country version of our model is a good approximation of the Euro Area aggregates. We calibrate the one-country version to our German calibration.

Figure 12: Macroeconomic impact of the energy crisis with first- and second-order solution



Notes: Impulse responses to a 20% reduction in energy (natural gas) supply in the second-order solution compared to in the first-order solution as well as compared to a 35% reduction in the first-order solution. The black-dashed lines show the 20% reduction in the first-order solution, the blue solid lines show the 35% reduction in the first-order solution, and the red dashed lines show the 20% reduction in the second-order solution. Retail energy price at Home is the energy price minus the subsidy, $p_t^E - \tau_t^E$. Production is in terms of each country's final output, Y_t not in terms of the final consumption good. Y-axis: In log-point deviations (log deviations multiplied by 100) from the steady state. Inflation percentage points year-over-year. X-axis: quarters.

C Robustness

C.1 Second-order approximation

This section compares the linear and nonlinear impulse responses of the shock. We measure the nonlinear effect by solving the model with a second-order perturbation. To facilitate the solution of the model, we solve a one-country version of the model (see Section B.4). Otherwise, the second order solution is not feasible. Comparing the impulse responses for a 20% reduction in energy supply in Figure 12 shows that while there are differences between the two solutions, these differences mainly affect the amplification of the shock, but not the shape of the impulse responses. Thus, once we correct for the lack of amplification in the first-order solution by increasing the size of the shock to a 35% reduction in energy supply, the impulse responses are almost perfectly superimposed. Given that our baseline solution is linear, the finding implies that we can expect all our results to be practically precise up to the scale of the shock.

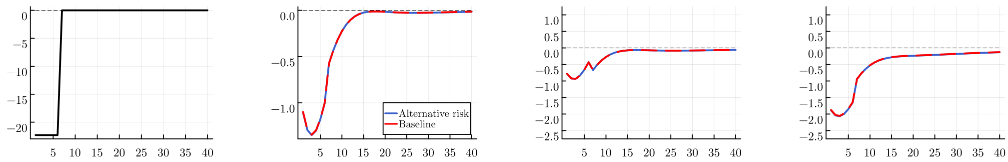
C.2 Alternative idiosyncratic income risk

We follow our calibration strategy in earlier work (Bayer et al., 2024) which implies different idiosyncratic income risk variance across the two-countries. In this section, we perform a robustness check by changing the idiosyncratic income risk to understand how our results are shaped by this assumption. First, we set the variance in the rest of the euro area equal to the German variance, so that the parametrization is the same in both countries. We then increase

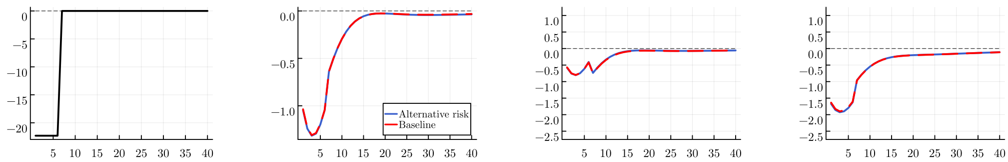
Figure 13: Macroeconomic effects of energy crisis with alternative risk calibration

(a) Energy supply	(b) Production	(c) Cons. of low energy types	(d) Cons. of high energy types

Germany



Rest of EA



Notes: Robustness with respect to an alternative calibration for the income risk. The upper panels compare the impulse responses under our alternative calibration with our baseline in Germany and the lower panels do the same for the rest of the euro area.

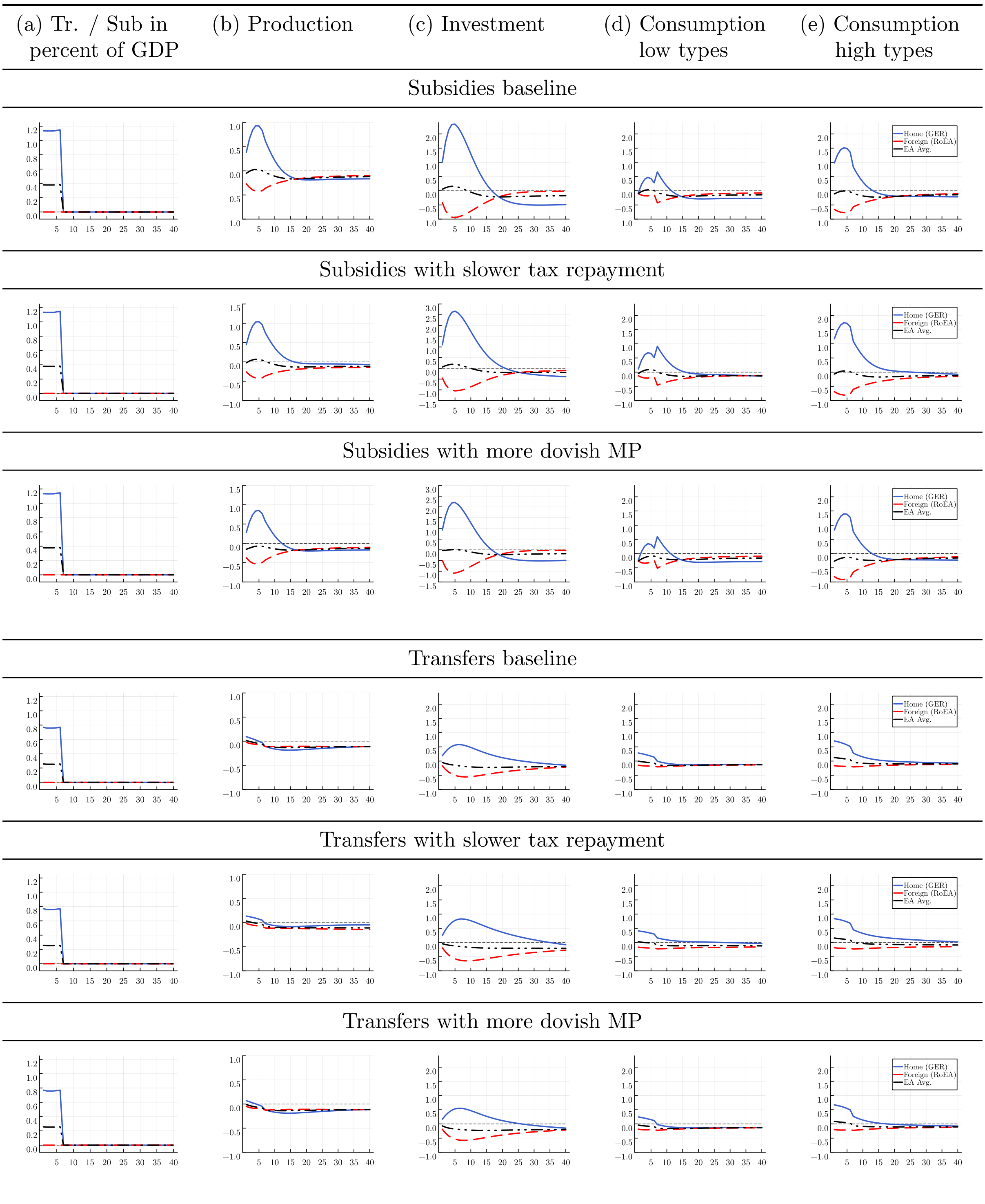
the persistence of the idiosyncratic risk so that the half-life of the shock is increased by 10%. We then adjust the discount rates in both countries so that the debt levels in both countries are the same as in our baseline. Changing the idiosyncratic risk processes has virtually no effect on our results. Figure 13 shows this for the crisis scenario, comparing the IRFs in both countries with their respective counterparts in our baseline. While qualitatively the recession is slightly less severe in Germany and slightly more severe in the rest of the euro area, quantitatively the differences are so small that the respective IRFs are virtually on top of each other.

C.3 Alternative calibration of monetary and fiscal rules

This section considers the robustness of our results with respect to changes in the monetary and fiscal policy rules. First, we consider a slower repayment through taxes, so that the repayment parameter γ_B is now 0.01 instead of 0.02. Second, we consider a more dovish monetary policy rule with $\gamma_\pi = 1.25$ instead of 1.5 and $\rho_R = 0.9$ instead of 0.85. Qualitatively, transfers are almost unaffected by these rule changes. Quantitatively, assuming a fiscal rule with a slower repayment rate increases the impact of transfers at Home, as repayment through distortionary taxes is further delayed. A more dovish monetary policy, however, slightly dampens the effects. The reason for this is that the transfers in the euro area as a whole were contractionary, so that union-wide monetary policy would stabilize by lowering interest rates. A more dovish monetary policy now means that interest rates are cut less.

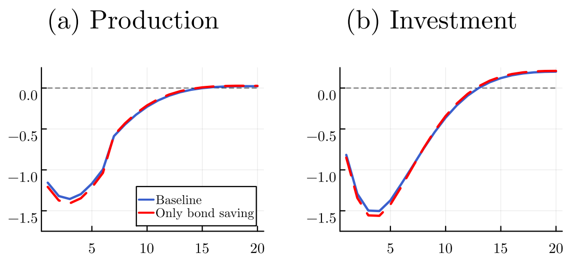
Similarly, subsidies are qualitatively more expansionary at Home with slower tax redemption, but less expansionary with a more dovish monetary policy. The reasoning is exactly the same as for transfers.

Figure 14: Macroeconomic effects of energy transfers and subsidies under different fiscal and monetary policy rules



Notes: Robustness of subsidy and transfer policy with respect to the fiscal policy and the monetary policy rule. For each policy it shows our baseline result, the respective policy with a tax rule in which the debt repayment parameter, γ_B is 0.01 instead of 0.02 and the respective policy with a more dovish monetary policy rule ($\theta_\pi = 1.25$ $\rho_R = 0.9$ instead of 1.5 and 0.85, respectively).

Figure 15: Macroeconomic impact of energy crisis with third country



Notes: Impulse responses to a 20% reduction in energy (natural gas) supply without policy intervention with a third country owning the gas. The blue solid lines depict the case in which the representative agent is parameterized to spend the windfall profit in gas as the average entrepreneur in our baseline ("Baseline") and the red dashed lines depict a case in which the third country does not spend any of the windfall profit but only invests it in bonds ("Only bond saving"). Production is in terms of final output, Y_t not in terms of the final consumption good. Y-axis: In log-point deviations (log deviations multiplied by 100) from the steady state. X-axis: quarters.

C.4 Adding a third - energy exporting country

In the paper we assume that energy producing firms are owned by entrepreneurs within the union which implies that the rise in energy profits accrue to domestic agents. In this section, we instead model an additional third country that exports gas and captures the profits. More precisely, we model the gas exporting country as described by a simple representative agent. As our robustness check assesses the importance of this modeling assumption, for simplicity, we do so in a version where the whole union is represented by a country with heterogeneous agents.

We start by assuming that the representative household in the gas-exporting country has the same preferences as the entrepreneurs in our baseline model. This implies that it buys the same amount of consumer goods and capital in response to a change in gas prices as the entrepreneurs do in our baseline and, hence, nothing changes in terms of impulse responses to the gas crisis. Comparing against this benchmark, we then consider an alternative behavior of the gas exporter. It follows a simple demand rule such that it accumulates liquid assets in the euro area when the income from selling gas is above the steady state, and then slowly decumulates the debt by increasing consumption above the steady state in the future. In other words, the gas exporter does not increase domestic demand by buying domestic consumption goods or capital as a reaction to increased energy profits. Figure 15 shows that while this increases the recession after the energy shock, quantitatively the difference between the two scenarios is negligible.

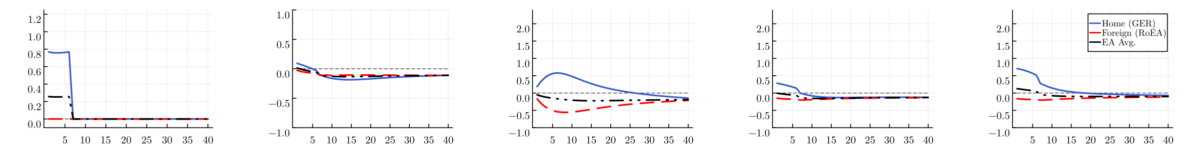
C.5 Alternative transfer scheme based on income/wealth instead of past energy consumption

Throughout the paper, we assume that the government has information on the gas consumption of each household such that it can pay out Slutsky transfers (see Section 4.3). In this robustness exercise, we explore the implications if the government did not have this kind of information, but had to base transfers on average gas consumption conditional on income and wealth. More precisely, the transfer payments to households are based on the average gas consumption that households with a given level of income and wealth have. Note that from a macroeconomic

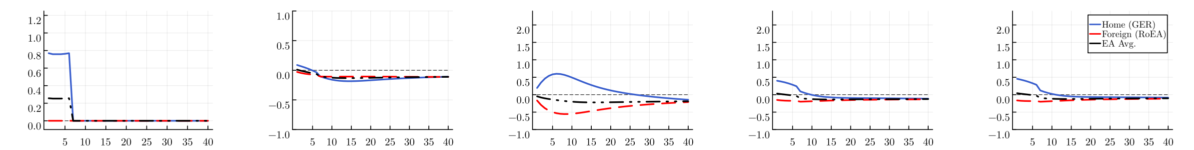
Figure 16: Macroeconomic effects of energy transfers with limited information

(a) Transfer in percent of GDP	(b) Production	(c) Investment	(d) Consumption low types	(e) Consumption high types

Transfers baseline



Transfer conditional on income and wealth only

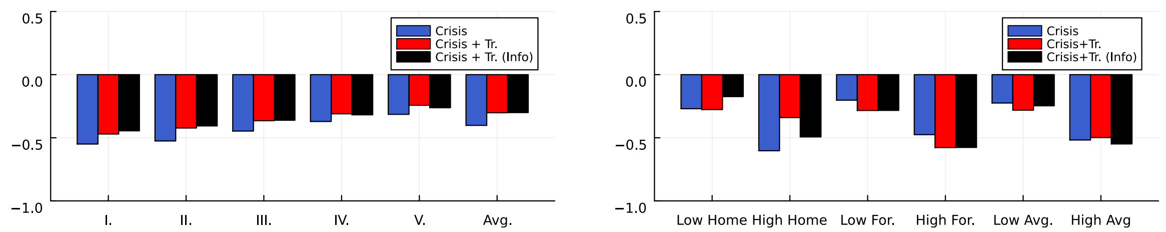


Notes: Macroeconomic effects of transfer paid out according to average gas consumption conditional on households wealth and income.

Figure 17: Welfare impact of transfers with limited information

Overall effect

by income quintile at Home	by type of heating

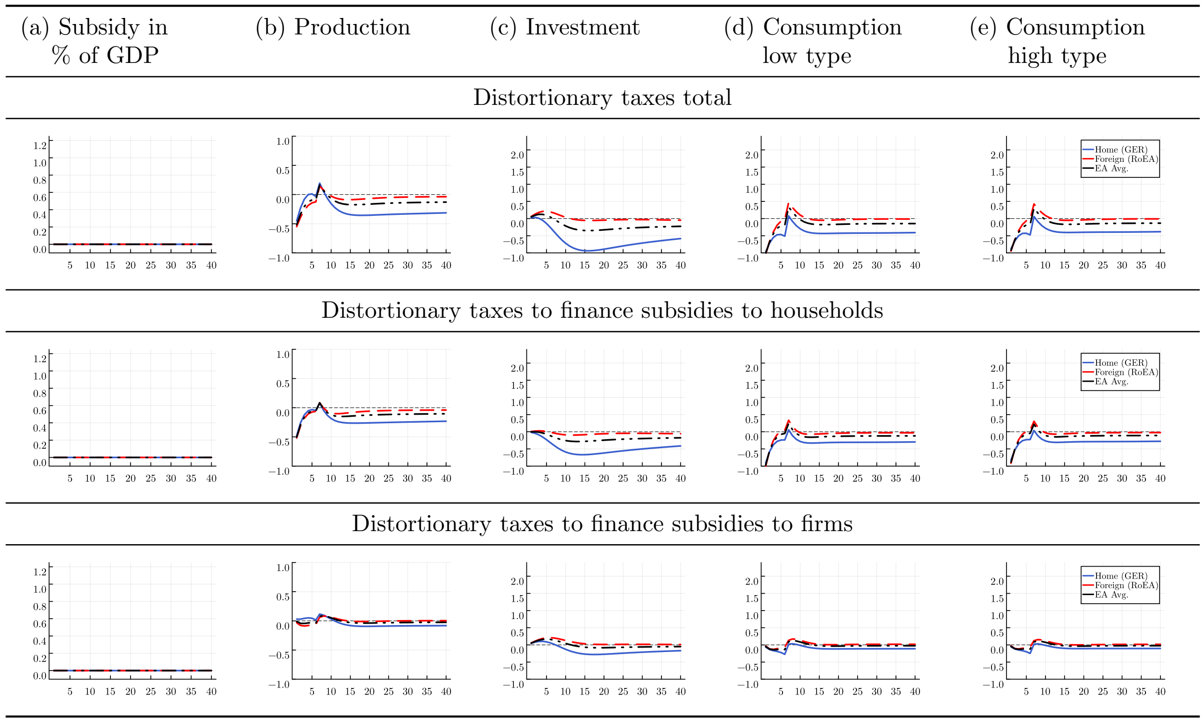


Notes: The top row shows the average (within-group) welfare effect in terms of the energy crisis in terms of consumption equivalents. Left: only in Home, by income. Right: by energy intensity, both Home and Foreign. The red bars show our baseline results while the black bars show the transfers with limited information "Crisis + Tr. (Info)".

perspective, this would have the same effect as basing the transfers on gas consumption directly. The reason is that the MPC of a given household is only a function of its wealth and income, but not of its energy type. Thus, the incidence of the transfer MPC is exactly the same as in our baseline. The same argument applies to the average, first-order welfare effects, which are again the same as in the baseline.

At the micro level, however, such a policy implies that the government is less able to shield high energy types from the incidence of the energy shock. This can be seen from the fact that the consumption of high energy types is less stabilized compared to the baseline case, while the consumption of low energy types now increases more compared to the baseline.

Figure 18: Distortionary effects of taxes required to finance subsidies: Decomposition



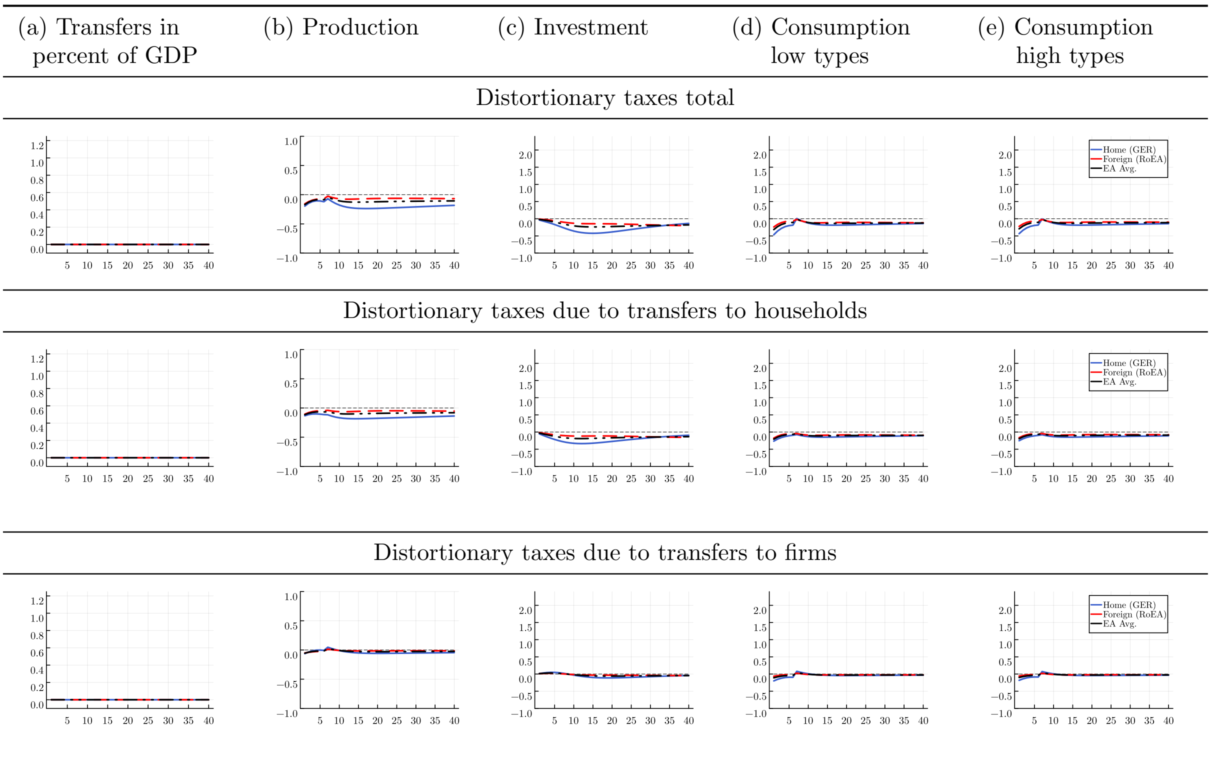
Notes: Decomposition of the effects through changes in distortionary taxes required to finance the subsidy paid by the Home country as presented in the last row in Figure 6. *Top row:* Total effect of the change in distortionary taxes (equals last row in Figure 6). *Second row:* the effect of only changes in distortionary taxes required to finance a subsidy for households. *Third row:* the effect of only changes in distortionary taxes required to finance a subsidy for firms.

C.6 Decomposing the distortionary effects of taxes

In Section 4.2, we decompose the effects of subsidies paid out by the home country in three parts: the effects caused by subsidies which are only paid to households assuming that they could be financed through non-distortionary taxes, the effects caused by subsidies which are only paid to firms assuming that they could be financed through non-distortionary taxes, and the effects caused by the fact that taxes are in fact distortionary (see Figure 6). Figure 18 now further decomposes the last effect (depicted in the first row) into i) the effect that is caused through changes in distortionary taxes which are required to finance subsidies which are only paid to households (depicted in the second row) and ii) the effect that is caused through changes in distortionary taxes which are required to finance subsidies which are only paid to firms (depicted in the third row). This shows that the larger part of the adverse effects stems from the taxes that are required to finance the subsidies to households. The reason is that, as reported in Table (1), the share of energy in consumption is much higher than it is in production and, hence, the fiscal costs of subsidies to households is larger than that to firms. Accordingly, taxes need to raise more strongly because of the subsidies to households than they do as a response to subsidies paid to firms.

Figure 19 redoes this exercise for the case in which the Home country pays out transfers as analyzed in Section 4.3. The top row shows again the adverse effect caused by changes in distortionary taxes required to finance these transfers, as depicted in Figure 9 in the main

Figure 19: Distortionary effects of taxes required to finance transfers: Decomposition



Notes: Decomposition of the effects through changes in distortionary taxes required to finance the transfers paid by the Home country as presented in the last row in Figure 9. *Top row:* Total effect of the change in distortionary taxes (equals last row in Figure 9). *Second row:* the effect of only changes in distortionary taxes required to finance transfers for households. *Third row:* the effect of only changes in distortionary taxes required to finance transfers for firms.

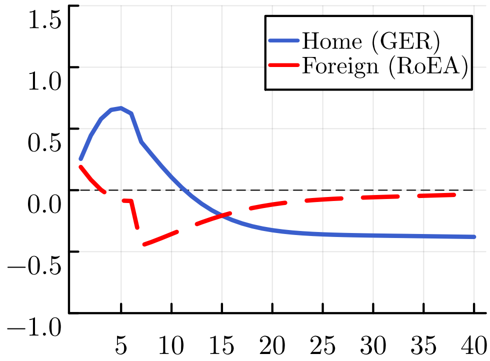
text. The second row depicts the effects caused by the distortionary taxes required to finance the transfers paid to households whereas the third row depicts the effects caused by the distortionary taxes required to finance subsidies paid to firms. Again, the adverse effect stemming from the distortionary taxes required to finance the transfer to households is much larger. But overall, the adverse effects through distortionary taxes are smaller than in the subsidy case as the transfer policy is fiscally cheaper than the subsidy policy.

D Additional results

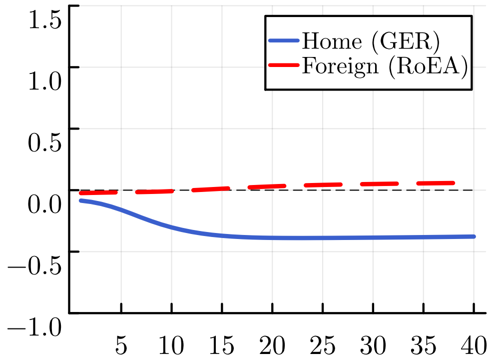
D.1 Comparison of RANK^2 and HANK^2

Figure 20: Macroeconomic impact subsidies and transfers in RANK^2 and HANK^2

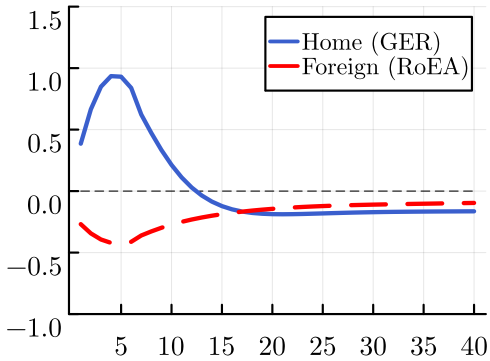
(a) Subsidy in RANK^2



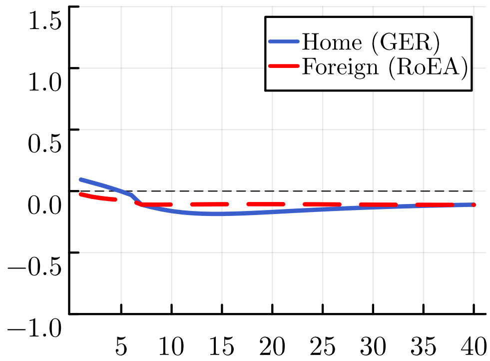
(b) Transfers in RANK^2



(c) Subsidy in HANK^2



(d) Transfers in HANK^2



Notes: Production response of transfer and subsidy policies in RANK^2 model and HANK^2 model. Production is in terms of final output, Y_t, not in terms of the final consumption good. Y-axis: In log-point deviations (log deviations multiplied by 100) from the steady state. X-axis: quarters.

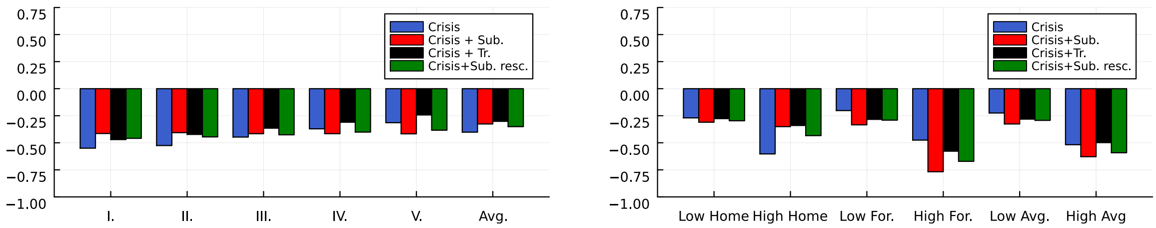
D.2 Subsidies and transfer payments of equal size

In Section 4.5, we show that transfers are better than subsidies in terms of welfare at Home as well as in Foreign. Part of this is due to them being fiscally cheaper than subsidies. Figure 21 reports the welfare implications of a subsidy whose total cost is equal to the total cost of transfers. Next to the results in the paper, the green bar shows the welfare impact of such a subsidy. The figure shows that subsidies equal to the transfer payments are still welfare improving for the lower income and gas-intensive households, but that households at Home and Foreign would prefer transfer payments to subsidies, except for the lowest income quintile at Home.

Figure 21: Welfare impact including smaller subsidies

Overall effect

by income quintile at Home | by type of heating



Notes: The top row shows the average (within-group) welfare effect in terms of the energy crisis in terms of consumption equivalents. Left: only in Home, by income. Right: by energy intensity, both Home and Foreign. The first three bars are as in our baseline result. The fourth, green bars depict the case in which the subsididy is rescaled such that it has the same fiscal costs than the transfers.

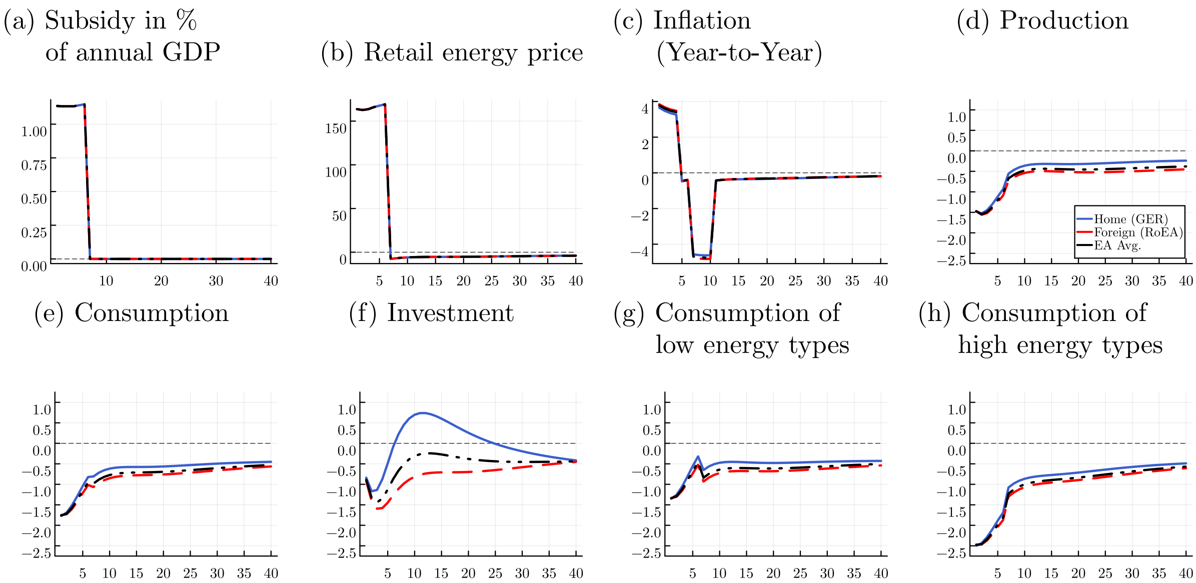
D.3 Coordinated union-wide subsidies of smaller size

In Section 4.4, we show that trying to stabilize the union-wide energy prices requires extremely high subsidies which trigger a massive recession. This section provides results if instead both countries agree to pay the same amount in subsidies as Home does in Section 4.2. Figure 22 shows the results of these smaller coordinated subsidies. With this limited subsidies, the government no longer guarantees a fixed retail price of energy, but finances a fixed spread between retail and wholesale price. Figure 22 shows that in this case, energy prices are only barely noticeably lower than without policy interventions. The reason is that coordinated subsidies are ineffective in moving the energy prices in partial equilibrium: as the energy market needs to clear and energy supply is fixed, the retail price must still move as in the baseline scenario. Through general equilibrium, subsidies have recessionary effects through the fiscal budget as they require distortionary taxes which lower production and incomes. Since this reduces overall demand, it reduces energy consumption which triggers the small decline in energy prices. Hence, also smaller union-wide subsidies do not increase but decrease union-wide production. This implies further that coordinated subsidies are also ineffective in terms of redistribution across income groups and across energy intensity.

D.4 Intertemporal substitution, intratemporal substitution, and real interest rates

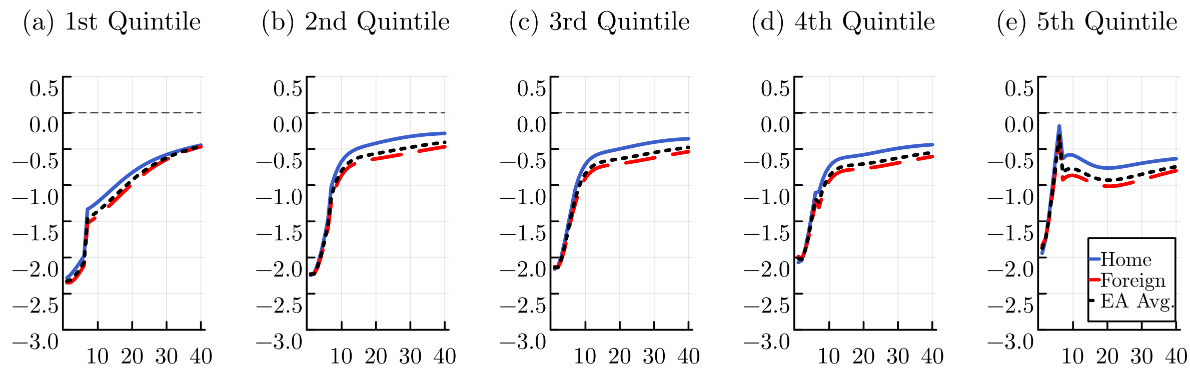
Our results in Section 4.2 and 4.3 show that unilateral subsidies are much more successful in stabilizing output than the transfer payments. Moreover, our decomposition in Figure 6 shows that this is due to the subsidies to households, not due to the subsidies to firms. Interestingly, Auclert et al. (2024) find the opposite result for subsidies and transfers to households. In their exercise, they assume a very peculiar but theoretically attractive monetary policy, namely one that fixes the real interest rate for each household. In contrast to their scenario, we consider a monetary union of two large countries in which monetary policies leans against union-wide inflation. We also assume that only Home provides subsidies, while Foreign is exposed to

Figure 22: Macroeconomic effects of smaller energy subsidies union-wide



Notes: See Figure 2. Impulse response to the energy crisis when the both countries pay an energy subsidy with the same fiscal costs as the Home country does in Figure 4.

Figure 23: Effects of smaller energy subsidies on household consumption along the income distribution



Notes: See Figure 2. Consumption response by income quintile when both countries pay an energy subsidy with the same fiscal costs as the Home country does in Figure 4.

potential spillovers. Furthermore, we allow for heterogeneity in energy consumption across households. As a result, the consumer price of a household with energy intensity a^C, expressed in terms of the physical good, is given by

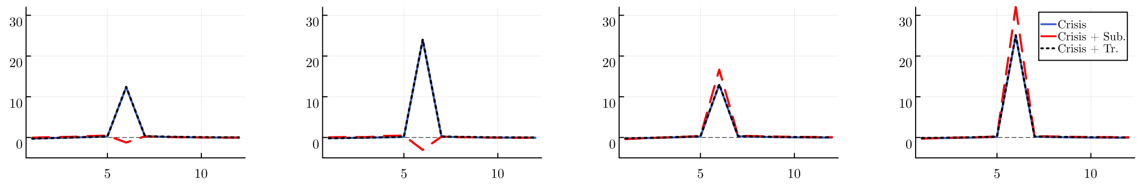
$$p_t^c(a_{it}^C) = \left((1 - a_{it}^C) + a_{it}^C \, (p_t^E - \tau_t^E)^{(1-\sigma_C)}\right)^{\frac{1}{1-\sigma_C}}. \tag{62}$$

Consequently, there are four different inflation rates: one for high energy-intense households at home, one for low energy-intense households at home, one for high energy-intense households abroad, one for low energy-intense households abroad. With one nominal interest rate, monetary policy cannot harmonize real interest rates for each household—there is, a one-size-doesn't-fit-all issue. Hence, the real interest rate differs across households.

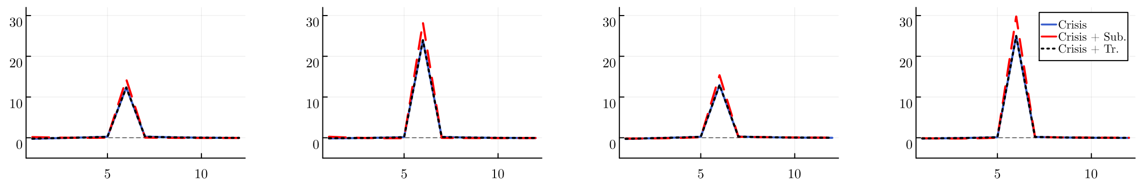
Figure 24: The effects of subsidies/transfers on the expected real interest rates of households

Home		Foreign	
(a) Low-energy type	(b) High-energy type	(c) Low-energy type	(d) High-energy type

Transfers/subsidies to households



Transfers/subsidies to firms



Notes: Evolution of the implied expected real interest rate for households of different energy intensity at Home and in Foreign: $\mathrm{E}_1 R_t \frac{p_t(a^C)P_t}{p_{t+1}(a^C)P_{t+1}}$. Crisis refers to the energy crisis without policy intervention. Transfers and Subsidies are as described in the main text.

Thus, under our assumption of a standard Taylor rule, energy subsidies affect the expected real interest rate faced by households, which makes the real interest rate of households energy-type and country specific. This means that changes in energy prices not only lead to an *intratemporal* substitution between energy and physical consumption that is heterogeneous across households, but in addition to an *intertemporal* substitution and some heterogeneity therein. As stressed above, some of this is efficient from the households' point of view, even though it translates into lower production by lower utilization of capital and lower employment in general equilibrium. With less energy available, the production of final consumption requires more labor, and under flexible prices and complete markets, households would want to forego consumption today for consumption after the energy crisis. This leads to the substitution away from consumption towards leisure during the energy crisis. At the same time, due to nominal rigidities, some of this desired intertemporal substitution leads to inefficient output declines, because output is demand determined.

Figure 24 illustrates this further and shows the expected real interest rate for different household types during the energy crisis. We contrast the baseline without policy intervention (blue solid line) the scenario with subsidies (red solid line) and with transfers (black dashed line). The initial increase in energy prices does only affect realized but not expected inflation. Thus only the expected normalization of energy supply in quarter 6 impacts the real interest rate expectation. Inflation decrease with energy normalization which implies an increase in the real rate. In all figures, we see that the transfers do not alter this path of the real interest rate. While this also holds true for subsidies during the first five periods of the crisis, this changes in the quarter in which the energy crisis ends. The subsidy to households prevents retail energy prices at Home from moving. Thus, there is no increase in the expected real interest rate in quarter 6. In consequence, not only the intratemporal substitution but also the intertemporal substitution is suppressed by the subsidy. At the same time, since the subsidy raises retail energy prices abroad, it makes the intratemporal and the intertemporal substitution in Foreign even stronger (see top row of figure 24). However, note that the effect of the subsidy at Home on the expected real interest rate (difference of the red line to the blue line) outweighs the effect in Foreign. Therefore, the average expected real rate in the Euro Area declines and in the end the subsidy works *as if* there is an expected real interest rate cut in period 6. In other words, it operates as an expansionary unconventional fiscal policy (Bachmann et al., 2021; Correia et al., 2013; Seidl and Seyrich, 2023) stimulating union-wide consumption. Since prices are sticky, this has second-round effects: It shifts output and raises household income, most importantly for the liquidity-constrained households. Notably, from a monetary policy perspective, the subsidy generates an asymmetry which gives rise to the one-size-doesn't-fit-all problem for monetary policy. From the point of view of the foreign economy, monetary policy is too tight; from the point of view of the domestic economy, it is too loose. As we will see, this leads to welfare consequences similar to those found in Bayer et al. (2024) for asymmetric productivity shocks.[23]

[23]Subsidies to firms are different. They reduce firms' marginal costs, but they raise the price of direct energy use by consumers both at home and abroad. Since prices are sticky, the direct effect on consumers is dominant and therefore they raise the real interest rate for all types of households in all parts of the economy (see bottom row of Figure 24). Again, this has aggregate demand feedback.