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Hicks in HANK: Fiscal Responses to an Energy Shock

Christian Bayer¹
Alexander Kriwoluzky²
Gernot J. Müller³
Fabian Seyrich⁴

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¹ University of Bonn, Email: christian.bayer@uni-bonn.de

² Freie Universität Berlin, Email: akriwoluzky@diw.de

³ University of Tübingen, Email: gernot.mueller@uni-tuebingen.de

⁴ Berlin School of Economics & Freie Universität Berlin, Email: fabian.seyrich@gmail.com

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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 that we calibrate to the euro area. Energy subsidies can stabilize the domestic economy, but are fiscally costly and generate adverse spillovers to the rest of the monetary union: What the subsidizing country gains, the other countries lose. Transfers based on historical energy consumption in the form of a Hicks/Slutsky compensation are less effective domestically as subsidies but do not harm economic activity abroad. In addition, transfers increase welfare at Home while subsidies reduce welfare.

Keywords: Energy crisis, Subsidies, Transfers, HANK², monetary union, spillovers, heterogeneity, inequality, households

JEL-Codes: D31, E64, F45, Q41

*Bayer: University of Bonn, CEPR, CESifo, and IZA, christian.bayer@uni-bonn.de; Kriwoluzky: Freie Universität Berlin and DIW Berlin, akriwoluzky@diw.de; Müller: University of Tübingen, CEPR, and CESifo, gernot.mueller@uni-tuebingen.de; Seyrich: Berlin School of Economics, Freie Universität Berlin, and DIW Berlin, fabian.seyrich@gmail.com. This research is based on a policy report written for and partly financed by the German Ministry of Finance. It has further received financial support from the Leibniz Association through the project “Distributional effects of macroeconomic policies in Europe”. Christian Bayer gratefully acknowledges support by the DFG through CRC-TR224 EPoS, subarea C05. Christian Bayer was visiting the Department of Economics at the University of Oxford while writing this paper. Their hospitality is gratefully acknowledged. The usual disclaimer applies. To be precise, the title of the paper should be Slutsky in HANK, but since we are looking at first-order approximations, Hicks and Slutsky compensations are the same, and “Hicks in HANK” is easier to remember.

1 Introduction

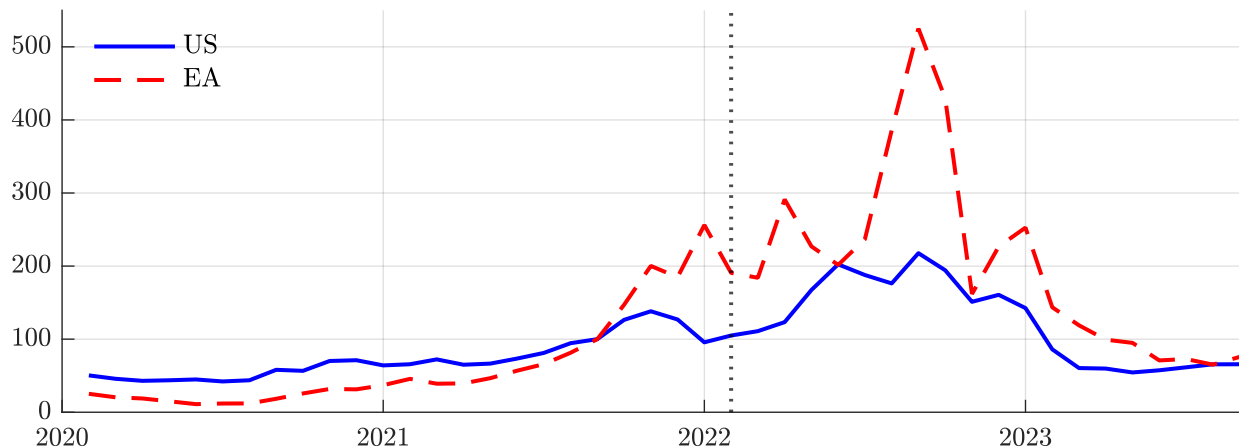
The Russian invasion of Ukraine in 2022 triggered a massive energy crisis in Europe. Europe is an energy importer, with an import dependency rate of 55.5%, and natural gas looms large in its energy mix, notably when it comes to heating (Eurostat, 2023). And while the market for gas is well integrated in Europe, it is highly fragmented at the global level, in contrast to the market for oil: Transporting gas requires pipelines or gas liquefaction terminals that 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.

How to deal with an adverse energy supply shock? The fallout of the shock is twofold. First, it hits firms and households and, among those, the poor in particular since energy often makes up a disproportionately large share of their expenditures. Second, as the purchasing power of firms and households is curtailed, the recessionary impact of the shock is amplified. And since the shock hit 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. In this paper, we consider two distinct policies which have been proposed in the context of the European energy crisis. The first is to pay a subsidy to households and firms in order to stabilize the effective price of natural gas. The second is to pay transfers to households and firms conditional on their pre-crisis level of energy consumption. These policies actually capture the essence of the policy response in France and Germany, respectively.

We analyze these policies in a model of a large open economy that operates within a currency union such that we can account for their cross-country spillovers. In the model, households face idiosyncratic income shocks and financial markets are incomplete. As a result, there is a non-degenerate distribution of income and wealth and transfer policies are non-neutral. We simulate the effects of an adverse energy supply shock in response to which the price of energy shoots up, the economy contracts, and inflation rises. The impact of the shock is similar across the countries of the union but differs within countries along the income distribution. We find that paying a subsidy in the domestic economy is more effective in limiting the recessionary impact of the shock, but comes with sizeable adverse spillovers to the rest of the union: As it stabilizes gas consumption at high levels, it pushes prices further up. Transfers, instead, stabilize the consumption of high-energy consumers without preventing substitution effects and without harming production in the rest of the union.

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

Figure 1: The price of natural gas 2018–2023



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.

More in detail, in this paper we extend the two-country heterogeneous agents New Keynesian model (or HANK² model for short) that we developed in earlier work (Bayer, Kriwoluzky, Müller, and Seyrich, 2023): We explicitly model the market for energy, accounting for the energy consumption of households and firms. Importantly, we assume that the total supply of energy in the union is inelastic, reflecting a given import capacity that may not be adjusted in the short run for reasons discussed above. Energy features in both, production and consumption, and we allow for heterogeneity in the energy share of households’ consumption baskets, in line with the data. The domestic economy and the rest of the union are characterized by isomorphic technologies and preferences and the energy market is perfectly integrated across the union.

The other model features are by now fairly standard. Financial markets are incomplete and households face idiosyncratic risk in response to which they self-insure via savings. For this purpose, they may use liquid and illiquid assets as in the medium-scale HANK model of Bayer, Born, and Luetticke (2020). Wages and prices are sticky in the conventional New Keynesian way. We calibrate the domestic economy, or “Home”, based on data for Germany and assume it accounts for one-third of the union. We use data for Italy to pin down parameter values for the rest of the union, or “Foreign”. As we target key features of aggregate data, including those that capture the cross-country co-movement, we assume that parameters are the same in both countries. At the micro level, instead, we allow for cross-country differences in terms of household heterogeneity. We do so because the distributional impact of the energy supply shock is the focus of our study.

The calibrated model is able to capture key aspects of the data—simultaneously at the micro and the macro level and, in addition, for two major European economies—and is therefore well suited to study the impact of the European energy crisis and the effect of alternative policy responses. For the baseline scenario, we assume a drop of energy 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. However, within countries, the distributional impact of the shock is quite large: Consumption drops by about 1.5 percent for the lowest income quintile, but by less than 1 percent for the highest.

Given the shock scenario, we contrast two policy interventions that we assume to be implemented in Home only so as to study their spillovers to the rest of the union. The first policy we consider is a price subsidy which caps prices at the pre-crisis level in Home. Because the energy market is fully integrated and supply drops exogenously such a policy would not be feasible for the union as a whole.² The policy is effective in stabilizing consumption in Home: Across the income distribution the decline of consumption is much reduced, and so is the drop in GDP. However, because the energy market is fully integrated, subsidizing energy in Home raises its price in Foreign further, thus amplifying the effect of the shock abroad.

The second policy we consider is a transfer conditional on the pre-crisis level of energy consumption. Technically, this amounts to a Slutsky compensation: because of the transfer, the old consumption bundle remains feasible as prices go up. Up to the first-order approximation for which we solve the model, the Slutsky compensation is equivalent to a Hicks compensation. (Hence, the title of the paper.) 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 expected increase in tax distortions in the future, necessary to finance the transfer, dampens activity from the onset. In contrast to the subsidy, the transfer policy does not harm production in Foreign, as some of the additional resources are spent abroad.

Both policies have sizeable fiscal costs, but subsidies are about 50% more expensive than transfers. Initially, these costs are covered by newly issued debt which is gradually paid back 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. We see this, as we compute the consumption-equivalent variation of both policies. However, the subsidy generally fares much worse in this dimension. Subsidies even decrease welfare at Home while transfers increase welfare at Home. Intuitively, subsidizing energy

²In principle, it is conceivable that if both countries pay the subsidy, the gas price and, consequently, the fiscal costs of the subsidy increase so much that total demand decreases sufficiently for the demand of gas to fall enough to clear the gas market. We do not pursue this scenario below.

consumption in the face of a massive supply contraction is inefficient. Here transfers differ. Their welfare costs are almost exclusively due to tax distortions. And because they alter the terms of trade they spill over to the Foreign economy, too.

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 provides a summary of the model. Most of the details are relegated to the appendix. Instead, the exposition focuses on the energy market. Section 3 presents details of the calibration of the model and Section 4 the results. The final section offers some conclusions.

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, 2018; 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 (2023) 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. 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 (2023) also analyzes 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 (“coordination”) resort to subsidizing energy. 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. Chan, Diz, and Kanngiesser (2023) 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 energy crisis based on an extension of the HANK² model developed in Bayer, Kriwoluzky, Müller, and Seyrich (2023). Specifically, in what follows we account for energy use in production and directly in household consumption (heating). The model features two countries that form a monetary union, incomplete financial markets, and assets with different liquidity (bonds and capital). It thus captures key aspects of the European macroeconomy as well as household heterogeneity within countries. For these reasons, we consider it particularly suitable to study the European energy crisis of 2022/23 and the policy options that have been discussed to confront it. The following is a brief summary of the model, with a particular focus on energy. A full description of the model can be found in the Appendix.

2.1 Summary of the model

The model represents a monetary union of two countries. Markets are incomplete and households face idiosyncratic, that is, 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.³ Each country consists of a corporate 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 goods from homogeneous domestic intermediate goods; (c) a representative consumer goods firm that puts together domestic and imported foreign final 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 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 goods and, in addition, energy. Households earn income from supplying (raw) labor and capital to the national labor and capital markets and

³The set up in each country is closely related to the HANK model in Bayer, Born, and Luetticke (2020)

from owning their national firm sector, absorbing any rents arising from the market power of unions and final goods producers and from diminishing returns to scale in capital goods production. We also assume that households own the energy sources. Income from these is treated like 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.⁴

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.

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 isomorphic and our exposition focuses on Home. Specifically, we assume intermediate goods Y_t are produced with the (nested) CES production function:

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

As this expression shows, the intermediate good is made 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, 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

⁴Assuming that energy sources are owned by a third, energy exporting country is unlikely to matter for our main results regarding the effects of alternative fiscal responses to the crisis. Hence, we maintain our HANK² framework to keep the analysis focused.

combined in a CES aggregator:

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

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:

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

where A is a linear function of the human capital quintile and B is a constant that captures that it is in general 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 type transitions as infrequent, so that the energy intensity of the household is very persistent—in line with the fact that people move homes rather infrequently.

The differences in energy intensity also imply heterogeneity in inflation rates across households when energy prices move. Since energy is a component of household consumption, an increase in energy prices—triggered, for example, by a supply shortage—raises the household price index and, all else equal, leads to a reduction in real income and, potentially, consumption. This effect is more pronounced for households with high energy consumption than for households with low energy consumption. Households with a high share of energy consumption are in the data low-income households. Those households are often living in more energy-intensive homes. Consequently, those households experience the strongest decrease in real income. As those households are among those with a high marginal propensity to consume, this exacerbates the recession.

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:

$$E_t = E_t^C + E_t^Y + E_t^{C,*} + E_t^{Y,*}. \quad (4)$$

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 two alternative fiscal policies in response to an energy crisis. Firstly, national policies can subsidize energy prices in their country. Alternatively, they can opt to pay a transfer that compensates either the difference in income (Slutsky compensation) or the change in utility (Hicks compensation) caused by the shock. In each instance, we focus on a scenario where the policy is implemented in Home only. This allows us to analyze potential spillover effects on the rest of the union.

2.3.1 Policy option 1: subsidies

Formally, we assume the subsidy to offset entirely an increase in energy prices such that prices are stabilized at the pre-crisis level \bar{p}^E for both, households and firms. It is given by:

$$\tau_t^E = p_t^E - \bar{p}^E. \quad (5)$$

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, Tagliapietra, Trasi, and Zachmann, 2023). And indeed, Auclert, Monnery,

Rognlie, and Straub (2023) and Langot, Malmberg, Tripier, and Hairault (2023) advocate this as a policy that helps to overcome the spillovers through demand channels that incomplete markets generate.

2.3.2 Policy option 2: Hicks (Slutsky) compensation

As an alternative to the subsidy of energy, national authorities can compensate the households and firms in the economy for the rise in energy costs through transfers. Transfers can be designed in a way that they offset the change in income (Slutsky compensation) or the change in utility (Hicks compensation), in turn, caused by the increase in energy prices. However, given that we solve the model based on a first-order perturbation, both types of compensations are equivalent for a marginal change in prices.⁵ As both are equivalent, we pick the Hicks compensation in the remaining paper when we refer to transfers.⁶ More precisely, we model the Hicks compensation as the transfer equal to the price increase such that the transfers to household i is:

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

where \bar{p}^E is the steady-state price of energy, \bar{E}_i^C is the consumption of energy a household with the characteristics of household i has in the steady state. When such a policy was implemented in Germany in practice, the reference quantity was the energy consumption (for heating) in 2020 of the apartment/house the household was living in. Conditioning the transfer on the full set of contemporaneous characteristics avoids the introduction of historical consumption as another state variable to the model and is for a slow-moving variable such as energy consumption a good approximation of the actual policy. The transfers to firms are accordingly defined as:

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

⁵Consider the following simple example: denote the consumption basket by x , one good by x_i , its price by p_i , and available income by m . Households maximize utility $u(x)$ s.t. $\sum_{i=0}^I p_i x_i = m$. The Slutsky compensation for a marginal change in price p_i is $\frac{dm}{dp_i} = x_i$.

The indirect utility function V of the household is $V(m, p)$. The Hicks compensation after a marginal change in price is the change in m to keep the indirect utility unchanged, i.e. $\frac{\partial V}{\partial p_i} dp_i = -\frac{\partial V}{\partial m} dm$. Straightforward algebra gives: $\frac{\partial V}{\partial p_i} dp_i = \lambda x_i dp_i$ and $\frac{\partial V}{\partial m} dm = -\lambda dm$, where λ is the Lagrange multiplier on the budget constraint. Using both expressions and the Hicks compensation equation yields $\frac{dm}{dp_i} = x_i$. In other words, for a *marginal* change in price, Hicks and Slutsky compensations are identical.

⁶Admittedly, the title of the paper plays a non-trivial role in the choice.

Table 1: Calibration of the energy sector

	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

3 Calibration

The HANK² model is well able to capture key features of the euro-area business cycle, including the cross-country co-movement, and—at the same time—the heterogeneity at the household level within countries. We show this for a calibrated version of the model in earlier work (Bayer, Kriwoluzky, Müller, and Seyrich, 2023). 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- and the more self-insurance-based Southern European model. After all, this aspect is central when it comes to understanding differences in the heterogeneity of household portfolios across country. 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 no direct income support. Instead, the government facilitates self-insurance by issuing more government bonds. Admittedly, this is a simplifying 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. 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.

Table 2: Expenditure on gas (heating and hot water)

Expenditure on gas (including hot water) 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.

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 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 by Germany, as reported by Moll, Schularick, and Zachmann (2023).

Finally, we calibrate the energy sector symmetrically across countries, based on German data, and—given the focus on this—paper—report the key parameters related to this sector in some detail, see Table 1. Specifically, we choose the energy share, a^P , for the firm sector to match the steady-state gas expenditure shares of 0.5% of production costs. We set the elasticity of substitution in production σ_P to 0.2. This captures 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 the energy consumption of households: the energy share in the consumption basket of high and low energy intensive households (a_H^C, a_L^C) and the parameters ($\bar{\rho}, B, A$) which govern the process that determines the energy type of households, given in Equation (3) above. We set these parameters so that the average expenditure share on gas amounts to 2.5%,⁷ the average annual probability to switch energy types to just over 10%, and the dispersion of energy expenditures within and across incomes as shown in Table 2. Concretely, we match three additional targets: (i) the average increase in energy expenditures across income quintiles, (ii) the interquartile range within the top income quintile, (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.

In this way, we 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 themselves. 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 parameterization. It shows the figures implied by the model alongside the empirical distribution from German micro data (the German equivalent of the Consumption Expenditure Survey, CEX).

4 Results

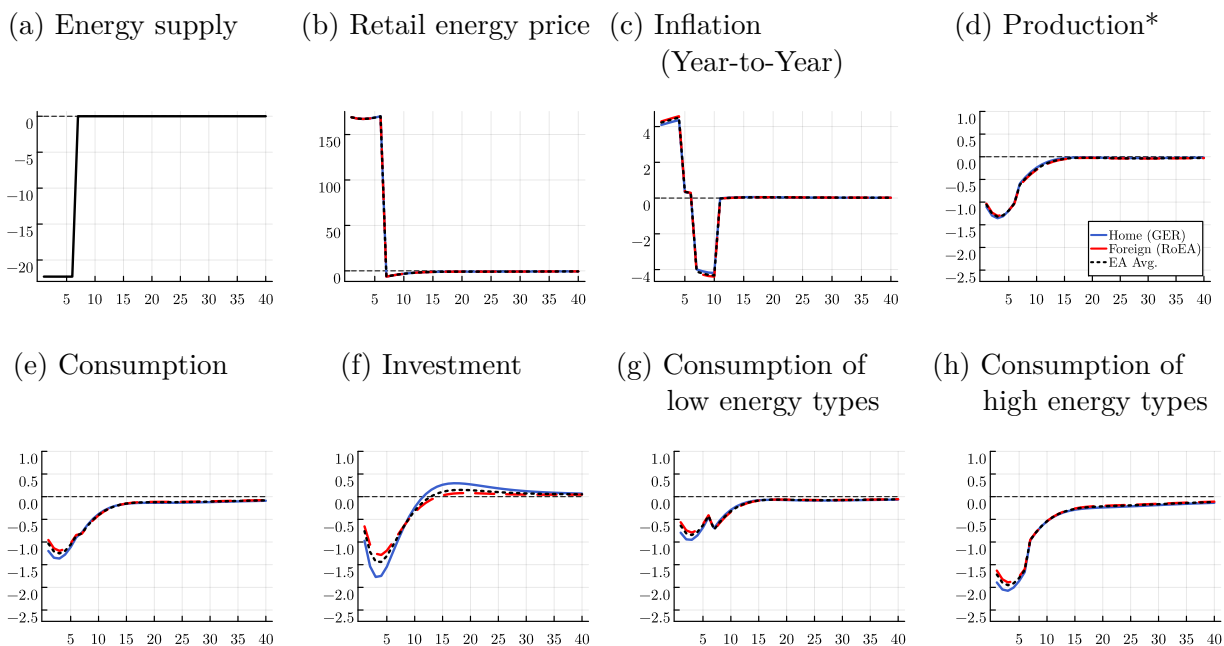
In what follows, we first study the effects of energy scarcity through the lens of the calibrated model. We compute a linearized state-space solution using the toolkit provided by Bayer, Born, and Lueticke (2020).⁸ We then run two policy experiments and analyze the effect of policies that respond to the increase in energy prices with either i) subsidies or ii) transfers. We choose the subsidies to be large enough to fully offset their general equilibrium effect on energy prices. For both experiments, we assume households expect the policy to last for as long as the energy shortage. Both 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

⁷In 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 percent. However, since it is important for the macro effects of the energy crisis, we choose to use the aggregate expenditure share.

⁸The linearization results in a somewhat benign decrease in potential output, as marginal output losses increase with the size of the shock, and a 20% energy reduction is clearly not marginal. However, the focus of this paper is on the policy measures.

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



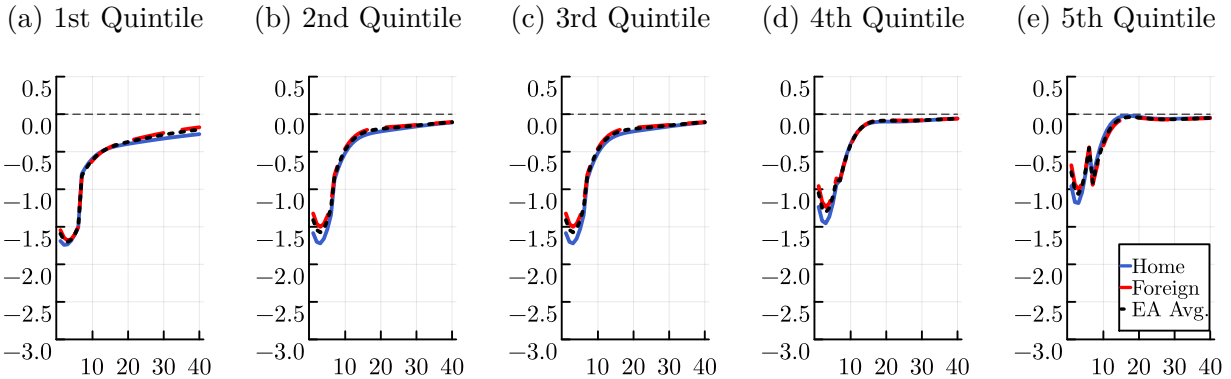
Notes: Impulse responses to a 20% reduction in energy (natural gas) supply to the Euro Area (log-linearized solution). The blue solid lines show the impact on the Home economy (GER), the red dashed line shows the response of the Foreign (rest of Euro Area) response, and the black dashed-dotted line shows the euro-area-wide response. Retail energy price 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.

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 distortionary taxes is then calculated as a residual. Lastly, we also study the welfare impact of both policies in terms of consumption equivalent variation.

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 in Home (blue solid line), in 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 again footnote 1. Also, the duration of

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



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

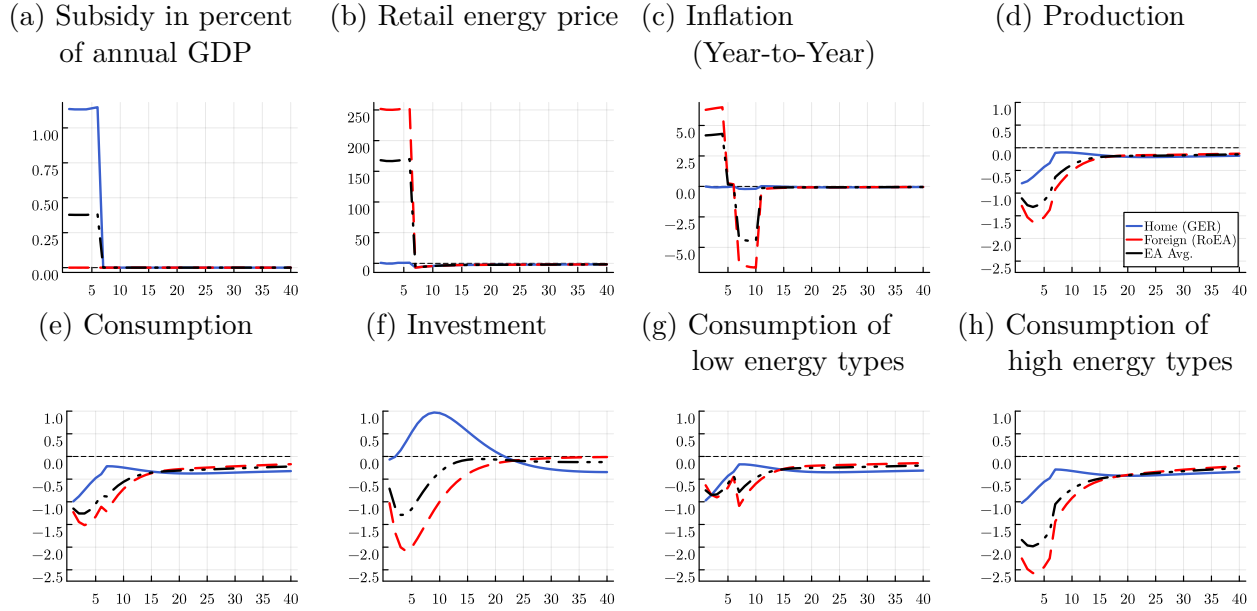
the price increase turned about to be shorter. Nevertheless, we assume the energy crisis lasts 6-quarters in line with what market participants expected in the spring/summer of 2022 as reflected by prices of futures for natural gas deliveries for the year 2023.

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 1.5%, as shown in panels d) to f). This reflects the complementarity of energy in both production and consumption. The differences between Home (Germany) and the rest of the euro area 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, Home 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 as they foresee a normalization of energy prices after 6 quarters and therefore expect deflation then. Panels g) and h) of Figure 2 shows 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 consumption response to the shock for across the income distribution. The consumption response of income-poor households shown in panel a) is the strongest and about 70 percent larger than for the richest quintile (panel e). For the poor, the share of energy

Figure 4: Macroeconomic effects of energy subsidies in Germany



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.

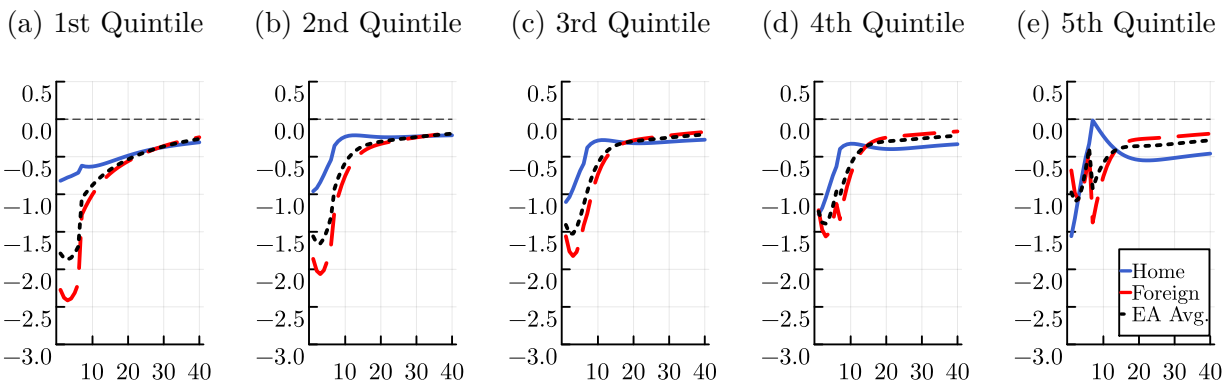
expenditure is particularly high, so they see a particularly sharp erosion of their real income. In addition, they are more dependent on labor income and thus exposed to indirect effects (Känzig, 2023). Given the strong welfare state in Home, even the median household has little savings. In Foreign, calibrated to Italy, households hold more assets to insure themselves. Therefore, their consumption decline is somewhat lower.

4.2 Policy option 1: subsidies

We now turn to the policy experiments and consider the subsidy first. Recall, that we confine the policy to take place in Home only. It turns out that an energy subsidy is quite effective in shielding the domestic economy from the adverse aggregate impact of the shock. 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 because of Home's subsidy. And while consumers and firms in Home enjoy prices at

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.

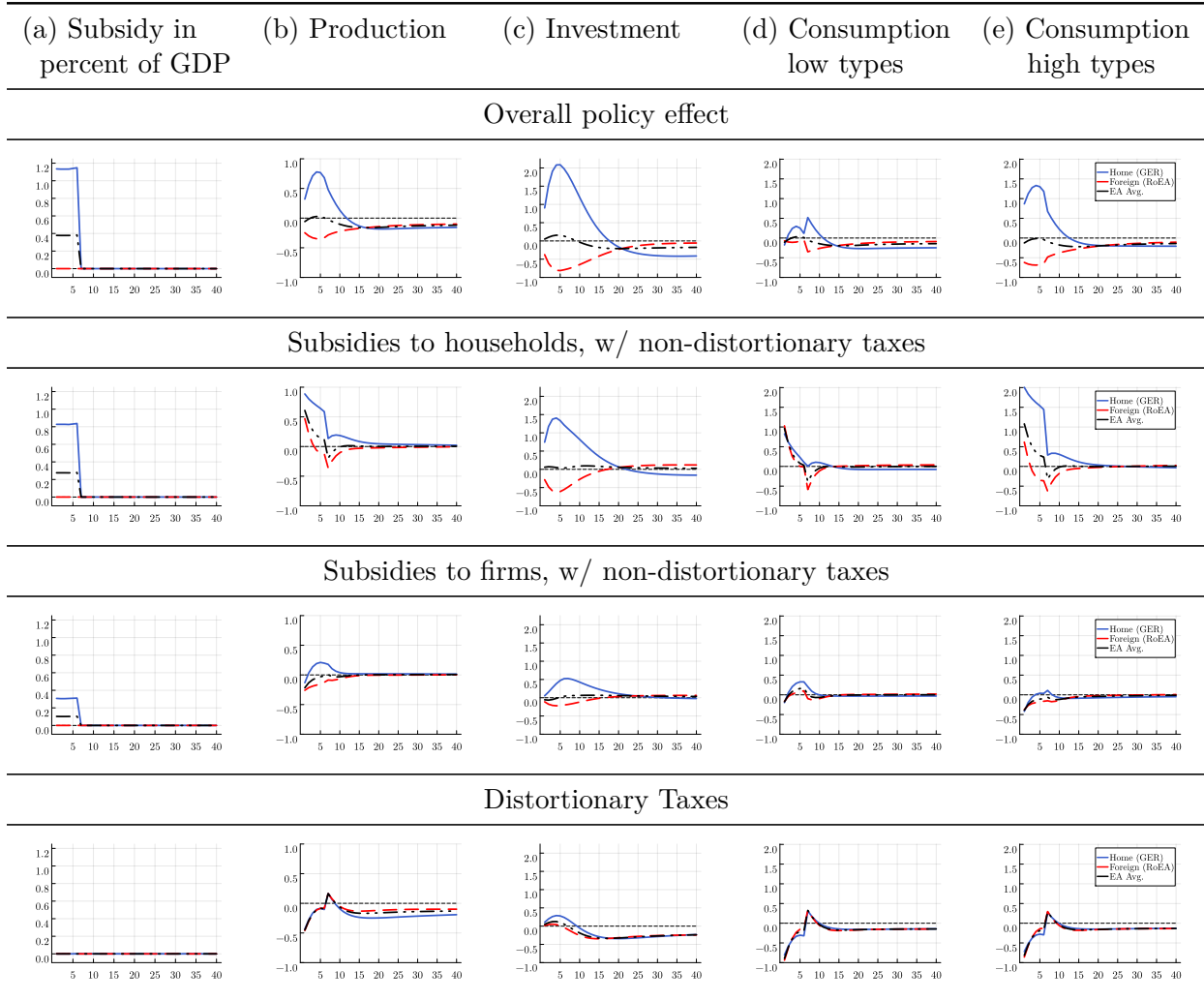
pre-crisis levels, because of the increase in wholesale gas prices, the fiscal costs of the subsidy are significantly higher than the increase of retail prices which it eliminates.⁹ And while the subsidy prevents inflation from rising in Home, the increases of inflation in Foreign is larger still than in the baseline without policy response, as panel c) illustrates. The response of union-wide inflation is thus very similar to the baseline. 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).

The subsidy is fiscally costly: Over the course of the six quarters of the intervention, the Home country spends around seven percent of its annual GDP on energy subsidies. This is more than twice the total annual energy bill we calibrated the model to. The result is a significant increase in distortionary taxes, leading to a decline of output and consumption in the medium run: see again panels d) and c) of Figure 4. These adverse effects in the medium run are not confined to Home, but also show up in Foreign—because of the short-run amplification of the crisis via the subsidy, the fiscal costs of the crisis go up there, too.

The subsidy is very effective, however, in undoing the distributional impact of the shock. In fact, in Home it shifts the burden of adjustment from the income poor to the rich. Figure 5 breaks down the consumption response by income group. The consumption of the lowest quintile now falls by less than the consumption of the highest quintile—effectively altering the order of the baseline response without fiscal intervention. This reversal reflects the

⁹Interestingly, the absolute peak of natural gas prices at the TTF was roughly 300€/MWh in August 2022. At this time, there was a significant policy debate in many European economies, including Germany, on whether all should follow the French example and subsidize the consumption of energy. The German Federal Commission on Gas and Heating very quickly advocated against such a model in its first interim report in mid-October 2022.

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.

unequal change in the tax burden down the road. In Foreign, in contrast, the poor suffer the most because they are particularly exposed to the energy price increase. But as the Home subsidy amplifies the crisis for Foreign, the Foreign country's rich expect to pay higher taxes in the future and thus lose out, too, and reduce their consumption more strongly than in the baseline.

Figure 6 offers a breakdown of the total effect of the subsidy into 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 shows the overall effect of the policy, that is, the change in the adjustment dynamics relative to the baseline without policy intervention.

The second row shows results when only households receive the energy subsidy. Subsidizing household energy demand (funded by a non-distortionary surcharge to labor taxes) expands consumption and, because it is demand-driven, also production. The reason is two-fold: first, the income of poor households goes up and, second, households do not substitute intertemporarily from, because of scarce energy, expensive consumption today towards cheaper consumption after the crisis. By contrast, the effect of subsidizing energy in production, shown in the third row, overall impacts production adversely, at least on impact. This holds even if taxes are non-distortionary. Intuitively, the subsidy pushes up energy prices in non-subsidized markets, which, all else equal, crowds out production in the Foreign economy and household energy consumption, too. In this way, subsidizing energy in production generates a negative effect on demand at Home. The final row of Figure 6 isolates the effect of distortionary taxes. It shows that roughly half of the expansionary effects of the subsidy at Home and all of the expansionary effects in Foreign that would obtain under lump sum taxes are eliminated by the substantial negative distortionary effects of the future taxation needed to finance the subsidy.

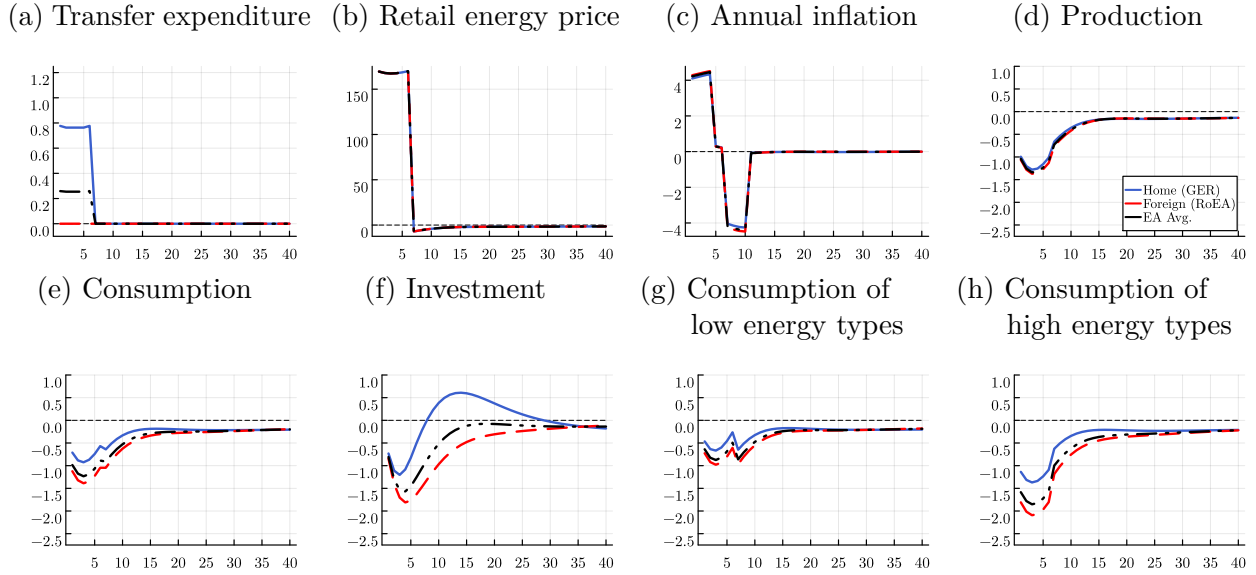
In sum, the subsidy policy only shifts consumption from one country to the other, raises output at Home, but lowers output in the Foreign country. Because of this beggar-thy-neighbor nature of the subsidy policy, there is little movement in euro area inflation. In the medium-run output drops when distortionary taxes need to be raised.

4.3 Policy option 2: Hicks (Slutsky) compensation

The second policy experiment that we consider are transfers. Such transfers were in fact implemented in Germany in response to the energy crisis, not least because policymakers and their advisors anticipated adverse spillovers of a subsidy scheme on the rest of the euro area (ExpertInnen-Kommission Gas und Wärme, 2022). The German response instead was largely following an early proposal by Bachmann et al. (2022b) and Bachmann et al. (2022a). The transfer was conditional on energy consumption in 2020/21 and applied to both households and firms. In the model, we implement transfers to firms as transfers to entrepreneurs that increase profits and assume that transfers fully compensate for the increase gas prices, see Section 2.3.2 above.

Figure 7 shows the aggregate effects of the crisis once the transfer scheme is put in place. The figure is organized in the same way as Figure 2 above. Comparing aggregate dynamics with transfers to the baseline without fiscal response, we find that the effect of transfers on

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



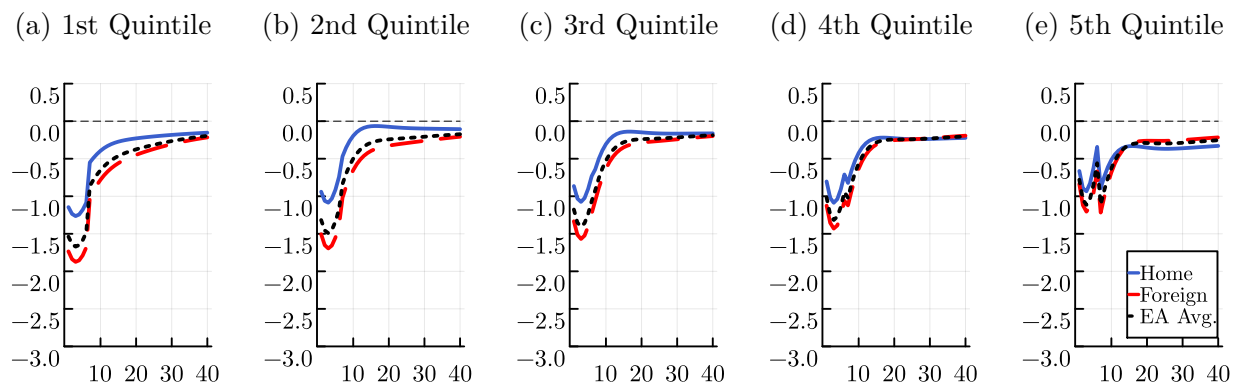
Notes: See Figure 2. Impulse response to the energy crisis when the Home country provides households and firms with transfers to compensate for the energy price increase.

aggregate dynamics is moderate. The transfers reduce the output loss in Home by about 10 percent (an increase of 0.11% at the peak), see panel d) Household consumption in Home increases relative to the crisis scenario (about +0.5%), but less than with the subsidy (about +0.7%), see panel e). Importantly, the policy does not generate important spillovers. The dynamics in the rest of the euro area are basically unchanged relative to the baseline and the same holds for the retail price of energy, shown in 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 8 shows the response of consumption along the income distribution with the transfer in place. Comparing it with the results for the baseline shown in Figure 3 above, we find that transfers are able to limit the adverse distributional impact of the shock substantially. The decline of consumption of the poor in particular is much reduced. However, comparing the responses under transfers in Figure 8 with the responses with the subsidy in place shown in Figure 5, we observe that the distributional impact of the shock remains larger under transfers. This holds for Home only because while the subsidy in Home amplifies the distributional impact in Foreign, transfers do not.

As before we decompose the effect of the transfer policy into the components that are received by households and firms and look into the role of distortionary taxes. Figure 9 shows the results. It is organized as Figure 6, we provides the decomposition for the subsidy. We

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

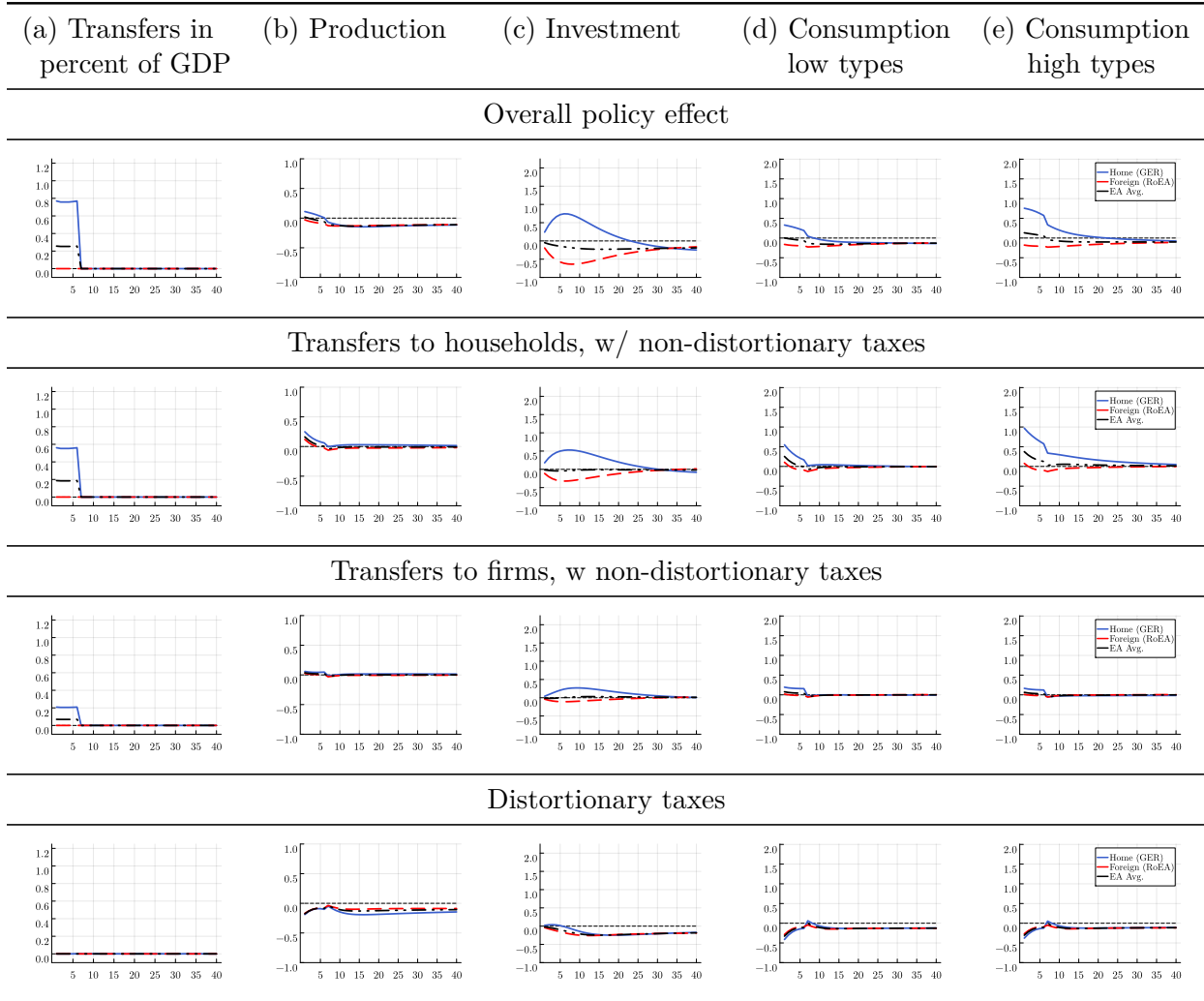


Notes: See Figure 2. Consumption response by income quintile when the Home country provides transfers to compensate for the energy price increase.

observe that compared to subsidies, transfers boost consumption less. Because transfers do not stabilize energy prices, households reduce their energy use as in the baseline without a policy intervention. However, they not only shift their expenditure towards non-energy consumption (intra-temporal substitution) but also over time (inter-temporal substitution). This effect has recently been emphasized by Guerrieri, Lorenzoni, Straub, and Werning (2022) in their analysis of the pandemic. Intuitively, adverse supply shocks in one sector can depress demand in other sectors when there are strong complementarities between goods, that is, when the elasticity of intra-temporal elasticity of substitution is low compared to the inter-temporal elasticity of substitution (so called, “Keyensian supply shocks”). These conditions are satisfied in the context of our analysis, too. And the effect is particularly strong for households with high energy intensity. The effective price of their bundled energy-goods consumption jumps during the crisis, and it jumps more than for the average household. Therefore, they have an additional incentive to postpone consumption. Put differently, they face a particularly high personal real interest rate and find it optimal to shift consumption into the future. The fact that they obtain an income compensation to buy the old intra- and inter-temporal consumption bundles does not change these incentives. 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 above. We will discuss this in more detail in the next subsection.

This finding also illustrates why it is important to capture the heterogeneity of energy demand, even from an aggregate perspective. The energy-intensive households are more often poor and more often have a high marginal propensity to consume. Therefore, their particularly high loss in real income translates into a higher loss in consumption demand. At

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.

the same time, however, a larger reduction of consumption is actually part of their optimal intertemporal behavior even when they are not borrowing-constrained. It is clear that in a model with complete markets, all transfers to households and firms would have no positive aggregate effect.¹⁰ Only in a model where many households have a high marginal propensity to consume can the transfer scheme develop a positive demand effect. The importance of

¹⁰Instead, there is an adverse impact of transfers if taxes that fund the transfers (in the medium run) are distortionary.

making transfers targeted is further illustrated by the results shown in the third row of the figure, which zooms in on the transfers to firms. Transfers to entrepreneurs, a group of rich households with low MPCs do not generate much of an effect.

Lastly, the bottom row of Figure 9 shows the effects of higher distortionary taxation in isolation. These taxes will increase eventually to fund the costs of the fiscal intervention: these—all else equal—have adverse effects on the economy, but less so than in case of the subsidy, simply because the fiscal costs of the transfer is smaller.

4.4 Intertemporal substitution, intratemporal substitution, and the role of monetary policy

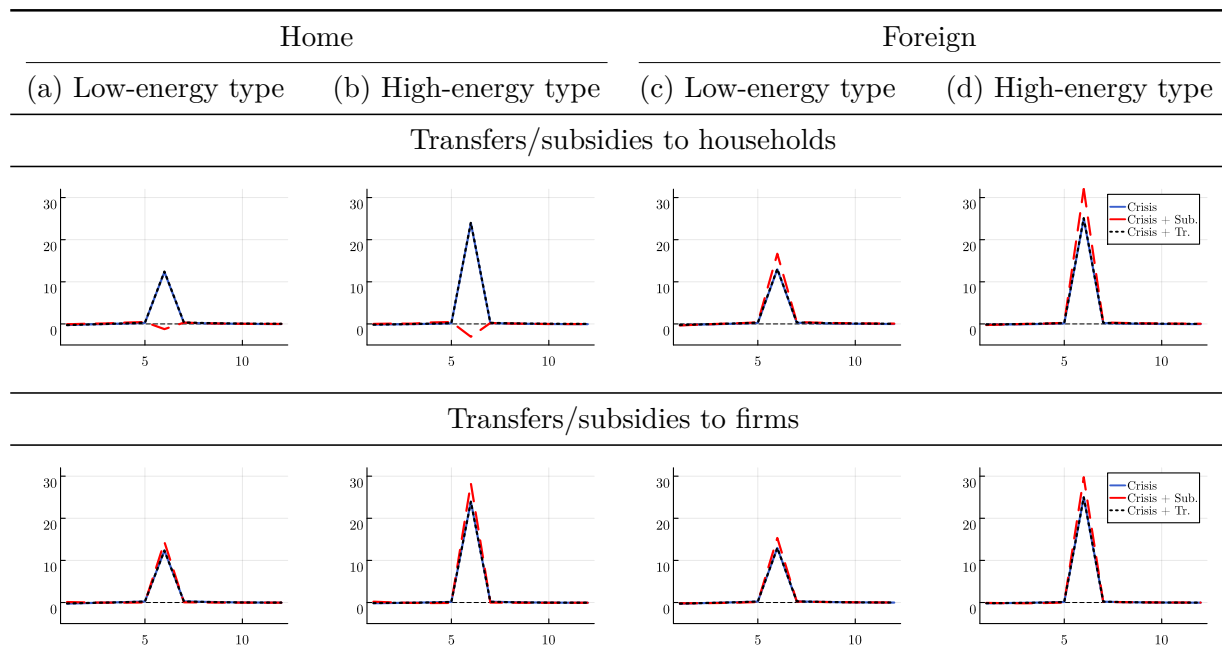
Our results show that the subsidy to households is much more successful in stabilizing output than the transfer payments. Moreover, our decomposition in Figure 6 shows that this is due to the subsidies to households, not due to the subsidies to firms. Interestingly, Auclert, Monneray, Rognlie, and Straub (2023) 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 only Home provides subsidies, while Foreign is exposed to potential spillovers. Furthermore, we allow for heterogeneity in energy consumption across households. In our environment, monetary policy cannot stabilize the real interest rate for each household—there is, a one-size-doesn't-fit-all issue at two levels: countries and households. Hence, the real interest rate differs across households. More precisely, the consumer price of a household with energy intensity a^C , expressed in terms of the physical good, is given by

$$p_t^c(a_{it}^C) = \left((1 - a_{it}^C) + a_{it}^C (p_t^E - \tau_t^E)^{(1-\sigma_C)} \right)^{\frac{1}{1-\sigma_C}} \quad (8)$$

and thus CPI inflation is different for households at home and abroad, as well as for households with high and low energy intensity.

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

Figure 10: The effects of subsidies/transfers on the expected real interest rates of households



Notes: Evolution of the implied expected real interest rate for households of different energy intensity at Home and in Foreign: $E_1 R_t \frac{p_t(a^C)P_t}{p_{t+1}(a^C)P_{t+1}}$. Crisis refers to the energy crisis without policy intervention. Transfers and Subsidies are as described in the main text.

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.

Figure 10 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 10). 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, Farhi, Nicolini, and Teles, 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, Kriwoluzky, Müller, and Seyrich (2023) for asymmetric productivity shocks.¹¹

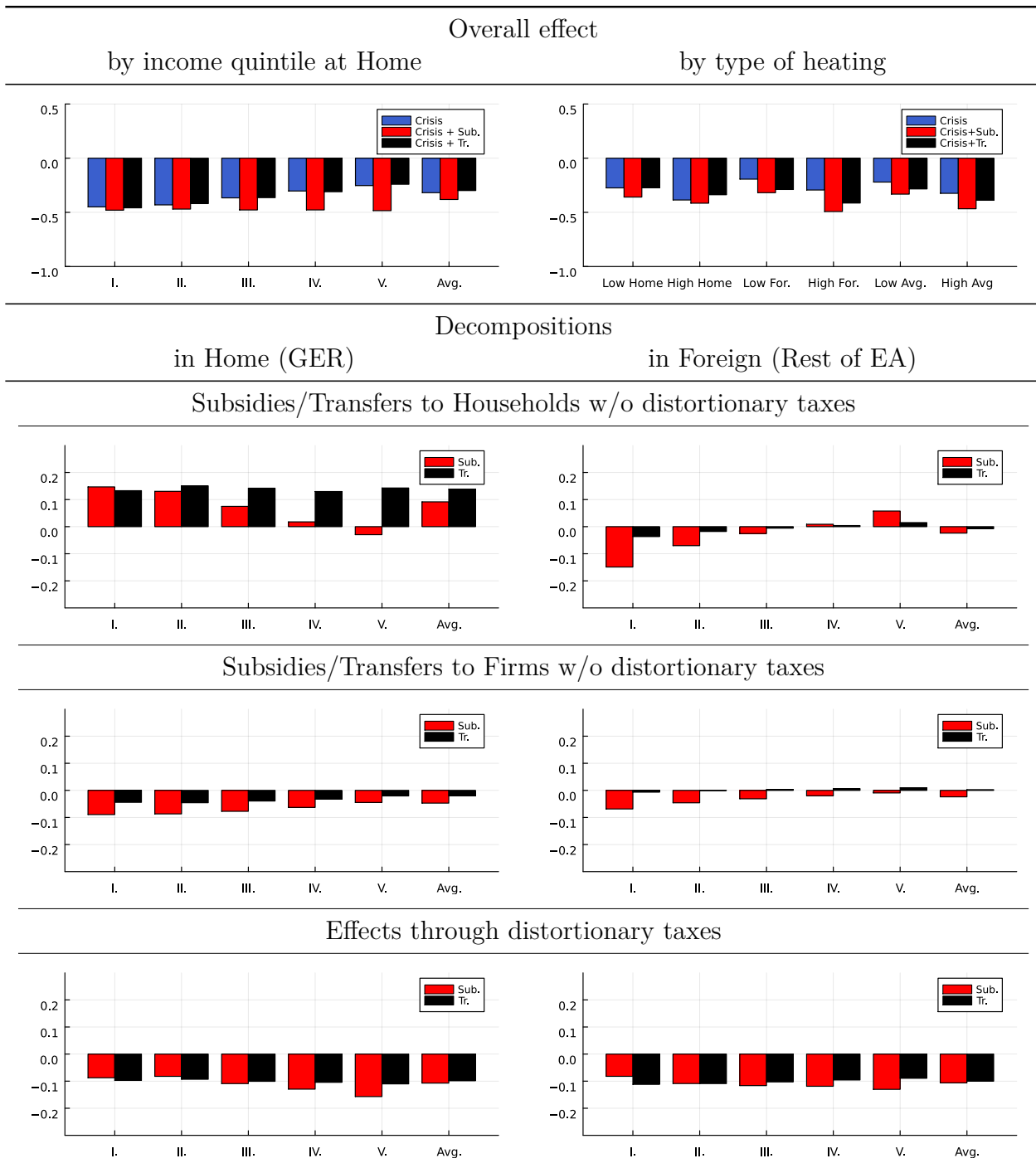
4.5 Welfare comparison

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 alternative fiscal policies. Figure 11 shows the results of this exercise. On average households in the Euro area would be willing to give up 0.26% of lifetime consumption to avoid going through the 6 expected quarters of energy scarcity.

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 next three rows only show the differential effects of the fiscal measures in a decomposition analogous to that of Figure 6. From an aggregate, euro area-wide perspective, both alternative fiscal policies produce additional welfare losses (see the bars for the high and low energy-intense households for the area-wide average, “Avg.”, in the top right-hand panel). The subsidy policy even produces additional welfare losses at Home, while the transfers improve welfare at Home (top right panel, first two groups

¹¹Subsidies 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 10). Again, this has aggregate demand feedback.

Figure 11: Welfare impact of energy subsidies



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.

of bars). The largest welfare gains from the transfer policy occur for households in highly energy-intensive dwellings (again two left-hand group of bars in the top right-hand panel). By splitting the effects along the decomposition exercise from the previous subsections (next three rows, compare Figure 6), Figure 11 also sheds light on the mechanisms that lead to welfare gains and losses. Transfers and subsidies to households increase domestic welfare (left panel, row 2). For subsidies, we find the same beggar-thy-neighbor welfare result as for production (right panel, row 2). Poor households gain the most in the Home economy and rich households gain the least; the effect in Foreign is mirrored. The income gradient can be rationalized by the implicit real interest rate movements that the subsidy generates, see Bayer, Kriwoluzky, Müller, and Seyrich (2023) for a detailed discussion of the re-distributive effects of monetary policy in a monetary union.

Overall, subsidies to households, if they could be financed through non-distortionary taxation, would eliminate 28% of the welfare loss from the energy crisis at Home (compare the red bar in “Avg.” in row 2, left panel, with the blue bar in “Avg.” in the top left panel). However, this is largely at the expense of poor foreign households (right panel, row 2). Transfers provide an even larger welfare boost at home (43% of the welfare loss from the crisis, compare black bar in “Avg.” in row 2, left panel, and blue bar in the top left panel), while barely affecting the welfare of the foreign economy. Subsidies to firms (third row, red bars) and, to a lesser extent, transfers to firms (third row, black bars) are a loss to everyone in the economy, both at Home and Foreign (except for the rich entrepreneurs who receive the transfers).

The last row of Figure 11 shows clearly where the negative welfare effects of the fiscal alternatives come from: the necessary increase in distortionary taxation needed to finance them. The subsidies and transfers have both a direct and an indirect negative effect on both economies through taxes. Directly, because the Home economy must raise taxes to finance the subsidies and transfers. The cost of the distortion is partly externalized through the effect that a fall in domestic output has on the terms of trade. This has second-round effects on taxes in Foreign (and Home), as the tax base shrinks and tax rates have to be raised further. As a result, there are significant welfare costs from the distortions necessary to finance the fiscal intervention.

5 Conclusion

In response to the European energy crisis of 2022/23, many countries have resorted to discretionary fiscal policies to limit the impact of the sharp rise in natural gas prices. In this paper, we use a two-country HANK model to evaluate these policies along a number

of dimensions. Not only do we look at their business cycle impact on macroeconomic aggregates, but also at how they play out along the income distribution in both countries. And, importantly, our two-country framework also allows us to study the spillovers of these policies: we assume that they are implemented in the domestic economy but may spill over 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 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 Hicks/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. Finally, such transfers do not prevent substitution effects when energy supply collapses.

Heterogeneity is a recurring theme in our analysis, with high marginal propensity to consume (MPC) playing an important role in the effectiveness of transfers. Understanding the diversity of exposure to energy shocks is crucial for understanding welfare implications and intertemporal decisions. Our study also shows that transfers to firms, whether in the form of subsidies or outright transfers, appear to yield limited benefits, suggesting that policymakers should reconsider such allocations in favor of more effective policy options.

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 HANK² model in Bayer, Kriwoluzky, Müller, and Seyrich (2023). 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. The assumption is made because we assume that the profits go to rich households outside the euro area, e.g. Norway, which reinvest their profits in the euro area.

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:

$$\tilde{h}_{it} = \begin{cases} \exp(\rho_h \log \tilde{h}_{it-1} + \epsilon_{it}^h) & \text{with probability } 1 - \zeta \text{ if } h_{it-1} \neq 0, \\ 1 & \text{with probability } \iota \text{ if } h_{it-1} = 0, \\ 0 & \text{else.} \end{cases} \quad (9)$$

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, $\int \tilde{h}_{it} di$, 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.¹²

With respect to leisure and consumption, households have Greenwood, Hercowitz, and Huffman (1988) (GHH) preferences and maximize the discounted sum of felicity:

$$E_0 \max_{\{c_{it}, n_{it}\}} \sum_{t=0}^{\infty} \beta^t u[c_{it} - G(h_{it}, n_{it})] \quad (10)$$

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:

$$c_{it} = \left((1 - a_{it}^C)^{\frac{1}{\sigma_C}} c_{it}^P{}^{\frac{\sigma_C-1}{\sigma_C}} + a_{it}^C{}^{\frac{1}{\sigma_C}} (E_{it}^C)^{\frac{\sigma_C-1}{\sigma_C}} \right)^{\frac{\sigma_C}{\sigma_C-1}}. \quad (11)$$

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 human capital quintile. With higher human 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

¹²This 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, Diaz-Giménez, and Ríos-Rull (1998). The entrepreneur state does not change the asset returns or investment opportunities available to households.

$\xi > 0$,

$$u(x_{it}) = \frac{1}{1 - \xi} x_{it}^{1 - \xi}, \quad (12)$$

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

$$y_{it} := (1 - \tau_t) w_t h_{it} n_{it}, \quad (13)$$

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

$$\frac{\partial G(h_{it}, n_{it})}{\partial n_{it}} = (1 - \tau_t) \frac{w_t}{p_t^c(a_{it}^C)} h_{it} = \frac{y_{it}}{n_{it}} / p_t^c(a_{it}^C). \quad (14)$$

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 , $\frac{\partial G(h_{it}, n_{it})}{\partial n_{it}} = (1 + \gamma) \frac{G(h_{it}, n_{it})}{n_{it}}$ with $\gamma > 0$, we can simplify the expression for the composite consumption good, x_{it} , making use of this first-order condition (14), and substitute $G(h_{it}, n_{it})$ out of the individual planning problem:

$$x_{it} = c_{it} - G(h_{it}, n_{it}) = c_{it} - \frac{1}{1 + \gamma} y_{it} / p_t^c(a_{it}^C). \quad (15)$$

When the Frisch elasticity of labor supply is constant and the tax schedule has the form (13), 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 $\int h_{it} di = 1$.¹³

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:

$$tr_{it}^E = (p_t^E - \bar{p}^E) \bar{E}_i^C, \quad (16)$$

where p_t^E are the price of energy in terms of the consumption good c , and \bar{E}_i^C 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:

$$y_{it} = \left[(1 - \tau_t) w_t / p_t^c(a_{it}^C) \right]^{\frac{1+\gamma}{\gamma}} h_{it} + \mathbb{I}_{h_{it} \neq 0} (1 - \tau_t) \Pi_t^U + \mathbb{I}_{h_{it} = 0} (1 - \tau_t) \Pi_t^{fi} + tr_{it} + tr_{it}^E. \quad (17)$$

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:

$$p_t^c(a_{it}^C) c_{it} + b_{it+1} + q_t k_{it+1} = y_{it} + b_{it} \frac{R(b_{it}, R_t^b)}{\pi_t^{core}} + (q_t + r_t) k_{it}, \quad k_{it+1} \geq 0, b_{it+1} \geq \underline{B} \quad (18)$$

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

¹³This 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.

obtain the budget constraint for the composite leisure-consumption good:

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

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:

$$R(b_{it}, R_t^b) = \begin{cases} R_t^b & \text{if } b_{it} \geq 0 \\ R_t^b + \bar{R} & \text{if } b_{it} < 0 \end{cases}. \quad (20)$$

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:

$$\begin{aligned} V_t^a(b, k, h, a^C) &= \max_{k', b'_a} u[x(b, b'_a, k, k', h, a^C)] + \beta \mathbb{E}_t \mathbb{W}_{t+1}(b'_a, k', h, a^C) \\ V_t^n(b, k, h, a^C) &= \max_{b'_n} u[x(b, b'_n, k, k, h, a^C)] + \beta \mathbb{E}_t \mathbb{W}_{t+1}(b'_n, k, h, a^C) \\ \mathbb{W}_{t+1}(b', k', h, a^C) &= \lambda V_{t+1}^a(b', k', h, a^C) + (1 - \lambda) V_{t+1}^n(b', k, h, a^C). \end{aligned} \quad (21)$$

Expectations about the continuation value are taken with respect to all stochastic processes

conditional on the current states, i.e., over both human capital, 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

$$N_t = \left(\int_0^{n_A} \hat{n}_{jt}^{\frac{\eta_W-1}{\eta_W}} dj \right)^{\frac{\eta_W}{\eta_W-1}}. \quad (22)$$

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

$$\hat{n}_{jt} = \left(\frac{W_{jt}}{W_t^{fi}} \right)^{-\eta_W} N_t \quad (23)$$

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

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_w^t \frac{W_t^{fi}}{P_t} N_t \left\{ \left(\frac{W_{jt}(\bar{\pi}_W)^t}{W_t^{fi}} - \frac{W_t}{W_t^{fi}} \right) \left(\frac{W_{jt}(\bar{\pi}_W)^t}{W_t^{fi}} \right)^{-\eta_W} \right\}. \quad (24)$$

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:

$$\log \left(\frac{\pi_t^W}{\bar{\pi}^W} \right) = \beta \mathbb{E}_t \log \left(\frac{\pi_{t+1}^W}{\bar{\pi}^W} \right) + \kappa_w \left(mc_t^w - \frac{1}{\mu^W} \right), \quad (25)$$

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

$$F_t = \left\{ (1 - (1-n)\omega_A)^{\frac{1}{\sigma}} A_t^{\frac{\sigma-1}{\sigma}} + ((1-n)\omega_A)^{\frac{1}{\sigma}} B_t^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{1-\sigma}}, \quad (26)$$

$$F_t^* = \left\{ (n\omega_B)^{\frac{1}{\sigma}} A_t^{\frac{\sigma-1}{\sigma}} + (1-n\omega_B)^{\frac{1}{\sigma}} B_t^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{1-\sigma}}. \quad (27)$$

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:

$$A_t = \left[\left(\frac{1}{n_A} \int_0^{n_A} A_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right) \right]^{\frac{\epsilon}{\epsilon-1}}, \quad B_t = \left[\left(\frac{1}{1-n_A} \int_{n_A}^1 B_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right) \right]^{\frac{\epsilon}{\epsilon-1}}, \quad (28)$$

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

$$P_t^*(j) = \mathcal{E}_t P_t(j), \quad (29)$$

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 (26) and (28). 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

$$Y_t^d(j) = \left(\frac{P_t(j)}{P_{At}} \right)^{-\epsilon} \left\{ \left(\frac{P_{At}}{P_t} \right)^\sigma (1 - (1-n)\omega_A)(C_t + I_t) + (1-n)\omega_B Q_t^{-\sigma} (I_t^* + C_t^*) + G_t \right\}, \quad (30)$$

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

where the price indices are given by

$$P_{At} = \left[\frac{1}{n} \int_0^{n_A} P_t(j)^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}}, \quad P_{Bt} = \left[\frac{1}{1-n} \int_{n_A}^1 P_t(j)^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}} \quad (32)$$

and

$$P_t = [(1 - (1-n)\omega_A)P_{At}^{1-\sigma} + ((1-n)\omega_A)P_{Bt}^{1-\sigma}]^{\frac{1}{1-\sigma}}, \quad (33)$$

$$P_t^* = [(n\omega_B)(P_{At}^*)^{1-\sigma} + (1 - n\omega_B)(P_{Bt}^*)^{1-\sigma}]^{\frac{1}{1-\sigma}}. \quad (34)$$

The real exchange rate is given by

$$Q_t = \frac{P_t \mathcal{E}_t}{P_t^*}. \quad (35)$$

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 (30) 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

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_Y^t (1 - \tau_t) \left(\frac{p_{jt}(\bar{\pi})^t}{P_t} - \frac{MC_t}{P_t} \right) Y_t^d(j) \quad (36)$$

with a time-constant discount factor.

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

$$\log \left(\frac{\pi_{At}}{\bar{\pi}} \right) = \beta \mathbb{E}_t \log \left(\frac{\pi_{At+1}}{\bar{\pi}} \right) + \kappa_Y \left(mc_t - \frac{1}{\mu^Y} \right) \quad (37)$$

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 $\Pi_t^E = np_t^E(E_t^C + E_t^Y) + p_t^{E,*}/Q_t(1 - n)(E_t^{C,*} + E_t^{Y,*})$ is the union wide energy profit.

A.2.4 Intermediate goods producers

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

$$Y_t = \left((1 - a_P)^{\frac{1}{\sigma_P}} Y_t^P \frac{\sigma_P - 1}{\sigma_P} + a_P \frac{1}{\sigma_P} (E_t^Y)^{\frac{\sigma_P - 1}{\sigma_P}} \right)^{\frac{\sigma_P}{\sigma_P - 1}}, \text{ where } Y_t^P = (u_t K_t^s)^\alpha N_t^{1-\alpha}. \quad (38)$$

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,

$$mc_t Y_t - w_t^{fi} N_t - [r_t^F + q_t \delta(u_t)] K_t - (p_t^E - \tau_t^E) E_t^Y, \quad (39)$$

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:

$$MPK_t = p_{At} mc_t (1 - a_P) \left(\frac{1}{\sigma_P}\right) \alpha \left(\frac{K_t}{N_t}\right)^{(\alpha-1)} \left(\frac{Y_t}{Y_t^P}\right)^{\left(\frac{1}{\sigma_P}\right)}, \quad (40)$$

$$r_t = 1 + MPK_t u_t - q_t \delta(u_t), \quad (41)$$

$$w_t^{fi} = p_{At} mc_t (1 - a_P) \left(\frac{1}{\sigma_P}\right) (1 - \alpha) \left(\frac{u_t K_t}{N_t}\right)^\alpha \left(\frac{Y_t}{Y_t^P}\right)^{\left(\frac{1}{\sigma_P}\right)}, \quad (42)$$

$$p_t^E - \tau_t^E = p_{At} mc_t a_P \left(\frac{1}{\sigma_P}\right) \left(\frac{Y_t}{E_t^Y}\right)^{\left(\frac{1}{\sigma_P}\right)}. \quad (43)$$

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

$$MPK_t = q_t [\delta_1 + \delta_2(u_t - 1)] \quad (44)$$

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 maximize¹⁴

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t I_t \left\{ q_t \left[1 - \frac{\phi}{2} \left(\log \frac{I_t}{I_{t-1}} \right)^2 \right] - 1 \right\}. \quad (45)$$

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

$$q_t \left[1 - \phi \log \frac{I_t}{I_{t-1}} \right] = 1 - \beta \mathbb{E}_t \left[q_{t+1} \psi \log \left(\frac{I_{t+1}}{I_t} \right) \right], \quad (46)$$

and each capital goods producer will adjust its production until (46) is fulfilled.

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

$$K_t - (1 - \delta(u_t))K_{t-1} = \left[1 - \frac{\phi}{2} \left(\log \frac{I_t}{I_{t-1}} \right)^2 \right] I_t \quad (47)$$

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.

¹⁴As 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.

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:

$$\frac{R_{t+1}^b}{\bar{R}^b} = \left(\frac{R_t^b}{\bar{R}^b} \right)^{\rho_R} \left(\frac{n\pi_{At} + (1-n)(\pi_{Bt})}{\bar{\pi}} \right)^{(1-\rho_R)\theta_\pi} \left(n \frac{Y_t}{Y_{t-1}} + (1-n) \frac{Y_t^*}{Y_{t-1}^*} \right)^{(1-\rho_R)\theta_Y} \epsilon_t^R. \quad (48)$$

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_t^R is an i.i.d. monetary policy shock.

A.3.2 Fiscal Policy

The budget constraint of the national fiscal policy reads

$$G_t + Tr_t + TP_t = B_{t+1} + T_t - \frac{R_t^b}{\pi_t^{CPI}} B_t. \quad (49)$$

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

$$T_t = \tau_t(w_t N_t + \mathbb{I}_{h_{it}=0} \Pi_t^{fi} + \mathbb{I}_{h_{it} \neq 0} \Pi_t^U). \quad (50)$$

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

$$\frac{\tau_t}{\bar{\tau}} = \left(\frac{B_{t+1}}{\bar{B}} \right)^{\gamma_B^{\bar{\tau}}}, \quad (51)$$

where $\gamma_B^{\bar{\tau}}$ 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:

$$tr_{it} = \max\{0, a_1 \bar{y} - a_2(1 - \tau_t)w_t h_{it} n_{it}\}, \quad (52)$$

where \bar{y} is the median income and $0 \leq a_1, a_2 \leq 1$. Thus, transfers decrease in individual income with a transfer withdrawal rate of a_2 and no transfers are paid to households whose net labor income $(1 - \tau_t)w_t h_{it} n_{it} \geq \frac{a_1}{a_2} \bar{y}$. Total transfer payments of the government in Country A are then

$$Tr_t = \mathbb{E}_t tr_{it}, \quad (53)$$

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:

$$tr_{it}^E = (p_t^E - \bar{p}^E) \bar{E}_i^C \quad (54)$$

where \bar{p}^E is the steady state price of energy, \bar{E}_i^C 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:

$$TP_t = T_t^{E,C} + T_t^{E,Y} + Tr_t^{E,C} + Tr_t^{E,F}, \quad (55)$$

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:

$$E_t = E_t^C + E_t^Y + E_t^{C,*} + E_t^{Y,*}. \quad (56)$$

The national labor market in Country A clears at the competitive wage given in (42). A symmetric labor market clearing condition is in place in Country B. The bond markets clear whenever the following equations hold:

$$\begin{aligned}
B_{t+1} &= B^d(p_t^E, Tr_t^{E,C}, Tr_t^{E,Y}, R_t^b, r_t, q_t, \Pi_t^{fi}, \Pi_t^U, w_t, \pi_t, \tau_t, \Theta_t, \Theta_t^*, \mathbb{W}_{t+1}) - \frac{B_{Bt+1}}{Q_t} \\
&:= \mathbb{E}_t[\lambda \mathbb{B}_{a,t} + (1 - \lambda) \mathbb{B}_{n,t}] - \frac{B_{Bt+1}}{Q_t}, \\
B_{t+1}^* &= B^{d,*}(p_t^{E,*}, R_t^b, r_t^*, q_t^*, \Pi_t^{fi,*}, \Pi_t^{U,*}, w_t^*, \pi_t^*, \tau_t^*, \Theta_t, \Theta_t^*, \mathbb{W}_{t+1}^*) + \frac{n_A}{1 - n_A} B_{Bt+1} \\
&:= \mathbb{E}_t[\lambda \mathbb{B}_{a,t}^* + (1 - \lambda) \mathbb{B}_{n,t}^*] + \frac{n_A}{1 - n_A} B_{Bt+1}, \\
B_{t+1}^d + B_{t+1}^{d,*} &= B_{t+1} + B_{t+1}^*
\end{aligned} \tag{57}$$

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) $(p_t^E, Tr_t^{E,C}, Tr_t^{E,Y}, R_t^b, r_t, q_t, \Pi_t^{fi}, \Pi_t^U, w_t, \pi_t^{CPI}, \tau_t)$.¹⁵ 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:

$$\begin{aligned}
(1 - \tau_t)(w_t N_t + \Pi_t^U + \Pi_t^{fi}) + (P_{At} Y_t - w_t N_t - (\Pi_t^U + \Pi_t^{fi})) + Tr_t + Tr_t^E + B_t R_t^b / \pi_t \\
+ B_{Bt} R_t^b / (\pi_t^* Q_t) = C_t + I_t + \bar{R} B D_t + B_{t+1} + B_{Bt+1} / Q_t,
\end{aligned} \tag{58}$$

where $B D_t$ 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:

$$\begin{aligned}
K_{t+1} &= K^d(p_t^E, Tr_t^{E,C}, Tr_t^{E,Y}, R_t^b, r_t, q_t, \Pi_t^{fi}, \Pi_t^U, w_t, \pi_t^{CPI}, \tau_t, \Theta_t, \Theta_t^*, \mathbb{W}_{t+1}) \\
&:= \mathbb{E}_t[\lambda(\mathbb{K}_t) + (1 - \lambda)(k)]
\end{aligned} \tag{59}$$

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

¹⁵The 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:

$$\begin{aligned}
Y_t &= ((1 - (1 - n)\omega_A) \left(\frac{P_{At}}{P_t}\right)^{-\sigma} [C_t + I_t + BD_t\bar{R}] \\
&\quad + (1 - n_A)\omega_B Q_t^{-\sigma} [C_t^* + I_t^* + BD_t^*\bar{R}]) + G_t \\
Y_t^* &= n\omega_A Q_t^\sigma \left(\frac{P_{Bt}^*}{P_t^*}\right)^{-\sigma} [C_t + I_t + BD_t\bar{R}] \\
&\quad + (1 - n_A\omega_B) [C_t^* + I_t^* + BD_t^*\bar{R}] + G_t^*.
\end{aligned} \tag{60}$$

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 $\{p_t^E, \tau_t^E, T r_t^{E,C}, T r_t^{E,Y}, w_t, w_t^{fi}, \Pi_t^U, \Pi_t^{fi}, q_t, r_t, R_t^b, \pi_t^{CPI}, \pi_{At}, \pi_t^W, \frac{P_{At}}{P_t}, \tau_t, Q_t\}$ 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.

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

We solve the model by using the perturbation method in Bayer, Born, and Luetticke (2020).

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 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 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.

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 (2020)
δ_0	Depreciation rate	0.018	Wealth Gini = 0.61
δ_1	Depr. rate increase	5.0	Bayer, Born, and Luetticke (2020)
Households			
ξ	Risk aversion	4	Kaplan and Violante (2014)
γ	Inv. Frisch elast.	2	Chetty, Guren, Manoli, and Weber (2011)
Open economy			
σ	Trade-price elasticity	0.66	Standard value
ω	Home bias	0.66	Standard value
n	Country size	1/3	Size of GER in European gas market
Government			
$\bar{\tau}$	Tax rate	0.3	Standard value
\bar{R}^b	Gross interest rate	1.00	zero interest-growth difference
ρ_R	Pers. in Taylor rule	0.85	standard value
θ_π	Reaction to Infl.	1.5	standard value
θ_Y	Reaction to Output	0	ECB mandate

Table 5: Calibrated Model v Data

			Model		Data	
			F	H	ITA	GER
Steady state (targeted)	Assets	Debt (% of output)	132	71	132	71
		Capital-Output-Ratio	3.3	3.2	3.3	3.2
	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: 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 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 cyclical utility 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, Guren, Manoli, and Weber (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 the smoothing parameter to 0.85. The steady-state inflation is zero. We assume $n = 1/3$. The home bias parameter, ω , and the terms of trade elasticity, σ are both set to 0.66—again standard values in the literature.

For the sake of completeness, Table 6 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 7.

Table 7: Expenditure on gas (heating and hot water)

Expenditure on gas (including hot water) in EUR (HH with gas heating)				
Income quintiles	Expenditure quartiles			
	Mean	p25	p50	p75
0-20%	212	102	180	282
20-40%	254	129	218	336
40-60%	294	162	255	381
60-80%	310	177	270	393
80-100%	322	186	279	405
Total	281	150	240	363

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