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To Cap or Not to Cap? Energy Crises in a Currency Union

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Abstract

During the energy crisis in 2022 some Euro Area countries introduced price caps on energy, while others did not, leading to about 30 percentage points higher energy inflation in uncapped countries. This paper investigates the trade-offs policymakers face with energy price caps in a two-country currency union model with shared energy supply. The cooperative, optimal outcome is for neither country to impose a price cap, since the cap is a costly market distortion. However, capping allows a country to avoid a crisis at the cost of negative spillovers on the uncapped country, characterized by high inflation and lower output. The quantitative model with non-homothetic preferences and substitutability of energy sources shows that the cost of the price cap exceeds the cost of such spillovers, explaining why some countries capped prices while others did not. Moreover, I show that the spillovers from price caps contributed to about 10 (0.5) percentage points of energy (headline) inflation in the uncapped Euro Area countries in 2022. Targeted transfers, an alternative policy to the price cap, is a cheaper and more effective way to boost consumption of the poor without creating divergence within the union.

Keywords: Energy crisis, energy price cap, inflation, international spillovers
JEL codes: E31, E63, F45, Q41

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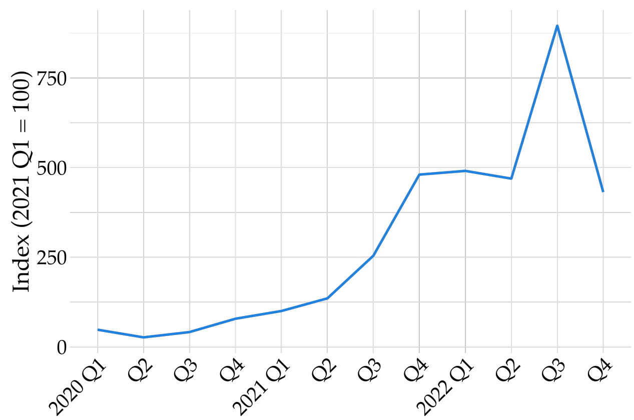
1 Introduction

The Euro Area, and Europe as a whole, experienced a large energy crisis in 2022. Energy prices began rising in mid-2021 and soared in 2022 after the Russian invasion of Ukraine, as shown in Figure 1. The increase in energy prices triggered energy price cap decisions from many, but not all governments. This paper investigates the effects of an energy price cap in a subset of countries in a currency union during an energy crisis, focusing on international spillovers and policy trade-offs of the price cap.

Figure 1: Natural gas price in Europe



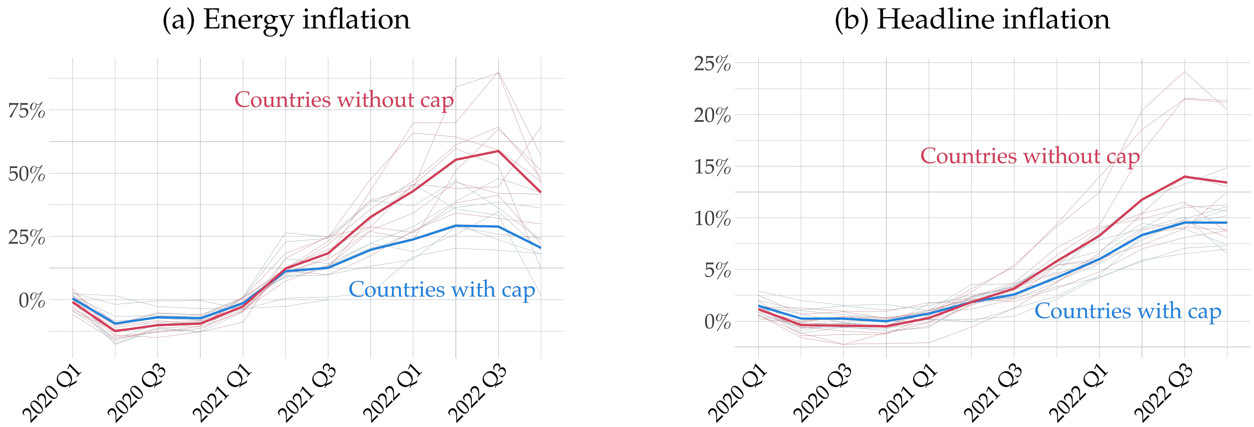
Notes: The price index of the Title Transfer Facility (TTF) gas in the Netherlands. Most price setters use this price as the reference price and gas contracts are indexed to this price, the TTF price index is the standard gas price benchmark for Europe (Rogge, 2024).[2] For longer time series, see Figure 16 in Appendix C. Data source: IMF Data (2024).

Inflation rates in uncapped countries were considerably higher than in capped countries, as shown in Figure 2. In 2022, France and Germany, among others, decided to impose an energy price cap, whereas other countries including The Netherlands and Italy did not. The energy inflation in countries without an energy price cap was about 30 percentage points higher than in the capped countries in 2022Q3, and for headline inflation the difference was about 5 percentage points. Figure 17 in Appendix C shows that the divergence of both energy and headline inflation in 2022 was at an unprecedented magnitude since the start of the Euro Area.

The paper uses a two-country currency union model with a shared energy supply to investigate the trade-offs of an energy price cap. In the absence of price caps, an adverse energy supply shock not only reduces energy consumption, but also acts as a cost-push shock to an economy: a decline in the exogenous supply of energy depresses output while increasing inflation. The assumption of an exogenous energy supply reflects the high dependency of Europe on Russian gas before 2022 (Pescatori & Steurmer, 2022; Moll

[2]Moreover, gas prices drive wholesale electricity prices as the highest marginal cost of energy production, so they are a good indicator for energy/electricity price movements (Pescatori & Steurmer, 2022).

Figure 2: Inflation in the Euro Area 2020 – 2022



Notes: Annualized energy and headline inflation rates in the Euro Area. Source: Eurostat. Countries with an energy price cap in 2022 are Austria, Estonia, France, Germany, Luxembourg, Malta, Portugal, Slovakia, Slovenia, Spain. Countries without are Belgium, Cyprus, Finland, Greece, Ireland, Italy, Latvia, Lithuania, The Netherlands. Bold lines are weighted averages for each group.

et al., 2023). Since the shock is essentially a relative price shock, it is a standard result in New Keynesian frameworks that it acts like a cost-push shock.

First, I find that capping the energy price allows a country to avoid the crisis while imposing negative spillovers on the uncapped country, causing divergence within the currency union. I define the energy price cap as a policy that fixes energy price. The government then pays the difference between the actual price of energy and its retail price. This setup is somewhat stylized, because in reality most governments imposed a price cap that was less strict. However, this assumption is not overly restrictive, as the strictness of the price cap shifts the overall level of responses but does not alter the underlying mechanisms.

With the price cap, a country does not suffer from the energy supply shock: output does not suffer a fall and inflation does not soar. Moreover, households can maintain their energy consumption. On the contrary, the uncapped country experiences a larger cost-push shock compared to the case of no price caps in the entire union, and also a larger decline in energy consumption. A crucial assumption behind these spillovers is the shared energy supply between the capped and uncapped countries, as is the case in Europe for Russian gas. During the adverse energy supply shock the capped country's energy consumption does not decrease because the price does not change. Then, the energy supply available in the uncapped country declines even more, which causes an even higher (energy) inflation and a lower welfare.

Second, the paper demonstrates that for policymakers facing the decision – to cap or not to cap – there is a trade-off between the cost of the price cap and the cost of the spillovers. I analyze the welfare implications of energy price caps in the two-country model, in which each country faces two policy decisions at the onset of an energy supply shock. The optimal, cooperative outcome occurs when both countries refrain from imposing a price cap. This outcome avoids market distortions, as energy prices reflect true scarcity during the crisis. However, because of the lack of cooperation between countries within the union, each country has an incentive to deviate from the cooperative strategy: if one country does not impose an energy price cap, the other country has an incentive to impose one to avoid the energy crisis as described above.

If one country imposes a price cap, should the other country follow suit? On one hand, imposing the price cap leads to inefficiencies and high costs, as artificially low prices in both countries encourage excessive energy consumption despite scarcity. On the other hand, not imposing the cap means bearing the negative spillovers from the first country's cap, which is also costly. In the quantitative model the cost of imposing the price cap are larger than the cost of these negative spillovers. Hence, the outcome of a static decision game is a price cap in one of the two countries, even though the cooperative strategy is for neither of the countries to impose the cap. This result explains why in reality some countries capped the energy price while others did not.

The key assumptions to this result are the type of household preferences and the substitutability of the energy source that is shared between the countries: they both affect the magnitude of the negative spillovers experienced by the uncapped country. The non-homothetic preferences are as in Boppart (2014): households spend a higher share of their income on energy when their income is low, which means they dislike reducing their energy consumption. These type of preferences are common in literature handling necessity goods like energy and food (Blanco & Diz, 2021; Olivi et al., 2023). Non-homothetic preferences amplify the negative spillovers, which results in costs from spillovers exceeding the costs of implementing the price cap depending on the substitutability of the energy source.

Endogenous energy production dampens the spillovers and explains why a country might prefer to bear the negative spillovers from the price cap as an uncapped country rather than imposing a price cap themselves. During the European energy crisis in 2022, the elasticity of substitution between gas, subjected to the exogenous supply shock, and non-gas energy was crucial, since the total energy consumption per capita did not decrease (Energy Institute, 2024). In the quantitative model, I estimate this elasticity of substitution and find that with the estimated parameters the cost of bearing the spillovers is smaller than the cost of implementing a price cap.

Third, I provide counterfactual exercises of price cap policies in Europe in 2022. I perform a historical shock decomposition of the energy and headline inflation rates in which the energy price cap is one of the shocks. I find that the energy price cap contributed to 10 percentage points of energy inflation and 0.5 percentage points to headline inflation in the uncapped countries in 2022. Moreover, the inflation rates in the capped countries would not have been much higher without the energy price cap, reinforcing the model result that the cooperative, optimal outcome involves no price caps.

Last, I introduce a version of the model with hand-to-mouth households to compare the energy price cap to targeted transfers as an alternative policy measure. Shielding low-income households from rising energy costs was a key priority for many governments (Sgaravatti et al., 2023). I show that targeted transfers are a cheaper and more effective way to boost the consumption of the poor during an energy crisis. Moreover, because targeted transfers do not distort the energy market in the union, they do not cause large spillovers nor divergence within the union.

The contributions of this paper are both general, on international policy coordination, and specific to the European energy crisis in 2022: first, I show that in a decision game of two countries and two cap options, the degree of non-homotheticity and the substitutability of the shared energy source determines the magnitude of the spillovers, and hence the incentives for policymakers to implement the price cap. Second, I quantify the model by estimating it with European data. I confirm the general result that the negative spillovers from the capped to uncapped country are much larger than the benefits the capped country experiences by implementing the cap.

Related Literature. This paper contributes to two strands of the literature. First, it builds onto the vast literature on monetary and fiscal policy in a currency union. Beetsma et al. (2001), Beetsma and Jensen (2005), Galí and Monacelli (2008), Ferrero (2009), and Hjortsoe (2016) are pioneers of this strand of literature and explore the optimal joint conduct of monetary and fiscal policy as stabilization tools under asymmetric shocks. Other authors like Anderson (2007) and Keen and Konrad (2013) focus on strategic interactions of regulatory policies, like taxes, trade policies, and industrial regulation. Later, papers on this topic consider long-term coordination, with the sovereign debt crises in mind (Trichet, 2013; Chang, 2015). In this paper, I introduce a new dimension of integration: a shared energy supply. I analyze the international coordination in energy price cap policies during a union-wide energy shock. The analysis focuses on the determinants of the magnitude of the cap's spillovers, and finds that fiscal coordination between countries is favorable. However, I show that countries do not always have the incentives to cooperate.

Second, this paper contributes to the rapidly expanding literature on energy crises. This paper is closest to Bayer et al. (2023), who also evaluate different fiscal responses to an energy shock in a currency union. They compare two types of energy price caps and the trade-off between stabilization of the domestic economy and costly spillovers abroad. Auclert et al. (2023) and Chan et al. (2024) study the macroeconomic effects of an energy price shock and look at the coordination of fiscal policies and optimal monetary policy, respectively. Moreover, Erceg et al. (2024) and Glocker and Wegmüller (2024) study the effectiveness of fiscal policies, including energy subsidies, in stabilizing inflation. This paper analyzes the trade-offs and the spillovers of the energy price cap in an international setting. I approach the topic with a novel angle: I adopt a tractable, game-theoretic approach to determine the cooperative energy price cap policy as well as the equilibrium that arises when countries have their own incentives.

The rest of this paper is organized as follows: Section 2 outlines the model with non-homothetic preferences, the price cap setup, and the model calibration. Section 3 discusses the results of the baseline model, including the magnitude of the spillovers. I also analyze the trade-offs between headline and core-inflation targeting. Then, in Section 4 I estimate the substitutability between the shared energy source (gas) and domestically produced energy (non-gas) and show that the costs of implementing a price cap are larger than the costs of bearing the negative spillovers. I also quantify the contribution of the energy price cap to (energy) inflation in 2022. Lastly, in Section 5 I investigate targeted transfers by adding hand-to-mouth households to the model. Section 6 concludes.

2 Model

The model considers a currency union with two countries, Home and Foreign $\{H, F\}$, and incomplete financial markets. The relative size of the Home country is $\Theta \in (0, 1)$ and hence of the Foreign is $1 - \Theta$. Time is discrete and indexed by $t \in \{0, \dots\}$. Both countries are inhabited by households, firms and a fiscal authority. There is one central bank setting monetary policy for the entire currency union.

Energy supply to the union is exogenous which follows from the high dependency of Europe on imported energy (Eurostat, 2023a). The energy market clears with a single price for the whole union reflecting the well-integrated energy market in Europe (Pescatori & Steurmer, 2022). When there is an energy price cap, the government pays for the difference between the actual price of energy and the retail price of energy. This setup for the energy market is similar to the one introduced by Bayer et al. (2023).

Households consume energy as part of their consumption basket. Households have non-homothetic preferences for energy, which ensure that they consume a higher expenditure share of energy when their income decreases. Firms in both countries produce tradable goods under monopolistic competition, using energy and labor as inputs. The law of one price holds for those goods and there is home bias.

Since the Home and Foreign country are symmetric, I explain only the Home-side of the union, unless otherwise stated. Foreign variables are denoted with an *. Appendix A provides a more detailed description of the model, including a list of relevant equilibrium conditions and the steady state.

This model includes non-homothetic preferences but not the substitutability of different energy sources. This version of the model is useful for understanding the core intuition and mechanics before introducing the substitutability of energy sources. In Section 4 I complete the model by adding domestic energy production and allowing for substitutability of the exogenous source of energy (gas) and domestically produced energy (non-gas).

2.1 Households

2.1.1 Preferences

Households derive utility from two types of goods: energy goods, E_t^h, and non-energy, other goods, C_{Ot}. Preferences of the households are non-homothetic as introduced by Boppart (2014). In this specification of preferences, the total nominal expenditure of the household, defined as $exp_t = P_{Et}E_t^h + P_{Ot}C_{Ot}$, matters for the share of expenditure spent on energy and the other goods. P_{Et} and P_{Ot} are prices for energy and other goods respectively. The indirect utility function of the representative household with non-homothetic preferences is:[3]

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{\varepsilon_1} \left[\left(\frac{exp_t}{P_{Ot}} \right)^{\varepsilon_1} - 1 \right] - \frac{\alpha_E}{\varepsilon_2} \left[\left(\frac{P_{Et}}{P_{Ot}} \right)^{\varepsilon_2} - 1 \right] \right\} \tag{1}$$

where $\alpha_E > 0$ is the share of energy consumption in the steady state and β is the discount factor. ε_1 governs the expenditure elasticity of demand: when $\varepsilon_1 > 0$, the expenditure elasticity of demand is strictly smaller than unity for energy and larger than unity for other goods. So, when total nominal expenditure, or total income available for consumption, decreases, the demand for energy decreases less than proportionally with income and the demand for other goods decreases more than proportionally. ε_2 controls the elasticity of substitution between energy and other goods. In steady state, the elasticity of substitution between energy and other goods is $\bar{\sigma} = 1 - \varepsilon_2 - \frac{\alpha_E}{1-\alpha_E}(\varepsilon_2 - \varepsilon_1)$.[4][5]

[3]An indirect utility function $v(p, exp)$ expresses the household's maximal attainable utility when faced with vector p of goods prices and an amount of expenditure exp. In general, a direct utility counterpart of this indirect utility function does not exist.

[4]See Lemma 3 in Boppart (2014) for the derivation and Appendix A.4 for the steady state.

[5]Another commonly used non-homothetic preference specification is the Stone-Geary preferences, with which the consumer derives utility from consumption that exceeds the subsistence level. Under Stone-Geary preferences the expenditure share of energy does not increase after a price increase. Since in practice the household energy expenditure share increased in Europe in 2022, I chose to use the preferences from Boppart (2014) (OECD, 2023; European Commission, 2024).

Relative demand between energy and other goods. The relative demand for energy and other goods obtained using Roy's identity reads as:[6]

$$C_{Ot} = \frac{1-\alpha_E \varpi_t}{\alpha_E \varpi_t} \frac{P_{Et}}{P_{Ot}} E_t^h \tag{2}$$

where

$$\varpi_t = \left(\frac{P_{Ot}}{exp_t}\right)^{\varepsilon_1} \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2} \tag{3}$$

is the energy expenditure share wedge. This wedge increases when the total expenditure decreases or when the price of energy increases, both relative to the price of the other goods. Consequently, the consumption demand is non-homothetic in income since the share of expenditure on energy, $\alpha_E \varpi_t$, increases when the household becomes poorer. When $\varepsilon_1 = \varepsilon_2 = 0$, Eq. (2) simplifies to $C_{Ot} = \frac{1-\alpha_E}{\alpha_E} \frac{P_{Et}}{P_{Ot}} E_t^h$, which is the standard Cobb-Douglas result. In this case, the expenditure elasticity for both types of goods are equal to unity. Section 3.2.4 discusses the case under preferences with Constant Elasticity of Substitution (CES).

Relative demand between Home and Foreign goods. The consumption of non-energy goods is a composite index, bundling consumption of Home-produced goods C_{Ht} and Foreign-produced goods C_{Ft}:

$$C_{Ot} = \left[(1-\alpha_I)^{1/\gamma} (C_{Ht})^{(\gamma-1)/\gamma} + (\alpha_I)^{1/\gamma} (C_{Ft})^{(\gamma-1)/\gamma}\right]^{\gamma/(\gamma-1)} \tag{4}$$

where $\alpha_I \in (0,1)$ is the share of imported goods in the consumption basket and γ is the elasticity of substitution between Home and Foreign goods. Since the preferences between Home and Foreign-produced goods are homothetic, the intratemporal consumption demand between Home and Foreign goods are standard:

$$\frac{C_{Ht}}{C_{Ft}} = \frac{1-\alpha_I}{\alpha_I} \left(\frac{P_{Ht}}{P_{Ft}}\right)^{-\gamma} \tag{5}$$

where P_{Ht} and P_{Ft} are the price indices of Home and Foreign goods respectively. The aggregate expenditure on other consumption is then:

$$\int_0^1 P_{Ht}(i) C_{Ht}(i) di + \int_0^1 P_{Ft}(i) C_{Ft}(i) di = P_{Ht} C_{Ht} + P_{Ft} C_{Ft} = P_{Ot} C_{Ot} \tag{6}$$

[6] See Appendix A for a detailed derivation of the first order conditions.

where P_{Ot} is the aggregate price index for non-energy goods:

$$P_{Ot} = \left[(1-\alpha_I)P_{Ht}^{1-\gamma} + \alpha_I P_{Ft}^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{7}$$

2.1.2 Intertemporal choices

The representative household makes intertemporal choices since it can trade in one-period bonds B_t with gross interest rate R_t. The household's income sources are from labor N_t for a nominal wage W_t per unit and from profits of domestic firms, D_t, and energy sellers, D_t^E.[7] The nominal budget constraint of the households is the following:

$$exp_t = P_{Et}E_t^h + P_{Ot}C_{Ot} = W_tN_t + D_t + D_t^E + R_{t-1}B_{t-1}^h - B_t^h - HC_t - T_t \tag{8}$$

where $HC_t = \frac{\tilde{\nu}}{2}(B_t^h - \bar{B}^h)^2$ are the portfolio adjustment costs of the household and T_t lump-sum taxes. The government uses those taxes to finance energy price caps. When the household maximizes their utility function (1) subject to the constraint, the Euler equation becomes:

$$\left(\frac{\mathbb{E}_t\left[exp_{t+1}\right]}{exp_t}\right)^{1-\varepsilon_1} = \beta\frac{R_t}{1+P_t\tilde{\nu}(b_t^h - \bar{b}^h)}\mathbb{E}_t\left[\left(\frac{1}{\Pi_{O,t+1}}\right)^{\varepsilon_1}\right] \tag{9}$$

where $b_t^h = \frac{B_t^h}{P_t}$ denotes real bond holdings and $\Pi_{Ot} = \frac{P_{Ot}}{P_{O,t-1}}$ gross inflation of the other goods. P_t is the aggregate price index, explained below. Households supply labor inelastically, such that $N_t = \bar{N}\ \forall t$. In Section 3.2.4, I briefly discuss the results under elastic labor supply.

2.2 Firms

Final good producer. The final good firms produce the final consumption good, Y_t, using intermediate goods, $Y_t(i)$, according to:

$$Y_t = \left[\int_0^1 Y_t(i)^{(1-\epsilon)/\epsilon}di\right]^{\epsilon/(1-\epsilon)} \tag{10}$$

where $Y_t(i)$ is the output of the intermediate firm i and ϵ the elasticity of substitution between different varieties of the intermediate good. The firms produce in a competitive market and maximize profits given by $P_tY_t - \int_0^1 P_t(i)Y_t(i)di$. The first-order condition to the maximization problem gives the demand function of the intermediate good i:

$$Y_t(i) = \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\epsilon} Y_t \tag{11}$$

[7] As in Bayer et al. (2023), households earn profits determined by deviations from steady state when selling energy.

and the price of the final good Y_t:

$$P_{Ht} = \left[\int_0^1 P_{Ht}(i)^{-(1-\epsilon)}\right]^{1-\epsilon} \tag{12}$$

where $P_{Ht}(i)$ is the price of the intermediate good i.

Intermediate good producers. The country has a continuum of $i \in [0, 1]$ firms who produce the (non-energy) other goods under monopolistic competition. They use both labor N_t and energy E_t^f as production inputs in their Constant Elasticity of Substitution (CES) production function:

$$Y_t(i) = A_t \left[\left(\alpha^f\right)^{1/\theta^f} \left(E_t^f(i)\right)^{(\theta^f-1)/\theta^f} + \left(1-\alpha^f\right)^{1/\theta^f} \left(N_t(i)\right)^{(\theta^f-1)/\theta^f}\right]^{\theta^f/(\theta^f-1)} \tag{13}$$

where α^f is the share of energy used in production and θ^f is the elasticity of substitution between input factors energy and labor. A_t is the total factor productivity which follows an AR(1) shock process. The firms face adjustment costs à la Rotemberg (1982), so their profit maximization problem is:[8]

$$\max_{P_{Ht}(i), N_t(i)} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta \left[\frac{P_{Ht}(i)}{P_{Ht}} Y_t(i) - \frac{W_t}{P_{Ht}} N_t(i) - P_{Et} E_t^f(i) - Y_t FC_t\right] \tag{14}$$

subject to

$$\text{demand curve} \quad Y_t(i) = \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\epsilon} Y_t \tag{15}$$

$$\text{price adjustment costs} \quad FC_t(i) = \frac{\xi}{2}\left(\frac{P_{Ht}(i)}{P_{H,t-1}(i)} - 1\right)^2 \tag{16}$$

where ξ governs the level of price adjustment costs.

The first-order condition with respect to $P_{Ht}(i)$ leads to the standard New Keynesian Philips Curve (NKPC). See Appendix A for detailed derivations. As in Aoki (2001), the relative price of energy shows up as a shift of the NKPC, like a cost-push shock, when re-writing the NKPC in terms of headline inflation.

Since all intermediate goods are identical, $P_{Ht}(i) = P_{Ht}$ and $N_t(i) = N_t$. Aggregate firm's profits reads:

$$D_t = P_{Ht} Y_t \left(1 - FC_t\right) - W_t N_t - P_{Et} E_t^f \tag{17}$$

[8]Since energy is an exogenous supplied good, Rotemberg (1982) and Calvo (1983) pricing are identical up to first order, unlike conventional two-sector models.

2.3 Monetary policy

The monetary authority targets the headline inflation of the two countries, Home and Foreign, with a Taylor rule set accordingly to their respective size. So, the Taylor rule for the nominal interest rate R_t is:

$$R_t = \frac{1}{\beta}\left(\frac{\Pi_t^W}{\bar{\Pi}^W}\right)^{\phi_\pi} \exp(\nu_t) \tag{18}$$

where superscript W indicates a union-wide variable, defined as:

$$\Pi_t^W = (\Pi_t)^{\Theta}(\Pi_t^*)^{1-\Theta} \tag{19}$$

The monetary authority only targets inflation, and no output gap, reflecting the European Central Bank's price stability mandate. The inflation that the central bank targets is:

$$\Pi_t = (\Pi_{Et})^{\alpha_E}(\Pi_{Ot})^{1-\alpha_E} \tag{20}$$

which corresponds to the Consumer Price Index (CPI), or headline inflation in common literature and data sources. The price level follows from the inflation term $\Pi_t = P_t/P_{t-1}$.[9]

2.4 Fiscal policy: The energy price cap

If the Home country introduces a cap on energy prices, the fiscal policy and the government budget constraint of the country become relevant. With an energy price cap in the Home country, the effective energy price becomes:

$$P_{Et}^{eff} = \begin{cases} \bar{P}_E & \text{with cap and } P_{Et} > \bar{P}_E \\ P_{Et} & \text{otherwise} \end{cases} \tag{21}$$

Hence, under the cap, the effective price for energy for the households and firms is equal to the steady state price of energy, $\bar{P}_E$. Consequently, when the fiscal authority introduces the price cap, the price of energy in households' and firms' equilibrium conditions is given by the effective price of energy $P_{Et}^{eff} = \bar{P}_E$.[10] The government runs a balanced budget and finances the cap by a lump-sum tax, such that the government budget constraint reads:

$$COST_t(E_t^h + E_t^f) = T_t \tag{22}$$

[9] The main results are robust to changing the central bank's target from CPI to core inflation. In Section 3.2.3 I discuss the implications of core targeting on inflation rates.

[10] The results are robust to changing the price cap target from both household and firms to just households.

where $COST_t = P_{Et} - \bar{P}_E$ denotes the cost of the cap per unit of energy for the government. Ricardian Equivalence holds in this model because consumption does not respond to changes in future expected taxes and government spending. Later, I introduce hand-to-mouth agents to the model as an extension in which case Ricardian Equivalence does not hold.

2.5 Equilibrium

The equilibrium of this economy is characterized by a sequence of prices $\{W_t, W_t^*, P_{Ht}, P_{Ft}, P_{Et}\}$ and allocations $\{E_t^h, E_t^{h*}, C_{Ht}, C_{Ft}, C_{Ht}^*, C_{Ft}^*, N_t, N_t^*, E_t^f, E_t^{f*}, b_t^h, b_t^{h*}\}$ such that the goods market is cleared for both Home and Foreign-produced goods, the energy market is cleared, the assets are in zero net supply between the countries, and the labor market is cleared in both countries. The full list of equilibrium conditions are in Appendix A.3.

2.5.1 Goods market clearing

The goods market clears for the Home country when the production in that country is equal to the demand for consumption goods produced in that country. Hence, the market clearing condition includes the demand for Home-produced goods in the Foreign country:

$$Y_t = C_{Ht} + C_{Ht}^* + HC_t + FC_t \tag{23}$$

$$= (1-\alpha_I)\left(\frac{P_{Ht}}{P_{Ot}}\right)^{-\gamma} C_{Ot} + \alpha_I^* \left(\frac{P_{Ht}}{P_{Ot}^*}\right)^{-\gamma} C_{Ot}^* + HC_t + FC_t \tag{24}$$

where C_{Ht}^* is the consumption of Home-produced goods in Foreign, and C_{Ot}^* is the consumption of other goods (both Home and Foreign-produced) in Foreign.

2.5.2 Energy market clearing.

The energy market is fully integrated across the two countries in the union. As in Bayer et al. (2023), I model the supply of energy E_t as exogenous. So, the supply of energy does not respond to price movements and the price of energy has to adjust for the market to clear. The energy market clears when the demand for energy by households and firms from both countries equals the exogenous supply:

$$E_t = E_t^h + E_t^f + E_t^{h*} + E_t^{f*} \tag{25}$$

2.5.3 Current account and the dynamics of net foreign assets

I derive the dynamics of net foreign assets, and hence the current account, by consolidating households' and firms resource constraints, (8) and (17):

$$B_t^h - B_{t-1}^h = r_{t-1}B_{t-1}^h + P_{Ht}Y_t\left(1 - FC_t\right) - P_{Ot}C_{Ot} - HC_t \tag{26}$$

where $r_t = R_t - 1$ is the net nominal interest rate set by the monetary authority. Since the right-hand side of the equation is the current account I can express the above equation as the following:

$$CA_t = b_t^h - b_{t-1}^h \tag{27}$$

$$CA_t = r_{t-1}b_{t-1}^h + \frac{P_{Ht}}{P_t}Y_t\left(1 - FC_t\right) - \frac{P_{Ot}}{P_t}C_{Ot} - \frac{1}{P_t}HC_t \tag{28}$$

where $b_t^h = \frac{B_t^h}{P_t}$ is real bond holdings. Since the union is a closed economy, to ensure mutual consistency of current accounts $CA_t = -CA_t^*$ needs to hold. Moreover, the assets are in zero net supply between countries.

2.6 Calibration

The model is calibrated at quarterly frequency. In the extended model, I perform a Bayesian estimation of some of the model parameters. Table 1 provides an overview of the baseline calibration values. The countries are identical except for their relative sizes.

Table 1: Baseline calibration of parameters

Parameter	*Description*	*Value*
Households		
α_I	Share of imports in consumption	0.25
α_E	Share of energy in consumption	0.066
γ	Elasticity of substitution between Home and Foreign goods	6
ϵ	Elasticity of substitution within goods	9
ε_1	Non-homotheticity parameter	1
ε_2	Non-homotheticity parameter	0.77
$\tilde{\nu}$	Adjustment cost for bonds	0.001
β	Discount factor	0.99
Firms		
α^f	Share of energy in production	0.011
θ^f	Elasticity of substitution between energy and labor	0.2
ξ	Price-adjustment cost	15.84
Monetary policy		
ϕ_π	Taylor-coefficient on inflation	1.5
α^{CB}	Share of energy for central bank's consideration	0.066
Currency union		
Θ	Relative GDP size Home country (with cap)	0.68

On the household side, Eurostat (2023b) reports that in 2022, the share of internationally traded goods and services relative to GDP was 25%. Hence, the share of imports in consumption, α_I, is 0.25. The share of energy in total consumption expenditure is on average 6.6%, so I set α_E as 0.066.[11]. The elasticity of substitution within different varieties of Home and Foreign, ϵ, is 9, in line with standard literature. The adjustment cost for bond-holdings, $\tilde{\nu}$, is 0.001, to match the canonical work by Schmitt-Grohé and Uribe (2003). The discount factor β is 0.99 as is standard in the literature. I perform a data matching exercise at the end of the subsection to calibrate the non-homotheticity parameters ε_1 and ε_2.

For the firms, I set the share of energy in production, α^f, to 1.1% to target the steady-state energy expenditure of the industry as share of total production value of 1%.[12] The elasticity of substitution of energy and labor, θ^f, is 0.2, following Bayer et al. (2023) and Bachmann et al. (2024).[13] I calibrate the Rotemberg (1982) price-adjustment cost parameter, ξ, such that the slope of the New Keynesian Philips Curve matches that of the Calvo (1983) price rigidities for the Calvo parameter 0.5. This value implies an expected price duration of two quarters, which is more frequent than standard, to reflect the fast change in prices in 2022. The corresponding price-adjustment cost parameter is $\xi = [(\epsilon - 1)0.5]/[(1 - 0.5)(1 - 0.5\beta)] \approx 15.84$

Monetary policy follows a standard Taylor (1993) rule, with the coefficient on inflation ϕ_π as 1.5. The monetary authority targets headline inflation, following the official target of the European Central Bank (ECB, 2021).[14]

To obtain the relative size of the two countries, I calculate the GDP ratio of countries that introduced a cap in 2022 and that did not introduce a cap in 2022.[15] Since the sum of GDPs of countries with an energy price cap in 2022 was about 68% of the total of countries in the Euro Area, I set the size of the Home country $\Theta = 0.68$.[16]

[11]Eurostat data, online data code: hbs_str_t223.

[12]I calculate the steady-state energy expenditure as share of total production value with data from Rademaekers et al. (2020) and Eurostat data (online data code: sbs_sc_ovw). The sectors included are selected manufacturing sectors, wholesale and retail trade, accommodation and restaurants, and information and communication, and the countries included are the 27 European Union members in 2020.

[13]Bachmann et al. (2024) show that when other production inputs are constant, the own-price elasticity maps directly to the elasticity of substitution. They estimate the own-price elasticity of energy to range from –0.15 to –0.20.

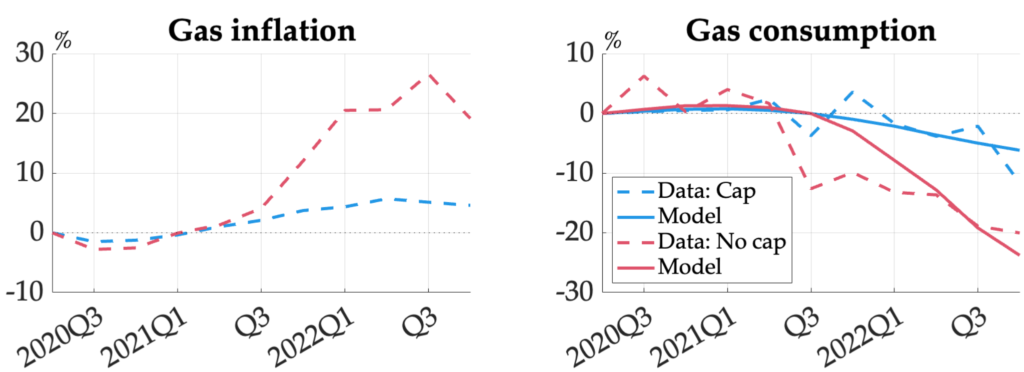
[14]Moreover, the press releases of the ECB monetary policy decisions between June 2022 and September 2023, when the ECB kept increasing interest rates, often mention energy prices as one of the key drivers of upwards pressures for inflation. The decision reports mention headline inflation figures to indicate how far the economy is off the 2% target (European Central Bank, 2024).

[15]Euro Area countries with an energy price cap in 2022: Austria, Estonia, France, Germany, Luxembourg, Malta, Portugal, Slovakia, Slovenia, Spain. Euro Area countries without an energy price cap in 2022: Belgium, Cyprus, Finland, Greece, Ireland, Italy, Latvia, Lithuania, The Netherlands. Croatia joined the Euro Area in 2023 and therefore excluded from the analysis in this paper.

[16]The results are robust against a calibration with equal-sized countries, so $\Theta = 0.5$.

Non-homotheticity parameters. For the calibration of the non-homotheticity parameters ε_1 and ε_2, I conduct a data matching exercise. I take the gas inflation data for France and the Netherlands from Eurostat from 2019 to 2022, and feed it into the model as perfect foresight energy price shocks, as shown Figure 3.[17] At the peak in 2022Q3, the Netherlands experienced a gas price inflation of about 30% in quarterly rates (over 90% in annual rates). France, on the other hand, imposed a price cap on gas inflation which barely exceeded 10% in quarterly rates (about 30% in annual rates). The gas consumption data reflect the policies: in the Netherlands, the gas consumption decreased about 15 percentage points more than in France. I conduct a parameter search for ε_1 and ε_2, imposing $0 \leq \varepsilon_1 \leq 1$ and $0 \leq \varepsilon_1 \leq 1$ to minimize the Mean Squared Error (MSE) between the energy consumption from the model in which I feed in the gas inflation data, and the realized gas consumption in 2020Q3 to 2022Q4 for both countries.[18] The results give $\varepsilon_1 = 1$ and $\varepsilon_2 = 0.77$, which implies an elasticity of substitution between energy and other goods of 0.25 in steady state, which is in line with other literature on energy shocks like Bayer et al. (2023) and Chan et al. (2024). I set the elasticity of substitution between Home and Foreign goods, γ, to 6, the upper bound of standard literature (Benigno, 2009), since the data exercise gives the lowest error under this calibration.

Figure 3: Data exercise to calibrate the non-homotheticity parameters



Notes: The left panel shows the gas inflation of France (cap) and the Netherlands (no cap). I feed this data into the model and find the parameters ϵ_1 and ϵ_2 that minimize the Mean Squared Error (MSE) between the gas consumption data (right panel, dotted) and the model-implied gas consumption (solid). Sources for data: Eurostat.

[17] I manipulate the data from Eurostat (online data code: prc_hicp_manr) to obtain quarterly rates. I use the observations from 2020Q3 to 2021Q3 to compute the steady state to express all data in deviations from steady state. France and the Netherlands are one of the most extreme cases of inflation divergence within the Euro Area. The countries are relatively close geographically and socio-economically, which make them good candidates for this data exercise. Including all countries in the Euro Area makes this exercise less clear cut, since idiosyncrasies, like proximity to Ukraine or Russia, affect the price dynamics in different ways than this reduced form exercise can handle. In the Bayesian estimation of the extended model, I include all countries in the Euro Area.

[18] The data is from Eurostat (online data code: nrg_c_gasm). With population data (intrapolated for the quarters), I obtain the gas consumption per capita. I seasonally adjust the data using X-13ARIMA-SEATS in R before taking quarterly data points and steady-state deviations from steady state.

Shock specification. In the numerical analyses in the following sections, I shock the model with an adverse energy supply shock of 15% that lasts for six quarters. In this way, I capture the decline in the supply of Russian gas in summer 2022 and the expectations of governments that the shock would last until spring 2023. More concretely, in July 2022 the European Union member states agreed to a gas consumption reduction target of 15% between August 2022 and March 2023, and another extension until March 2024, to prepare for possible supply disruptions (European Commission, 2023). Moreover, most countries introduced energy price caps lasting four to nine quarters in 2022.

3 Results

In this section, I conduct a series of simulations with the dynamic model to investigate the effect of an adverse energy supply shock on a currency union. First, I show how an adverse energy supply shock affects the economy in absence of price caps. The shock causes an increase in the price of energy, and a cost-push shock in the economy. Second, I take the scenario of the Euro Area in 2022, and impose an energy price cap in the bigger country in the union. I find that the capped country can avoid most of the crisis, while the uncapped country experiences a cost-push shock double the size. The size of such negative spillovers depend on the degree of non-homotheticity of energy and affect policy decisions. Moreover, I discuss the consequences of headline and core targeting and the trade-offs they impose.

3.1 Energy crisis without energy caps

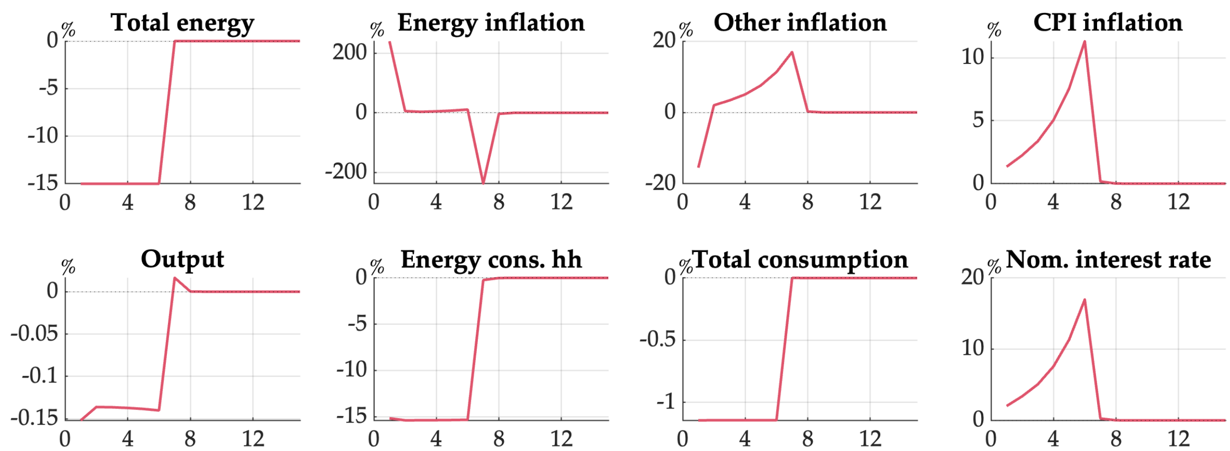
The shock is a 15% shock to the energy supply of the currency union and lasts six quarters. Since there are no energy price caps in either country and the countries are otherwise symmetric, the responses for the two countries are the same. Hence, the results in Figure 4 show one response per variable.

The adverse energy supply shock pushes up on the energy inflation. The recessionary shock decreases inflation for other goods on impact. In the later periods, the other goods inflation increases since energy is one of the production inputs. Consumer Price Index (CPI) inflation, or headline inflation, is a weighted average of energy inflation and other goods inflation, and hence peaks when other goods inflation is highest. Production and consumption of other goods decrease as a consequence of the energy supply declining.[19] Energy consumption by households decreases by about the same amount as the shock. Since the energy shock increases CPI inflation while depressing output, the shock acts

[19] Shown in the Output panel, since output is the production of other goods, which is equal to the consumption of other goods.

as a cost-push shock. The monetary authority conducts contractionary policy to dampen inflationary pressures, and returns to steady state together with CPI inflation.

Figure 4: Responses to an adverse energy supply shock | No caps



Notes: Impulse responses to a 15% decline in energy supply. Preferences are non-homothetic. Output is equal to the output gap. The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

3.2 Energy crisis with one cap and one no-cap country

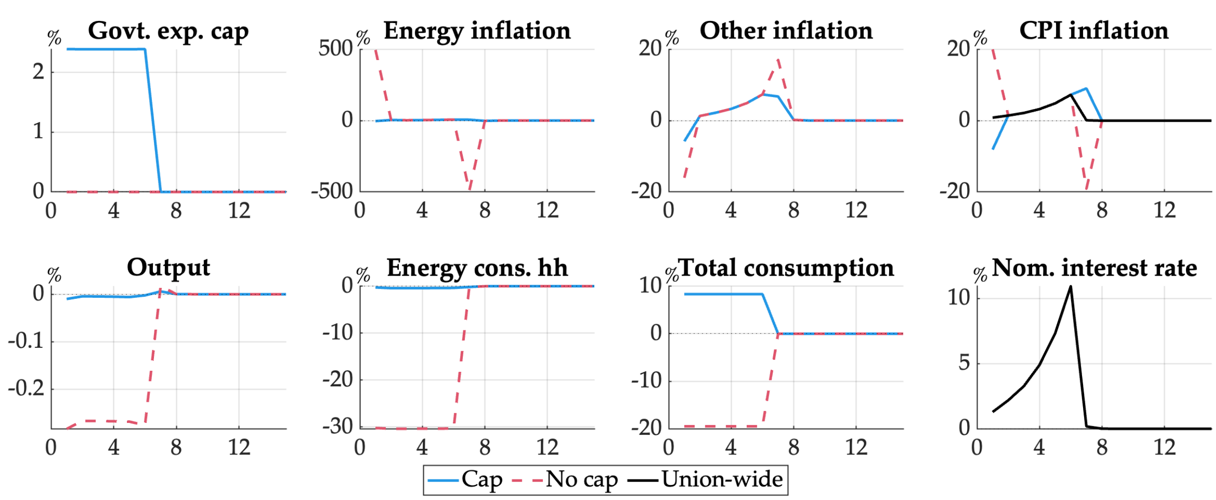
Now consider the case in which the the larger country introduces a price cap on the energy price, such that the retail energy price stays constant. Figure 5 shows the impulse responses for the economy when households have non-homothetic preferences. When the energy supply decreases by 15%, the bigger country (blue solid lines) introduces an energy price cap which costs about 2.5% of the annual GDP for the government. In the uncapped country (red dotted lines) the adverse energy supply shock is essentially doubled compared to the case without any price caps, since the capped country's share of the shock spills over.

In the capped country the economy avoids most of the energy crisis. Because their energy prices do not increase, households in this country have more purchasing power than households in the uncapped country. Therefore, they consume more of the other goods produced in their own country, but also more of the ones produced in the uncapped country. Moreover, the other goods inflation responses show that the goods from the uncapped country have become relatively cheaper because of the large recession in that country. Hence, total consumption in the capped country increases.

In the country without the cap the energy price increase doubles compared to the previous case without any caps. The energy scarcity is more severe due to the capped country not reducing their energy consumption. Since the capped country does not decrease their energy consumption, energy is an even scarcer good in the uncapped country. The adverse energy supply shock causes households in this country to reduce their energy consumption by twice as much relative to the case when the other country also did not introduce the energy price cap. The energy supply shock is essentially double the size in the uncapped country. Crucially, the other inflation fluctuations in both countries imply a terms-of-trade depreciation for the uncapped country, because their other inflation decreases more than the one in the capped country. Since the terms of trade depreciates for the uncapped country, their purchasing power decreases. Imports become more expensive and exports to the households in the capped country increases, which decreases total consumption in the uncapped country drastically.[20] Despite the increased demand from the capped country for goods produced in the uncapped country, the output in the uncapped country decreases due to the large energy supply shock.

The common monetary policy adopts a less contractionary stance than when neither of the countries implemented the energy price cap, in Figure 4. The central bank targets the weighted-average headline inflation in its Taylor rule, which is the black line in the CPI inflation graph in Figure 5. Since the inflation rates of the capped and uncapped countries peak at different times, the weighted-average inflation does not increase as much as in the case without any price caps, which causes a milder response from the central bank.

Figure 5: Responses to an adverse energy supply shock | Cap vs. no cap



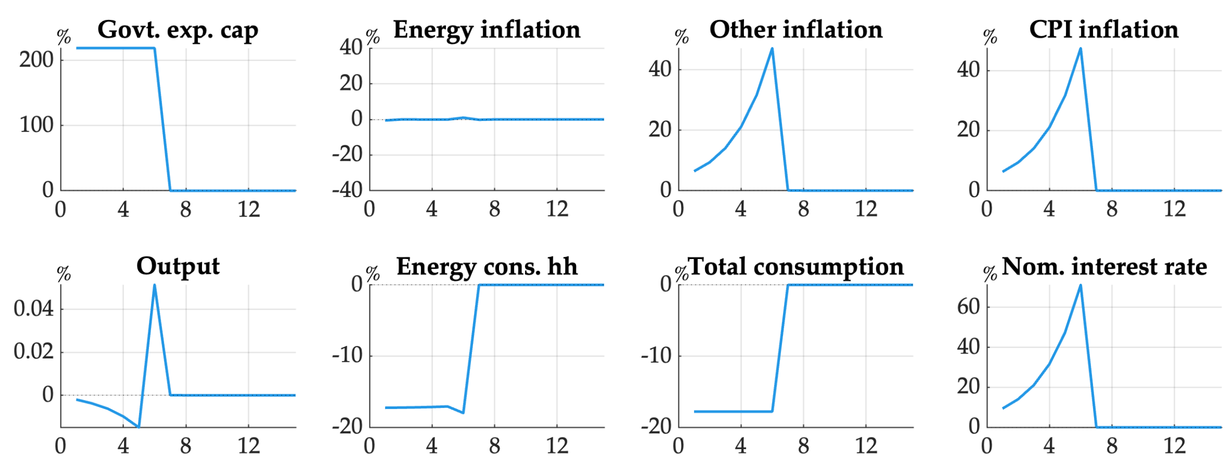
Notes: Impulse responses to a 15% decline in energy supply. Preferences are non-homothetic. The bigger country, of size Θ imposes a price cap on the energy price (blue, solid) and the smaller country, of size $1-\Theta$ does not (red, dashed). The black solid lines show the union-wide variables. Output is equal to the output gap. Government expenditure on the price cap (Govt. exp. cap) is the cost of the cap as a share of annual total output of the country (GDP). The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

[20]This result is similar to the terms-of-trade externality by for example Corsetti and Pesenti (2001), in which an expansionary fiscal policy causes a terms-of-trade appreciation for the country, hurting trading partners.

3.2.1 Energy crisis with energy price caps

Figure 6 shows the responses when both countries impose an energy price cap. In this case, the price of energy stays constant in the entire union. Because of the distorted price, consumers try to maintain their energy and other goods consumption. However, since the supply of energy is exogenous, the supply side of the economy cannot increase its production accordingly. Hence, there is high pressure on other goods inflation as well as the actual price of energy. Because the government pays the difference between the actual and retail price of energy, the price cap becomes a large cost for the government and ultimately for the consumers. Combined with the high other goods inflation, such high costs cause a big decline in the total consumption of the households.

Figure 6: Responses to an adverse energy supply shock | Caps



Notes: Impulse responses to a 15% decline in energy supply and a price cap in both countries. Preferences are non-homothetic. Output is equal to the output gap. The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

3.2.2 Implications for policy decisions and welfare

In this subsection, I analyze the welfare implications for each combination of policy strategies (cap and no cap, for both countries) and show the decision game is a classic Prisoner's Dilemma.

Policy outcomes under symmetric price cap policy. Table 2 summarizes the welfare results in a two-by-two matrix. The relevant metric is the consumption equivalent welfare gains and losses relative to the steady state of the economy.[21] First, focus on the cells on

[21] For the consumption equivalent, I find χ which satisfies:

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{\varepsilon_1} \left[\left(\frac{exp_t}{P_{Rt}} \right)^{\varepsilon_1} - 1 \right] - \frac{\alpha_E}{\varepsilon_2} \left[\left(\frac{P_{Et}}{P_{Rt}} \right)^{\varepsilon_2} - 1 \right] \right\} = \sum_{t=0}^{\infty} \beta^t \frac{1}{\varepsilon_1} \left\{ [\overline{exp}(1+\chi)]^{\varepsilon_1} - 1 \right\} \tag{29}$$

the diagonal where the policies are symmetric (cap-cap and no cap-no cap), which is the symmetric benchmark. Since the currency union is a closed economy, the symmetric benchmark is equivalent to the closed economy case. In this closed economy case, the adverse energy supply shock causes a welfare loss of 0.1% without an energy price cap and 1% with the cap.

With an energy price cap in the entire union the welfare losses are a tenfold bigger. As discussed, such a scenario is detrimental for household consumption since the demand distortions under the price cap increases the fiscal cost for the government to finance the cap, ultimately born by households, and the inflation of other goods. The consumption equivalent welfare loss is 1% when both countries introduce an energy price cap.

Table 2: Welfare gains/losses after energy supply shock

Non-homothetic preferences

		1/3 of union	
	%	Cap	No cap
2/3 of union	Cap	(-1.0, -1.0)	(0.5, -1.1)
	No cap	(-1.1, 0.4)	(-0.1, -0.1)

Notes: Welfare gains and losses after a 15% energy supply shock. Preferences are non-homothetic. The gains and losses are in terms of the consumption equivalent relative to the steady state. The circles are around the preferred policy choices (Cap or No cap) for the countries.

Policy outcomes under asymmetric price cap policy. When the countries do not have to cooperate, is the non-distortionary no-cap strategy still the Nash equilibrium? As the circles around the welfare values indicate in Table 2, the cooperative case is not the Nash equilibrium. Instead, as in the classic Prisoner's Dilemma, the non-cooperative decision, imposing the price cap, is the dominant strategy for both fiscal authorities.

First, *given 1/3 of the union does not impose an energy price cap*, does the rest, 2/3 of the union, have an incentive to deviate from the no-cap strategy? If they keep to the no-cap strategy, the union is in the cooperative case, in which both countries experience a welfare loss of 1%. However, the country representing 2/3 of the union has an incentive to deviate to the cap policy, which improves the welfare in that country (0.5%) at the expense of the no-cap country (–1.1%). This result is a summary of the impulse responses in Figure 5, with large spillovers from the capped to the uncapped country.

Second, *given 2/3 of the union imposes an energy price cap*, does the rest, 1/3 of the union, also have an incentive to impose the price cap? The large, negative spillovers are very costly for the uncapped country; they cause a welfare loss of 1.1%. Hence, the country has an incentive to also impose the price cap, even though both countries imposing the

So, χ is the fraction of total expenditure, i.e. total consumption, that the household would be willing to forgo in the economy in steady state (right-hand side) to live in the economy with the energy supply shock, as evaluated by the left-hand side of the equation.

cap causes a welfare loss of 1%. The loss is relatively big because when both countries implement an energy price cap, the cost for the cap spirals upwards: the only benefit from the price cap emerges from creating spillovers to the other country, which is not possible when both countries impose the cap.

The above argument also applies when the small and large countries switch: for both countries, it is better to impose the energy price cap when the other does, despite the large cost of the distortion, rather than bearing the negative spillovers.[22] Hence, imposing an energy price cap is the dominant strategy for both countries, leading to a Prisoner's Dilemma: both countries can gain from cooperating, but it is not rational to do so.

The Prisoner's Dilemma as the Nash equilibrium does not reflect the choices that policymakers made in reality. In the next section I introduce substitutability between energy sources, which is an important feature in energy crises, and show that the model achieves the Nash equilibria in which one country imposes an energy price cap and the other country does not.

Policy outcomes under homothetic preferences. How much do these results depend on the non-homotheticity of energy? Here, I illustrate that the above results are highly dependent on the degree of non-homotheticity. The welfare table for homothetic preferences is in Table 3. The degree of non-homotheticity does not affect the values on the diagonal of the symmetric cap policies. Again, the non-cooperative case when both countries impose a cap are much worse (–1%) than in the cooperative case without any caps (–0.1%) due to the market-distorting price cap.

Table 3: Welfare gains/losses after energy supply shock

Homothetic preferences

		1/3 of union	
	%	Cap	No cap
2/3 of union	Cap	$(-1.0, -1.0)$	$(0.1, -0.4)$
	No cap	$(-0.3, 0.0)$	$(-0.1, -0.1)$

Notes: Welfare gains and losses after a 15% energy supply shock. Preferences are homothetic (Cobb-Douglas). The gains and losses are in terms of the consumption equivalent relative to the steady state. The circles are around the preferred policy choices (Cap or No cap) for the countries.

However, non-homotheticity of preferences affects the magnitude of the spillovers significantly. Under the homothetic case, the externalities of the price cap are not as large, because energy is not a necessity. Hence, when the counterpart country implements a cap, the welfare losses associated with negative spillovers are not as large: –0.4% when the larger country imposes a cap and –0.3% when the smaller country imposes a cap. So, implementing the price cap is not worth the cost when the other country also has the cap. Thus, with homothetic preferences, there are two Nash equilibria, in which one country

[22] The externalities are smaller when the smaller country implements the energy price cap. However, not small enough to break symmetry in the preferred strategies in Table 2.

implements a price cap and the other does not. Although this reflects what occurred in reality, the assumption that energy is not a necessity is unrealistic. Instead of relying on homothetic preferences to dampen spillovers, I show in the next section that introducing substitutability between energy sources can achieve the same effect, leading to the desired outcome.

Recall that parameters ε_1 and ε_2 govern the degree of non-homotheticity of energy. Welfare outcomes under the baseline calibration with non-homothetic preferences, $\varepsilon_1 = \varepsilon_2 = 0.77$, are in Table 2: one Nash equilibrium which is a price cap in both countries. Welfare outcomes in the homothetic case, $\varepsilon_1 = \varepsilon_2 = 0$, are in Table 3: two Nash equilibria for differing cap policies. The magnitude of the spillovers are crucial in determining the size of the negative spillovers to the uncapped country and depend on the degree of non-homotheticity. The value for ε_1 and ε_2 for which the smaller country is indifferent about imposing a cap or not, when the bigger country has imposed a cap, is $\varepsilon_1 = \varepsilon_2 = 0.72$.

3.2.3 Implications for the central bank: Headline vs. core inflation targeting

In this subsection, I explore the different implications for the monetary authority when targeting Consumer Price Index (CPI) inflation, i.e. headline inflation, or other goods inflation, i.e. core inflation.[23] I show that there is a trade-off between stabilizing different inflation rates. However, since the relative inflation rates between the capped and uncapped country are similar in either targeting regime, the magnitude of the spillovers do not change much.

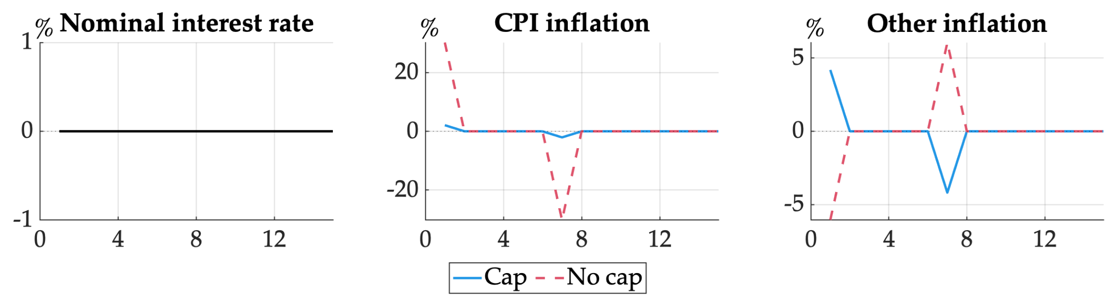
In the baseline analysis, the monetary authority targets headline inflation in its Taylor rule. In that case, Figure 5 shows that the monetary authority conducts contractionary monetary policy to stabilize union-wide headline inflation, which is the weighted average of the headline inflation rates of the two countries. However, under headline inflation targeting, there are large fluctuations in the core sector in both countries, but worse for the uncapped country. On top of the adverse energy supply shock, a contractionary monetary policy worsens the cost-push shock in the core sector of the economies.

Figure 7 present the responses of the interest rates and inflation rates with a central bank that targets core inflation in its Taylor rule. The figure shows that the central bank conducts expansionary policy in this case. Because the adverse energy supply shock is a cost-push shock to the core-goods sector, a central bank that targets core-goods inflation decreases its rates to stabilize the fluctuations in that sector. As expected, the expansionary monetary policy comes at the cost of a higher headline inflation.

All in all, a central bank with a target for other goods inflation should conduct relatively expansionary policy during an energy crisis with heterogeneous cap policies. When

[23]In the literature, core inflation refers to CPI inflation excluding food and energy inflation. Since my model does not have food inflation, I refer to CPI inflation excluding energy inflation as core inflation.

Figure 7: Responses to an adverse supply shock | Core inflation targeting



Notes: Impulse responses to a 15% decline in energy supply under core inflation targeting. Preferences are non-homothetic. The bigger country, of size Θ imposes a price cap on the energy price (blue, solid) and the smaller country, of size $1-\Theta$ does not (red, dashed). The black solid lines show the union-wide variables. The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

the target is for headline inflation, a more contractionary monetary policy mitigates the inflationary pressures from the high energy inflation in the uncapped country, reducing the headline inflation fluctuations. In Figure 18 in Appendix C I display the rest of the impulse responses, which show that for the magnitude of the spillovers, the targeting regime does not matter. This result arises because the relative inflation rates between the capped and uncapped country, which matters for the spillovers, is similar regardless of the targeting regime.

3.2.4 Robustness checks under alternative model specifications

In this section I conduct robustness checks with alternative assumptions of the model: elastic labor supply, flexible prices, flexible exchange rates, and preferences with Constant Elasticity of Substitution (CES). Most alternative model specifications confirm the robustness of the main results.

Elastic labor supply dampens the negative spillovers, which gives result to a welfare table that is in-between the non-homothetic and homothetic case. To allow for hours worked to adjust in the model, I implement an ad-hoc approach to elastic labor supply by incorporating a labor disutility term into the utility function, deviating from the preferences outlined by Boppart (2014).[24] Figure 20 and Table 8 in Appendix C.1 present the results for this alternative specification.

The impulse responses in Figure 20 imply that elastic labor supply does not change the

[24]The utility function with labor disutility is:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{\varepsilon_1} \left[\left(\frac{exp_t}{P_{Rt}} \right)^{\varepsilon_1} - 1 \right] - \frac{\alpha_E}{\varepsilon_2} \left[\left(\frac{P_{Et}}{P_{Rt}} \right)^{\varepsilon_2} - 1 \right] - \chi \frac{N_t^{1+\varphi}}{1+\varphi} \right\} \tag{30}$$

where χ is the disutility of labor and $1/\varphi$ the Frisch labor elasticity. The calibration is $\chi = \varphi = 1$, as is standard in the literature.

inflation dynamics of the two countries. However, because firms can now increase their production by employing more labor, the output responses are different to the baseline case. As discussed earlier, due to the increased demand in purchasing power of households in the capped country, they import more goods from the uncapped country. Contrary to the baseline case, the firms in the uncapped country now scale up their production by hiring more labor, which is beneficial for households in the uncapped country. Those households do not decrease their consumption as much as in the baseline case because of the increased labor demand. Accordingly, Table 8 shows that the costs of implementing a cap are higher than the cost of bearing the spillovers as the uncapped country, which is a similar result to the homothetic case.[25]

Under flexible prices the main results under the asymmetric price cap policies and the welfare table are robust. The results are in Appendix C.2. While the spillovers under asymmetric price cap policies are similar to the sticky price case, the symmetric cases shows some differences. Specifically, output does not decline following the energy supply shock, since price flexibility allows for efficient adjustments. Firms can adjust prices immediately, enabling the economy to absorb the shock without reducing output.

The tables and figures in Appendix C.2, C.3, and C.4 show the results for the last two alternative assumptions, flexible exchange rates and CES preferences. Even though the impulse responses are somewhat different, the welfare table is the same as under the baseline case. This result confirms that the crucial assumption to the mechanism is the shared energy supply, not the shared monetary authority. Moreover, CES preferences dampen the overall effect of the energy supply shock and the price cap spillovers on the economy, because the expenditure share of energy remains constant and energy is not a necessity good.

4 Endogenous energy production

So far, the analysis uses the model which only has an exogenous source of energy. This setup is valuable for understanding the core intuition and mechanics, as well as investigating the dynamics of the economies and their spillovers. However, during the European energy crisis in 2022 total energy consumption per capita did not decrease. When the supply of gas fell, other energy sources substituted out for gas, such that total energy consumption stayed roughly constant (Energy Institute, 2024). Therefore, to estimate the model, I add a domestic energy production sector to both countries. There is still an exogenous supply of gas which the two countries in the union share.

[25] In the reverse case, when the smaller country imposes the price cap and the bigger country does not, the positive effect on welfare from increased labor demand is not big enough to outweigh the costs of implementing the price cap.

With the extended model, I first perform a Bayesian estimation of the parameters. Then, I revisit the mechanism and the incentives about whether to cap or not. I show that the domestic production of energy dampens the negative spillovers of the energy price cap, such that Nash equilibria, with one capped and one uncapped country, matches the reality in 2022. Moreover, I demonstrate with a historical shock decomposition that the energy price cap contributed to 40% of energy inflation and 20% of CPI inflation in 2022Q3 in the uncapped countries.

4.1 Energy sector and energy market clearing in the model

To make sure there is a substitute for the exogenous supply of gas, I add energy firms to both countries in the union. Unless otherwise stated, all other equations in the model stay unchanged from the baseline specification.

Energy firms only use labor, N_{Et}, as their input in their production Y_{Et}:

$$Y_{Et} = A_{Et} N_{Et}^{\eta} \tag{31}$$

where A_{Et} is the total factor technology in the energy sector. η determines the share of profits from total revenue. The production function uses a diminishing-return technology, as in Ferrero and Seneca (2019), to match the oligopolies in the energy sector.

The representative energy producer takes the wages as given. I assume that the energy firms sell any quantity of energy at the prevailing price. This assumption reflects the findings by Zakeri et al. (2022) who find that the European electricity prices depend highly on natural gas prices. The energy firm's problem is

$$\max_{N_{Et}} P_{Et} Y_{Et} - W_t N_{Et} \tag{32}$$

subject to the production function (31). The first-order conditions are in Appendix A.5.

Energy market clearing. Energy supply comes from the exogenous, union-wide gas supply GAS_t^W and the domestically produced energy. Hence, the market clearing conditions for energy are:

$$E_t^h + E_t^f = \left[(1-\alpha_G)^{1/\zeta} (Y_{Et})^{(\zeta-1)/\zeta} + \alpha_G^{1/\zeta} (GAS_t)^{(\zeta-1)/\zeta} \right]^{\zeta/(\zeta-1)} \tag{33}$$

$$E_t^{h*} + E_t^{f*} = \left[(1-\alpha_G^*)^{1/\zeta} (Y_{Et}^*)^{(\zeta-1)/\zeta} + \alpha_G^{*\,1/\zeta} (GAS_t^*)^{(\zeta-1)/\zeta} \right]^{\zeta/(\zeta-1)} \tag{34}$$

$$GAS_t + GAS_t^* = GAS_t^W \tag{35}$$

where α_G is the share of gas in energy use and ζ governs the substitutability of gas and other energy.

4.2 Calibration and estimation of the parameters

In the model with domestic energy production, there are a few extra parameters to consider. Moreover, since the goal is to estimate the contributions of the energy price cap, I divert from the symmetric setup and calibrate some extra parameters differently for the capped and uncapped countries when there is distinguishing data. I calibrate the share of gas in energy use, α_G and α_G^*, the steady-state productivity of the energy sector, $\bar{A}_E$, and the share of profits, η, with data and matching targets. For the non-homotheticity parameters, $\varepsilon_1, \varepsilon_1^*, \varepsilon_2$ and ε_2^*, and the elasticity of substitution between gas and non-gas energy, ζ and ζ^*, I use Bayesian estimation.

4.2.1 Calibration

For the share of gas in energy use, α_G and α_G^*, I use the Harmonized Index of Consumer Prices (HICP) item weights from Eurostat and set them to 0.18 and 0.22 respectively for the capped and uncapped countries.[26] Even though the data for estimation starts a decade earlier than 2022, I group the countries already into capped and uncapped countries, referring to the energy price cap policy in 2022. To set the steady-state productivity of the energy sector, $\bar{A}_E$, and the share of profits, η, I match the following targets: the share of workers in the energy sector of 3.66% in Europe[27] and the relative price of energy and other goods of 1, as in the baseline model. The values that match the targets are $\eta = 0.19$ and $\bar{A}_E = 0.17$. These parameters are symmetric across the countries. Table 4 provides a summary.

4.2.2 Estimation

I estimate the non-homotheticity parameters, $\varepsilon_1 = \varepsilon_2$, and and the elasticity of substitution between gas and non-gas energy, ζ and ζ^*. Here, I outline the method used and steps taken for Bayesian estimation and present the outcome.

I use the Bayesian estimation techniques programmed in Dynare (Adjemian et al., 2024). I include the following shocks and measurement errors in the model: total factor productivity (TFP) shocks for other goods and energy sector, demand shocks, cost-push

[26] Eurostat data, online data code: prc_ hicp_inw. I take the weighted average according to Eurostat's country weights (data code: prc_ hicp_cow) when calculating the values for capped and uncapped countries. The categorization of capped and uncapped countries is in Footnote 15.

[27] Own calculations from the World Energy Employment report in 2022 by the International Energy Agency (IEA, 2022) and Eurostat data.

Table 4: Extra parameters in model with domestic energy production

Parameter	*Description*	*Value*
α_G	Share of gas in energy, "Cap"	0.18
α_G^*	Share of gas in energy, "No cap"	0.22
η	Share of profits for energy firms	0.19
$\bar{A}_E$	Steady-state productivity energy sector	0.17
ε_1	Non-homotheticity parameter	0.25
ε_2	Non-homotheticity parameter	0.25
ζ	Elasticity of substitution between gas and non-gas energy, "Cap"	14.88
ζ^*	Elasticity of substitution between gas and non-gas energy, "No cap"	34.89

Notes: Calibration of the extra parameters in the model with energy production. All other variables are the same as in the baseline case as in Table 1.

shocks in the other goods sector, shocks to gas supply, monetary policy shock, and measurement errors for energy consumption and energy inflation. Those shocks and measurement errors are separate for the two countries in the union, except for the monetary policy shock and the energy inflation measurement error.[28]

First, I compute the mode of the posterior distribution with the Monte-Carlo based optimization routine. Second, the Metropolis-Hastings algorithm evaluates the marginal likelihood of the model and produces the posterior distributions of the parameters. This method closely follows the Bayesian estimation approach in Smets and Wouters (2007). More details on the estimation method are in Appendix B.

Prior distributions. I only estimate the parameters which have no direct counterpart in the data or a sensible target to match. The non-homotheticity parameter $\varepsilon_1 = \varepsilon_2$ is bounded by zero and one.[29] Hence, I use the Beta distribution as the prior distribution. The prior mean is set to 0.77, the calibration value from the data exercise in the baseline model. For the elasticity of substitution between gas and non-gas energy, ζ and ζ^*, I use the Gamma distribution as the prior distribution. I set the prior mean to 2 with a loose standard error. Following Krause et al. (2008), all shock processes follow an AR(1) process. The prior means of all AR-coefficient parameters are 0.9 and the standard deviations are 0.01. The AR-coefficients are bounded by one and zero, so they follow a Beta distribution. The standard deviations follow an Inverse-gamma distribution.

[28] I add the measurement error for energy inflation with a tight prior to avoid stochastic singularity.

[29] I estimate with $\varepsilon_1 = \varepsilon_1^* = \varepsilon_2 = \varepsilon_2^*$. First, I assume that the "Cap" and "No cap" do not differ in their non-homotheticity to energy. Since the data series is not too long and the "Cap" and "No cap"-blocks only arose in 2022, I assume, as in the baseline calibration, that the countries are symmetric. The only exception I make is the elasticity of substitution between gas and non-gas, as explained in this paragraph. Second, I set $\varepsilon_1 = \varepsilon_2$ to keep tractability. When $\varepsilon_1 = \varepsilon_2$ the elasticity of substitution between energy and other goods is $1 - \varepsilon_2$.

Data. I use the following data series from 2008Q1 to 2019Q4 in the Bayesian estimation:[30] Energy inflation, gas inflation, CPI inflation, energy consumption, gas consumption, output, and the nominal interest rate. Since the union has an integrated energy market, and therefore also gas market, there is one energy and gas inflation rate each for the entire union. Moreover, since the model implies a shared supply of gas, the gas consumption is the same as well. All data are from Eurostat Data. I seasonally adjust the data and detrend them to get the cyclical component. More details are in Appendix B.

Estimation results. Table 5 presents the results of the Bayesian estimation. The non-homotheticity parameters, ε_1, and therefore also ε_1^*, ε_2, and ε_2^*, are 0.27.[31] Moreover, the substitutability of gas and non-gas energy, ζ and ζ^*, are 15.21 and 35.31 respectively. Interestingly, the country-bloc that in 2022 implements an energy price cap have a much lower elasticity of substitution between gas and non-gas energy. This policy decision seems to make sense given the relatively low ability to substitute away from gas. The parameters are well-identified because I use both gas and energy inflation rates and gas and energy consumption for the estimation.[32] The posterior distributions plots and some more details about the estimation results are in Appendix B.

Table 5: Priors and posteriors

Parameter	Prior dist.	Prior mean	Prior std.	Post. mean	Post. std.	90% HPD interval
ε_1	Gamma	0.8	0.1	0.27	0.07	[0.165,0.380]
ζ	Beta	2	1	15.21	1.86	[12.190,18.265]
ζ^*	Beta	2	1	35.31	3.31	[29.981,40.802]

Notes: The prior distribution, mean, standard deviation, posterior mean and standard deviation, and the Highest Posterior Density (HPD) interval of the Bayesian estimation.

4.3 Results

In this subsection, I first show the simulation results of the extended model with parameter values from the calibration and the estimation, as summarized in Table 4. I show that domestic energy production dampens the effect of the gas supply shock on the economy.

[30] I deliberately omit the COVID-19 pandemic year to keep the observables stable. For the estimation of the shocks later, I cannot avoid the pandemic year. The sample starts in 2008Q1 due to data availability.

[31] The estimated non-homotheticity values, 0.27, are substantially lower than the values from the data exercise in the baseline model, 0.77. A couple reasons to explain this difference: in the baseline model, the parameter captures the non-homotheticity of gas, whereas the extended model covers all energy. Moreover, the sample period of the data exercise was very short, 2020Q3 – 2022Q4, and not overlapping with the sample period of the estimation exercise. Despite the difference, the results of the extended model does not change qualitatively when I set the non-homotheticity parameter to 0.77 instead of 0.27.

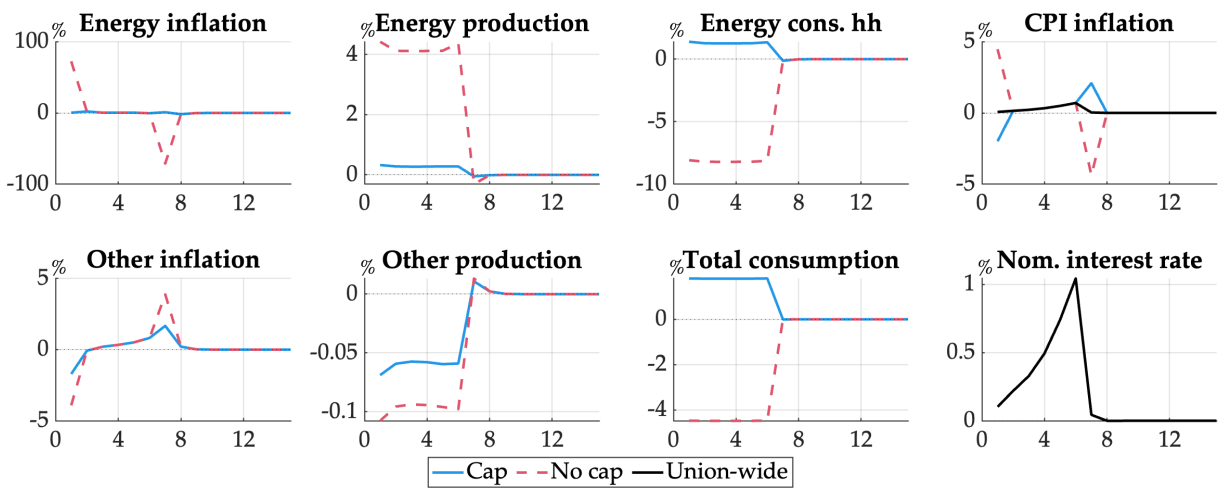
[32] Since gas inflation/consumption is a fraction of energy inflation/consumption, the data implies inflation/consumption of non-gas energy.

Consequently, the negative spillovers are also smaller, which leads the costs of implementing the price cap exceeding the costs of bearing the spillovers. Then, I conduct a historical shock decomposition to quantify the contribution of the energy price cap in 2022 to the energy and CPI inflation levels in both the capped and uncapped countries.

4.3.1 Simulation results

Figure 8 shows the impulse responses to an adverse energy supply shock when one country implements an energy price cap, with the model that allows for domestic energy production. The energy production in the uncapped country dampens the negative spillovers from the capped to the uncapped country substantially. For example, energy consumption for the households only decreases by about 10% compared to about 20% in the case without energy production in Figure 5. The response of CPI inflation, about 3% on impact, is also much lower than the 20% in the previous case.

Figure 8: Responses to an adverse gas supply shock | Energy production



Notes: Impulse responses to a 15% decline in gas supply, in a model with energy production. Preferences are non-homothetic. The bigger country, of size Θ imposes a price cap on the energy price (blue, solid) and the smaller country, of size $1 - \Theta$ does not (red, dashed). The black solid lines show the union-wide variables. The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

The welfare outcomes for the combinations of price cap strategies are in Table 6. Because the energy sector dampens the effect of the exogenous gas supply shock, the loss from the gas supply shock is 0.02% instead of 0.1% in the baseline case, when there are no price cap policies in place. Moreover, when both countries impose a price cap, in the baseline case the losses rose to 1%. The domestic energy production dampens this effect to a loss of 0.3%, implying that the actual price of energy, and therefore the cost for the government to implement the cap, does not rise as high as in the baseline case. Importantly, Table 6 shows that imposing a price cap is not the dominant strategy as it was in the baseline case in Table 2. Under the extended model there are two Nash equilibra in which one country imposes the price cap and the other country does not, explaining the reality in 2022. Because the energy sector dampens the negative spillovers of the energy price cap, imposing the cap when the opponent country also has one is not worth the cost.

Table 6 also displays the union-wide welfare losses, outside of the parentheses in case of differing cap policies. The union-wide welfare loss is biggest when both countries impose the energy price cap, 0.5%, because the cost of imposing the cap is high for the government, and there is no other country to spillover to. The cooperative outcome when there are no price caps in the entire union has the smallest union-wide welfare loss, –0.03%, compared to the weighted averages –0.03% (with higher precision) and –0.07%, when one of the countries impose the price cap. So, the Nash equilibra are not the optimal outcome for union-wide welfare, even if they benefit the bigger country.

Table 6: Welfare gains/losses after gas supply shock

Model with domestic energy production

	%	1/3 of union: Cap	1/3 of union: No cap
2/3 of union	Cap	$(-0.5, -0.5)$	$(0.1, -0.3); -0.03$
	No cap	$(-0.3, 0.1); -0.2$	$(-0.03, -0.03)$

Notes: Welfare gains and losses after a 15% gas supply shock, in a model with energy production. Preferences are non-homothetic. The gains and losses are in terms of the consumption equivalent relative to the steady state. The circles are around the preferred policy choices (Cap or No cap) for the countries. The values outside the parentheses are weighted averages, i.e. union-wide welfare.

To understand the forces behind the welfare gains and losses, I decompose the loss value -0.3 of the uncapped $1/3$ of the union in Table 7. The welfare loss of the uncapped country when the countries sharing a gas supply are in a currency union (iii), is, with higher precision, -0.26. By computing the welfare losses in the cases of (i) two autarkies sharing a gas supply and (ii) two trading countries not in a currency union sharing a gas supply, the Table decomposes the total welfare loss of the uncapped country into three components: loss coming from energy price distortions, loss coming from the terms-of-trade effect, and the loss coming from being in a currency union.

Table 7 shows that the welfare loss coming from the terms-of-trade effect is the largest. Energy price distortions, though they affect the inflation rates, do not seem to have a big contribution to the welfare losses. Lastly, being in a currency union does not seem to affect the welfare losses too much, as expected from the robustness checks in Appendix C.3.

Table 7: Decomposition of the welfare loss for uncapped country

%	(i) Autarkies ($\alpha_I = 0$, indep. CBs)	(ii) Trade partners ($\alpha_I = 0.25$, indep. CBs)	(iii) In union ($\alpha_I = 0.25$, one CB)
Energy price	–0.03	–0.03	–0.03
Terms of trade	-	–0.23	–0.23
Currency union	-	-	+0
Total loss	**–0.03**	**–0.26**	**–0.26**

Notes: Decomposition of the welfare loss of the uncapped country after a 15% gas supply shock, in a model with energy production. Preferences are non-homothetic. The losses are in terms of the consumption equivalent relative to the steady state. The first column indicates the welfare loss in the case in which the countries are autarkies, i.e. do not trade ($\alpha_I = 0$) and have independent central banks. The second column relaxes the no-trading assumption ($\alpha_I = 0.25$) but still assumes independent central banks. The third column is the full model, with countries trading and in a currency union.

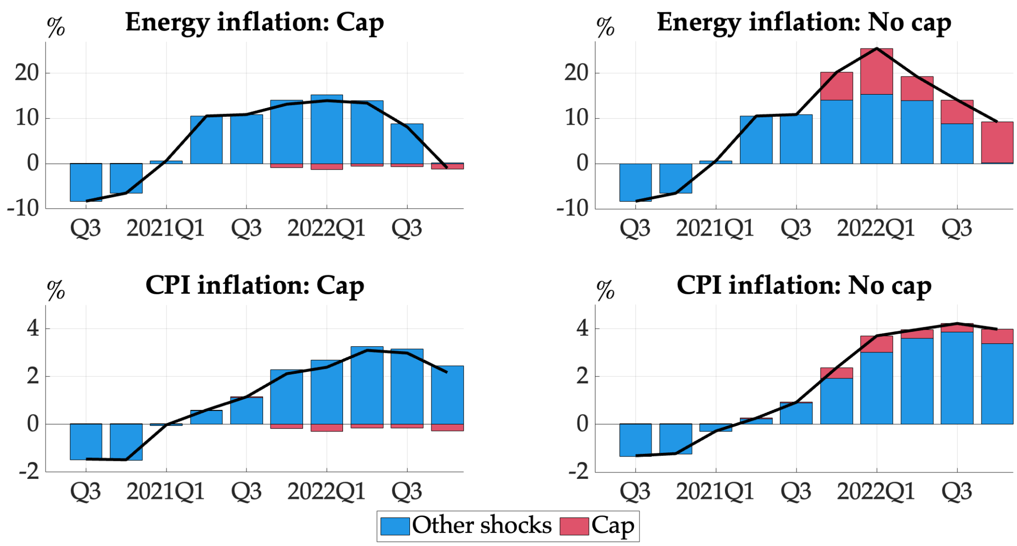
4.3.2 Historical shock decomposition

Using the calibrated and estimated values in Table 4, I perform a historical shock decomposition for the period 2008Q1–2022Q4. Again, I use the Bayesian estimation techniques in Dynare (Adjemian et al., 2024). I use the same shock processes and data series as described for the estimation of the parameters. I add the energy price cap as an additional shock. As before, all shocks follow an AR(1) process and I estimate the coefficients for the shock in the same way as before. After the estimation of the shock processes, I perform a historical shock decomposition. More details on the data and estimation method are in Appendix B.

The historical shock decomposition decomposes the fluctuations in the data series into the contributions from the shocks. The results are in Figure 9. I group all shocks but the energy price cap in one (blue bars) and keep the contributions from the cap separate (red bars). The top-right graph in Figure 9 shows that the energy price cap contributed to about 10 percentage points of energy inflation in the uncapped countries in 2022. In the last quarter of 2022, the price cap was responsible for virtually all of energy inflation in the uncapped countries. Even though the spillovers that the price cap created were large, the top-left graph shows that in the countries with the cap the energy inflation would not have been much higher without it. If there were no energy price caps, the burden of the gas supply shocks would have been shared equally in the union. The partial substitution to non-gas energy mitigates the upward pressure on energy inflation across the entire union.

Similarly, the bottom graphs show that there were negative spillovers of the price cap to the uncapped countries, the upward pressure on CPI inflation: the price cap contributed to about 0.5 percentage points of CPI inflation in the uncapped countries, depending on the quarter. Moreover, the contribution increasing CPI inflation in the uncapped countries was a lot larger than the cap's contribution lowering inflation in the

Figure 9: Historical shock decomposition | Contributions from the energy price cap



Notes: Historical shock decomposition of the annual inflation rates in deviations from the sample mean. "Other shocks" consist of total factor productivity (TFP) shocks for other goods and energy sector, demand shocks, cost-push shocks in the other goods sector, shocks to gas supply, monetary policy shock, and measurement errors for energy consumption and energy inflation. Those shocks and measurement errors are separate for the two countries in the union, except for the monetary policy shock. Mean energy inflation is 2.15% and 2.72% for capped and no-cap countries respectively. Mean CPI inflation is 1.42% and 1.46% for capped and no-cap countries respectively. The red bars indicate the contributions from the energy price cap, whereas the blue bars aggregate all other shocks. More details are in Appendix B.

capped countries.

5 TANK results

In this section I compare the energy price cap with targeted transfers. Most national governments conducted transfers to vulnerable groups in 2022, since the energy crisis affected them the most (Sgaravatti et al., 2023). To create heterogeneity within households, I add poor hand-to-mouth to the model with domestic energy production. A targeted transfer is a transfer to just those hand-to-mouth households. Since labor income is the only source for hand-to-mouth households and hence an important model feature, this version of the model includes elastic labor supply as discussed in Section 3.2.4. Therefore, the model becomes a Two-Agent New Keynesian (TANK) model.

The TANK version of the model does not alter in the transmission mechanism and the spillovers of the price cap and the aggregate welfare results discussed in the previous sections hold. An interesting aspect of the TANK model is its potential for evaluating the effects of targeted policies, such as the transfer program, on different household groups: I compare a country-wide energy price cap (to all households and firms) to a targeted transfer to the hand-to-mouth households. Since low-income, hand-to-mouth households spend a larger share of their income on energy, an adverse energy supply shock is particularly burdensome for them (Bayer et al., 2023). I find that with much lower cost for the government, the targeted transfers achieve more favorable results in terms of boosting consumption for the poor. Moreover, since the transfer does not distort the energy market, there is barely any divergence within the union even if only one country implements the transfers.

5.1 Adding hand-to-mouth households to the model

In the two-agent version of the model, there are financially constrained households who represent share $\lambda \in [0, 1]$ of the population, and unconstrained households who are share $1 - \lambda$. Financially constrained households have no access to the one-period bonds. Moreover, they earn no profits from firms nor the energy sellers. The budget constraints of the constrained and unconstrained households are respectively:

$$exp_t^c = P_{Et} e_t^{h,c} + P_{Rt} c_{Rt}^c = W_t n_t^c + P_t \tau_t^c + \mathcal{T} - T_t^c \tag{36}$$

$$exp_t^u = P_{Et} e_t^{h,u} + P_{Rt} c_{Rt}^u = W_t n_t^u + \frac{1-\delta}{1-\lambda} D_t + \frac{1}{1-\lambda} D_t^E + R_{t-1} \frac{B_{t-1}}{1-\lambda} - \frac{B_t}{1-\lambda} - HC_t + P_{Rt} \tau_t^u - T_t^u \tag{37}$$

where superscript c refers to variables belonging to constrained households and u to unconstrained ones. τ_t are redistributive transfers from the government explained below. $\mathcal{T}$ is a steady-state transfer from the constrained to unconstrained, to make sure their consumption is equal in steady state. The preferences are the same for both households and include the disutility for labor supply as in 3.2.4.

I aggregate energy and other goods consumption and labor as:

$$\lambda e_t^{h,c} + (1-\lambda) e_t^{h,u} = E_t^h \tag{38}$$

$$\lambda c_{Rt}^c + (1-\lambda) c_{Rt}^u = C_{Rt} \tag{39}$$

$$\lambda n_t^c + (1-\lambda) n_t^u = N_t \tag{40}$$

Labor supply of constrained and unconstrained households are therefore identical to the firms.

Following Debortoli and Galí (2018) and Komatsu (2023), the fiscal authority redistributes the taxed profits from firms D_t as transfers to the constrained households, τ_t^c, and unconstrained households, τ_t^u, according to the rules:

$$\tau_t^c = (1-\tau_0)\delta D_t \tag{41}$$

$$\tau_t^u = \left(1 + \frac{\tau_0 \lambda}{1-\lambda}\right)\delta D_t \tag{42}$$

where δ is the tax rate on firms' profits, where τ_0 indicates how much of the profits go to (un)constrained households, using $\lambda \tau_t^c + (1-\lambda)\tau_t^u = \delta D_t$. So, when τ_0 is equal to unity, all profits go back to the unconstrained households.

Calibration. The Household Finance and Consumption Survey (HFCS, 2022) collects household-level data in the Eurozone and estimate that credit-constrained households make up around 5-10% of the population. Hence, in the TANK version, the share of hand-to-mouth households, λ, is 0.1.[33] For the redistribution of taxed firms' profits, I set the tax rate on firm's profits at $\delta = 0.215$, which was the average corporate tax rate in 2022 of European OECD countries (Bray, 2023). The redistribution rule, τ, is equal to unity, such that all profits go to unconstrained households. All other calibration values are identical to the baseline model and the model with domestic energy production.

Consumption response decomposition. In the next subsection I investigate the consumption responses of constrained and unconstrained households in detail. Hence, I perform an impulse response decomposition by rearranging the log-linearized equations. Hatted variables indicate log-linear deviations from steady state.

For constrained households, take total consumption as a sum of energy consumption and other goods consumption:

$$\hat{c}_t^c = \frac{\bar{e}^c}{\bar{c}^c}\hat{e}_t^c + \frac{\bar{c}_R^c}{\bar{c}^c}\hat{c}_{Rt}^c \tag{43}$$

Using the choice between energy and other goods, Eq. (2), the definition of the energy expenditure wedge, Eq. (3), and their budget constraint, Eq. (36), I decompose the consumption of the constrained households:

$$\hat{c}_t^c = \underbrace{\mathbf{A^c}\hat{e}_t^c + \mathbf{B}\hat{p}_t^{rel,ER}}_{\text{energy consumption}} + \underbrace{\mathbf{C}\hat{w}_t}_{\text{real wage}} - \underbrace{\mathbf{D}\hat{t}_t}_{\text{taxes}} \tag{44}$$

where $\mathbf{A^c} = \frac{1}{\bar{c}^c}\left(\bar{e}^c + \bar{c}_R^c\right)$, $\mathbf{B} = \frac{\bar{c}_R^c}{\bar{c}^c}\left[1 + \frac{1}{1-\alpha_E}\left(\frac{1}{\overline{exp}}\varepsilon_1 \bar{W}\bar{N}\alpha_E - \varepsilon_2\right)\right]$, $\mathbf{C} = \frac{\bar{c}_R^c}{\bar{c}^c}\frac{1}{(1-\alpha_E)\overline{exp}}\varepsilon_1 \bar{W}\bar{N}$, and $\mathbf{D} = \frac{\bar{c}_R^c}{\bar{c}^c}\frac{1}{(1-\alpha_E)\overline{exp}}\varepsilon_1 \lambda$.

[33] 5-10% is the share of so-called "poor" hand-to-mouth households. When including the share of "wealthly" hand-to-mouth households, who own illiquid assets, the share of hand-to-mouth households rises to about 30%.

Analogously for unconstrained households, decompose total consumption using the choice between energy and other goods, Eq. (2), the definition of the energy expenditure wedge, Eq. (3):

$$\hat{c}_t^u = \underbrace{\mathbf{A^u}\hat{e}_t^u + \mathbf{E}\hat{p}_t^{rel,ER}}_{\text{energy consumption}} + \underbrace{\mathbf{F}e\hat{x}p_t}_{\text{consumption smoothing}} \tag{45}$$

where $\mathbf{A^u} = \frac{1}{\bar{c}^u}\left(\bar{e}^u + \bar{c}_R^u\right)$, $\mathbf{E} = \frac{\bar{c}_R^u}{\bar{c}^u}\left(1 - \frac{1}{1-\alpha_E}\varepsilon_2\right)$, and $\mathbf{F} = \frac{\bar{c}_R^u}{\bar{c}^u}\frac{1}{1-\alpha_E}\varepsilon_1$. I call the last term "consumption smoothing", since the Euler equation (9) determines the total nominal expenditures of the unconstrained household, $e\hat{x}p_t$.

5.2 Results: Price cap vs. targeted transfers

The TANK impulse responses after an adverse gas supply shock with one capped and one uncapped country are quantitatively and qualitatively similar to the representative agent model in Figure 8.[34] So, the analysis of the macroeconomic responses and welfare in the previous section still applies to the TANK model.

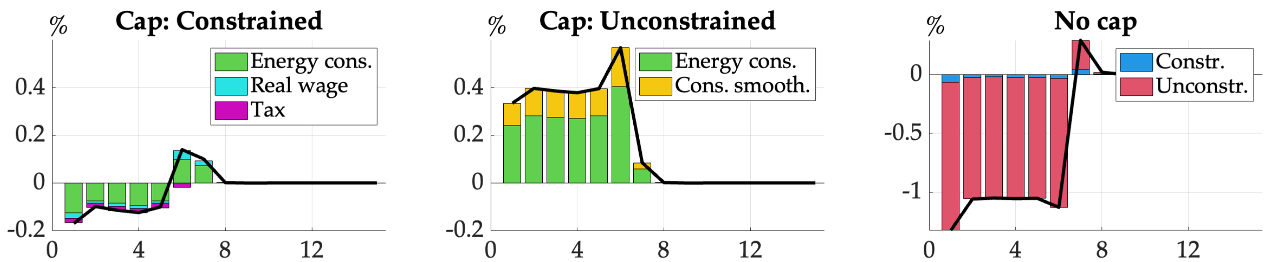
To investigate the consumption responses for constrained and unconstrained in detail, I decompose the consumption responses for the constrained and unconstrained as in Eq. (44) and (45). The results are in Figure 10. For the uncapped country, I decompose the aggregate consumption response into contributions from constrained and unconstrained households.

In the capped country, the consumption of the unconstrained increases, whereas the consumption of the constrained decreases. The unconstrained households increase their consumption both by increasing their energy consumption and from consumption smoothing. Recall the mechanism through which households benefit from the energy price cap in the baseline model: households increase their consumption because they consume cheap goods from the uncapped country, i.e. the capped country consumes more than it produces. This mechanism is *intertemporal*, since the capped country temporarily runs a current account deficit and borrows from abroad while the energy shock takes place. In the two-agent version, only unconstrained households make *intertemporal* decisions. Hence, unconstrained households can increase their consumption, whereas constrained households cannot.

The rightmost graph displays the large spillovers from the capped to uncapped country, similar to previous versions of the model. Because the price cap distorts the energy market in the union, it creates spillovers to the uncapped country. Next, I analyze whether targeted transfers are more effective in helping poorer, constrained households, and whether they create less distortions and spillovers.

[34] The responses for the TANK model are in Figure 19 in Appendix C.

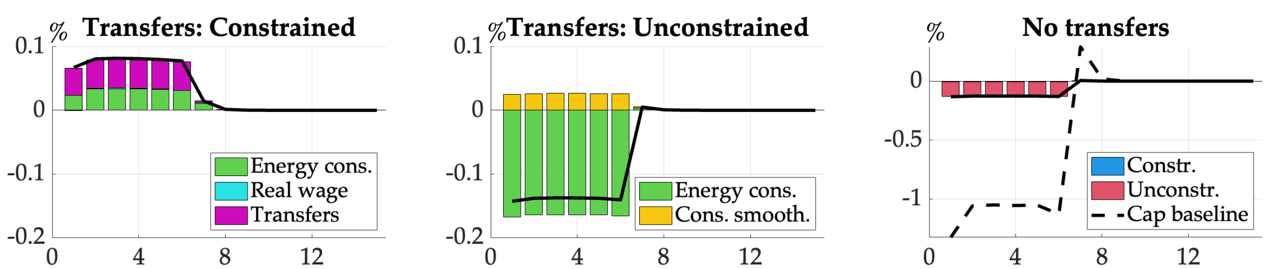
Figure 10: Consumption response decomposition | Cap and no cap



Notes: Impulse responses to a 15% decline in energy supply (black lines) and the decomposition of the responses (colored bars). Preferences are non-homothetic. The bigger country, of size Θ imposes a price cap on the energy price (left two panels) and the smaller country, of size $1-\Theta$ does not (rightmost panel). The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

Targeted transfers. For easy comparison with the price cap, I set the targeted transfers to the same per person government expenditure, but only for the constrained households. Since they are 10% of the population, the specified targeted transfer only costs 10% of the cost of the price cap. The consumption responses are in Figure 11. The left graph shows that the targeted transfers are effective in increasing the constrained household's consumption, while not lowering the consumption of the unconstrained too much. Moreover, the spillovers to the country without transfers substantially smaller than under the cap.

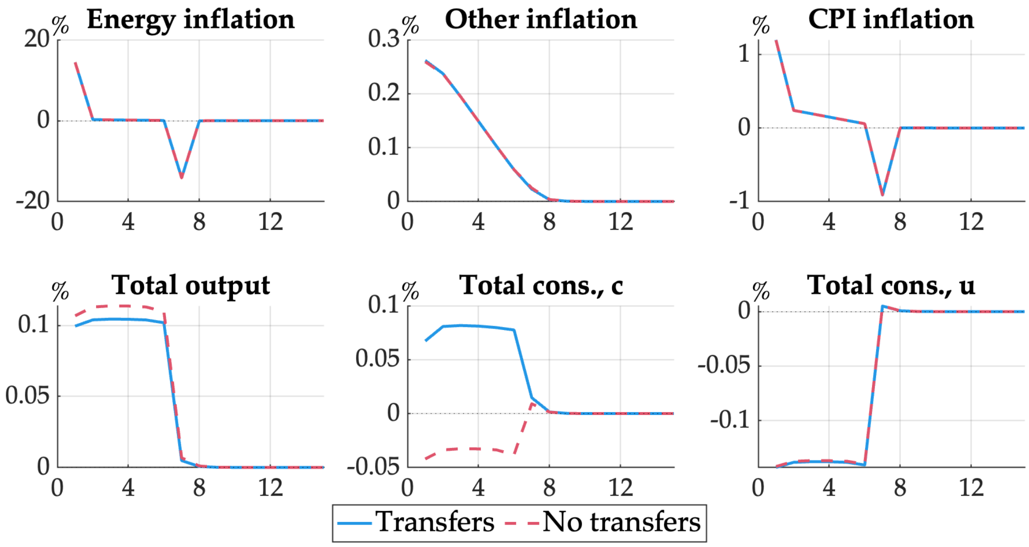
Figure 11: Consumption response decomposition | Transfers and no transfers



Notes: Impulse responses to a 15% decline in energy supply (black lines) and the decomposition of the responses (colored bars). Preferences are non-homothetic. The bigger country, of size Θ conducts targeted transfers to the constrained households (left two panels) and the smaller country, of size $1-\Theta$ does not (rightmost panel). The dashed line indicates the baseline scenario with the energy price cap. The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

The responses of some other macroeconomic variables for both the country with and without transfers are in Figure 12. Because transfers do not distort the integrated energy market in the currency union, they do not create much divergence within the union. The inflation response is significantly milder than in the case with price caps. So, together with the absence of divergence, the transfers are more preferable for the common central bank when stabilizing the inflation rates across the union. Moreover, the spillover in terms of consumption are also substantially lower than with the price cap.

Figure 12: Responses to an adverse energy shock | Transfers vs. no transfers



Notes: Impulse responses to a 15% decline in energy supply. Preferences are non-homothetic. The bigger country, of size Θ conducts targeted transfers to the constrained (c) households (blue, solid) and the smaller country, of size $1-\Theta$ does not (red, dashed). u stands for the unconstrained households. Output is equal to the output gap. The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

5.3 Discussion: A debt-financed energy price cap in a non-Ricardian monetary union

Contrary to the baseline model, Ricardian Equivalence does not hold in the TANK version of the model. If a country finances its cost of implementing the price cap through debt, being part of a monetary union prevents that country to fully benefit from the cap.

Considering the case of a two-country monetary union with one capped and one uncapped country, the capped country can limit the surge in inflation rates, whereas the uncapped country cannot. Since the countries are in a monetary union, the interest rates set by the central bank are too high for the capped country while too low for the uncapped country. Assuming the capped country financed its cap implementation costs through debt, the country faces debt-servicing costs higher than desired due to not having its own monetary policy. I intend to explore this idea in greater depth in future work.

6 Conclusion

This paper investigates the trade-offs of imposing an energy price cap during an energy crisis, based on the Euro Area energy crisis in 2022. I introduce a shared energy supply as an additional dimension of integration to a New Keynesian currency union model with two countries and rationalize the decisions that policymakers made in 2022. An adverse energy supply shock causes high energy inflation and a cost-push shock in the non-energy, core sector. I show that the cooperative policy is to refrain from introducing price caps. However, for an individual country it is welfare improving to impose a price cap, if the other country does not: the capped country avoids the crisis while the uncapped country experiences a supply shock of twice the magnitude.

The magnitude of those spillovers determine the preferred policy decisions – To cap or not to cap? On the one hand, a price cap ensures that households can maintain energy consumption levels. On the other hand, a cap is a cost to the government, and therefore ultimately the households. When one country imposes a price cap, the uncapped country incurs negative spillovers. So, there is a trade-off between paying for the cap and the paying for the negative spillovers. The magnitude of the spillovers depend on the non-homotheticity of preferences and the substitutability of energy sources. The quantitative model with both ingredients show that the cost of funding the price cap exceeds the costs of bearing negative spillovers. This result explains why some Euro Area countries did not introduce a price cap in 2022, while others did.

Moreover, I perform some counterfactual exercises. First, I use a historical shock decomposition to examine what energy and headline inflation would have been in the Euro Area in 2022 if none of the countries imposed an energy price cap. I find that the energy price cap contributed to about 10 percentage points to energy inflation and 0.5 percentage points to headline inflation in 2022. Second, I compare the energy price cap with targeted transfers and show that targeted transfers to those households is cheaper and more effective in boosting consumption of the poor. In addition, because the transfers do not distort the energy price, there is no divergence within the union.

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Appendices

A Model

In this section, I expand on the Household and Firm's side of the model. The market clearing, monetary and fiscal policy parts are as described in the main text.

A.1 Households

A.1.1 Preferences

Indirect utility function with non-homothetic preferences as in Boppart (2014):[35]

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{\varepsilon_1} \left[\left(\frac{exp_t}{P_{Ot}} \right)^{\varepsilon_1} - 1 \right] - \frac{\alpha_E}{\varepsilon_2} \left[\left(\frac{P_{Et}}{P_{Ot}} \right)^{\varepsilon_2} - 1 \right] \right\} \tag{A.1}$$

[35]Indirect utility function $v(p, exp)$: household's maximal attainable utility when faced with vector p of goods prices and an amount of expenditure exp. $v(p, exp) = u(x(p, exp))$. Recall Roy's identity:

$$E^h = -\frac{\partial v/\partial P_E}{\partial v/\partial exp} \qquad c_O = -\frac{\partial v/\partial P_O}{\partial v/\partial exp}$$

where $0 \leq \varepsilon_1 \leq \varepsilon_2 < 1$ and $\alpha_E > 0$. The utility assumes an inelastic labor supply and a per-period utility of the form $v = \frac{1}{\varepsilon_1}\left[\left(\frac{exp_t}{P_{Ot}}\right)^{\varepsilon_1} - 1\right] - \frac{\alpha_E}{\varepsilon_2}\left[\left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2} - 1\right]$. exp_t is the total nominal expenditure of the household on Energy and non-energy (Rest) goods, defined as $exp_t = P_{Et}E_t^h + P_{Ot}C_{Ot}$.

Choice between energy and non-energy other goods. Marshallian demand functions obtained with Roy's identity:

$$E_t^h = -\frac{\partial v / \partial P_{Et}}{\partial v / \partial exp_t} = \frac{\alpha_E \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2 - 1}}{\left(\frac{exp_t}{P_{Ot}}\right)^{\varepsilon_1 - 1}} \tag{A.2}$$

$$C_{Ot} = -\frac{\partial v / \partial P_{Ot}}{\partial v / \partial exp_t} = \frac{\left(\frac{exp_t}{P_{Ot}}\right)^{\varepsilon_1} - \alpha_E \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2}}{\left(\frac{exp_t}{P_{Ot}}\right)^{\varepsilon_1 - 1}} \tag{A.3}$$

Rearrange to express C_{Ot} in terms of E_t^h to get relative demand:[36]

$$C_{Ot} = \frac{\left(\frac{exp_t}{P_{Ot}}\right)^{\varepsilon_1} - \alpha_E \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2}}{\left(\frac{exp_t}{P_{Ot}}\right)^{\varepsilon_1 - 1}} = \frac{1 - \alpha_E \left(\frac{P_{Ot}}{exp_t}\right)^{\varepsilon_1} \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2}}{\frac{P_{Ot}}{exp_t}} = \frac{1 - \alpha_E \varpi_t}{\frac{P_{Ot}}{exp_t}} \tag{A.8}$$

$$= \frac{1 - \alpha_E \varpi_t}{\alpha_E \varpi_t} \frac{P_{Et}}{P_{Ot}} E_t^h \tag{A.9}$$

where

$$\varpi_t = \left(\frac{P_{Ot}}{exp_t}\right)^{\varepsilon_1} \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2} \tag{A.10}$$

is the energy expenditure share wedge. When $\varepsilon_1 = \varepsilon_2 = 0$ (Cobb-Douglas case), then

[36] Another way to rearrange the Marshallian demands:

$$E_t^h = \alpha_E \frac{exp_t}{P_{Et}} \varpi_t = \alpha_E \frac{exp_t}{P_{Et}} \left(\frac{P_{Ot}}{exp_t}\right)^{\varepsilon_1} \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2} \tag{A.4}$$

$$C_{Ot} = \frac{exp_t}{P_{Ot}} (1 - \alpha_E \varpi_t) = \frac{exp_t}{P_{Ot}} \left[1 - \alpha_E \left(\frac{P_{Ot}}{exp_t}\right)^{\varepsilon_1} \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2}\right] \tag{A.5}$$

- With $\varepsilon_1 > 0$, the expenditure elasticity of demand is positive, but strictly smaller than unity for energy and larger than unity for Rest. With $\varepsilon_1 = 0$, they are both equal to unity.
- The expenditure elasticity of demand for energy is $1 - \varepsilon_1$.

The expenditure shares of the two types of goods are:

$$\eta_{Et} = \frac{P_{Et}E_t^h}{exp_t} = \alpha_E \varpi_t = \alpha_E \left(\frac{P_{Ot}}{exp_t}\right)^{\varepsilon_1} \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2} \tag{A.6}$$

$$\eta_{Ot} = \frac{P_{Ot}C_{Ot}}{exp_t} = 1 - \alpha_E \varpi_t = 1 - \alpha_E \left(\frac{P_{Ot}}{exp_t}\right)^{\varepsilon_1} \left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2} \tag{A.7}$$

$C_{Ot} = \frac{1-\alpha_E}{\alpha_E}\frac{P_{Et}}{P_{Ot}}E_t^h$. Define relative total expenditure as:

$$exp_t^{rel} \equiv \frac{exp_t}{P_{Ot}} = \frac{P_{Et}}{P_{Ot}}E_t^h + C_{Ot} \tag{A.11}$$

Choice between Home and Foreign goods. The non-energy goods are bundled in a composite index:

$$C_{Ot} = \left[(1-\alpha_I)^{1/\gamma}(C_{Ht})^{(\gamma-1)/\gamma} + (\alpha_I)^{1/\gamma}(C_{Ft})^{(\gamma-1)/\gamma}\right]^{\gamma/(\gamma-1)} \tag{A.12}$$

where $\alpha_I \in (0,1)$ is the share of imported goods in the consumption basket and γ is the elasticity of substitution between Home and Foreign goods. C_{Ht}, C_{Ft} are consumption indices of H-produced and F-produced goods respectively:

$$C_{Ht} \equiv \left[\int_0^1 C_{Ht}(i)^{(\varepsilon-1)/\varepsilon}di\right]^{\varepsilon/(\varepsilon-1)} \qquad C_{Ft} \equiv \left[\int_0^1 C_{Ft}(i)^{(\varepsilon-1)/\varepsilon}di\right]^{\varepsilon/(\varepsilon-1)} \tag{A.13}$$

where ϵ is the elasticity of substitution between different varieties within Home and Foreign goods. The intratemporal consumption choice between different varieties of H-produced and F-produced non-energy goods is:[37]

$$C_{Ht}(i) = \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\varepsilon}C_{Ht} \qquad C_{Ft}(i) = \left(\frac{P_{Ft}(i)}{P_{Ft}}\right)^{-\varepsilon}C_{Ft} \tag{A.16}$$

where P_{Ht}, P_{Ht} are indices of prices of of H-produced and F-produced goods respectively:

$$P_{Ht} \equiv \left(\int_0^1 P_{Ht}(i)^{1-\varepsilon}di\right)^{1/(1-\varepsilon)} \qquad P_{Ft} \equiv \left(\int_0^1 P_{Ft}(i)^{1-\varepsilon}di\right)^{1/(1-\varepsilon)} \tag{A.17}$$

From Eq. (A.16) and (A.17), aggregate expenditure on H-produced and F-produced goods respectively:

$$\int_0^1 P_{Ht}(i)C_{Ht}(i)di = P_{Ht}C_{Ht} \qquad \int_0^1 P_{Ft}(i)C_{Ft}(i)di = P_{Ft}C_{Ft} \tag{A.18}$$

Intratemporal concumption choice between H-produced and F-produced goods bun-

[37]Solutions to the following problems:

$$\min_{C_{Ht}(i)} \int_0^1 P_{Ht}(i)C_{Ht}(i)di \quad \text{s.t.} \quad \left[\int_0^1 C_{Ht}(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right]^{\frac{\varepsilon}{\varepsilon-1}} \geq C_{Ht} \tag{A.14}$$

$$\min_{C_{Ft}(i)} \int_0^1 P_{Ft}(i)C_{Ht}(i)di \quad \text{s.t.} \quad \left[\int_0^1 C_{Ft}(i)^{\frac{\varepsilon-1}{\varepsilon}}di\right]^{\frac{\varepsilon}{\varepsilon-1}} \geq C_{Ft} \tag{A.15}$$

dle:[38]

$$C_{Ht} = (1-\alpha_I)\left(\frac{P_{Ht}}{P_{Ot}}\right)^{-\gamma} C_{Ot} \qquad\qquad C_{Ft} = \alpha_I \left(\frac{P_{Ft}}{P_{Ot}}\right)^{-\gamma} C_{Ot} \tag{A.19}$$

where P_{Ot} is the aggregate price index for non-energy goods:

$$P_{Ot} = \left[(1-\alpha_I)P_{Ht}^{1-\gamma} + \alpha_I P_{Ft}^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A.20}$$

Combining the intratemporal consumption choice between Home and Foreign goods, I get:

$$\frac{C_{Ht}}{C_{Ft}} = \frac{1-\alpha_I}{\alpha_I}\left(\frac{P_{Ht}}{P_{Ft}}\right)^{-\gamma} \tag{A.21}$$

From Eq. (A.19) and (A.20), aggregate expenditure on non-energy consumption is:

$$\int_0^1 P_{Ht}(i)C_{Ht}(i)di + \int_0^1 P_{Ft}(i)C_{Ft}(i)di = P_{Ht}C_{Ht} + P_{Ft}C_{Ft} = P_{Ot}C_{Ot} \tag{A.22}$$

A.1.2 Intertemporal consumption choices and labor supply

Nominal budget constraint:

$$exp_t = P_{Et}E_t^h + P_{Ot}C_{Ot} = W_tN_t + D_t + D_t^E + R_{t-1}B_{t-1} - B_t - HC_t - T_t \tag{A.23}$$

where D_t is the nominal profit paid by the domestic firms to the representative domestic household and D_t^E the profits from the energy sellers given by:

$$D_t^E = \frac{P_{Et}}{\bar{P}_E}\left(E_t^h + E_t^f\right) \tag{A.24}$$

HC_t are the portfolio adjustment costs of the household:

$$HC_t = \frac{\tilde{\nu}}{2}(B_t - \bar{B})^2 \tag{A.25}$$

where B_t is nominal bond holdings of the household. T_t are lump-sum taxes for the government to finance the energy price cap.

[38]Solution to the following problem:

$$\min_{C_{Ht},C_{Ht}} P_{Ht}C_{Ht} + P_{Ft}C_{Ft} \quad \text{s.t.} \quad \left[(1-\alpha)^{\frac{1}{\gamma}} C_{Ht}^{\frac{\gamma-1}{\gamma}} + \alpha^{\frac{1}{\gamma}} C_{Ft}^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}} \geq C_{Ot}$$

$$\mathcal{L} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{\varepsilon_1} \left[\left(\frac{exp_t}{P_{Ot}} \right)^{\varepsilon_1} - 1 \right] - \frac{\alpha_E}{\varepsilon_2} \left[\left(\frac{P_{Et}}{P_{Ot}} \right)^{\varepsilon_2} - 1 \right] \right.$$
$$\left. + \lambda_t \left[W_t N_t + D_t + D_t^E + R_{t-1} B_{t-1} - B_t - HC_t - exp_t \right] \right\} \quad (A.26)$$

$$\frac{\partial \mathcal{L}}{\partial exp_t} : \quad exp_t^{\varepsilon_1 - 1} P_{Ot}^{-\varepsilon_1} - \lambda_t = 0 \quad (A.27)$$
$$\frac{\partial \mathcal{L}}{\partial B_t} : \quad \lambda_t = \beta R_t \mathbb{E}_t[\lambda_{t+1}] \quad (A.28)$$

Euler equation:

$$\left(\frac{\mathbb{E}_t \left[exp_{t+1} \right]}{exp_t} \right)^{1-\varepsilon_1} = \beta \frac{R_t}{1 + P_t \tilde{\nu}(b_t - \bar{b})} \mathbb{E}_t \left[\left(\frac{1}{\Pi_{O,t+1}} \right)^{\varepsilon_1} \right] \quad (A.29)$$

where $b_t = \frac{B_t}{P_t}$ is real bond holdings and $\Pi_{Ot} = \frac{P_{Ot}}{P_{O,t-1}}$ is gross inflation. Inelastic labor means $N_t = \bar{N}$.

A.2 Firms

There is monopolistic competition among intermediate firms producing the other consumption goods. They face adjustment costs à la Rotemberg (1982).

Cost minimization

$$\min_{N_t(i), E_t^f(i)} W_t N_t(i) + P_{Et} E_t^f(i) \quad (A.30)$$

$$\text{s.t. demand curve} \quad Y_t(i) = \left(\frac{P_{Ht}(i)}{P_{Ht}} \right)^{-\epsilon} Y_t \quad (A.31)$$

$$\text{production function} \quad Y_t(i) = A_t \left[\left(\alpha^f\right)^{1/\theta^f} \left(E_t^f(i) \right)^{(\theta^f - 1)/\theta^f} + \left(1 - \alpha^f\right)^{1/\theta^f} \left(N_t(i)\right)^{(\theta^f - 1)/\theta^f} \right]^{\theta^f/(\theta^f - 1)} \quad (A.32)$$

First order condition w.r.t. $N_t(i)$ and $E_t^f(i)$:[39]

$$W_t = \left(1-\alpha^f\right)^{1/\theta^f} \mu_t^{nom} \left(\frac{Y_t(i)}{N_t(i)}\right)^{1/\theta^f} A_t^{(\theta^f-1)/\theta^f} \tag{A.33}$$

$$P_{Et} = \left(\alpha^f\right)^{1/\theta^f} \mu_t^{nom} \left(\frac{Y_t(i)}{E_t^f(i)}\right)^{1/\theta^f} A_t^{(\theta^f-1)/\theta^f} \tag{A.34}$$

Combining these equations, we get that the relative price of the production inputs determine the trade-off between them:

$$\frac{E_t^f(i)}{N_t(i)} = \frac{\alpha^f}{1-\alpha^f}\left(\frac{P_{Et}}{W_t}\right)^{-\theta^f} \tag{A.35}$$

The total factor productivity:

$$\ln(A_t) \equiv a_t = \rho_a a_{t-1} + \varepsilon_t^a \tag{A.36}$$

Price setting

$$\max_{P_{Ht}(i),N_t(i)} \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{t+1}\left[\frac{P_{Ht}(i)}{P_{Ht}} Y_t(i) - \frac{W_t}{P_{Ht}} N_t(i) - P_{Et}E_t^f(i) - Y_t FC_t\right] \tag{A.37}$$

$$\text{s.t. demand curve} \quad Y_t(i) = \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\epsilon} Y_t \tag{A.38}$$

$$\text{price adjustment costs} \quad FC_t(i) = \frac{\xi}{2}\left(\frac{P_{Ht}(i)}{P_{H,t-1}(i)} - 1\right)^2 \tag{A.39}$$

where $\Lambda_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma}$ is the stochastic discount factor and $\int_0^1 P_{Ht}(i) = P_{Ht}$ the average price of H goods. First order condition w.r.t. $P_{Ht}(i)$ is:[40]

$$\begin{aligned}(1-\epsilon)\left(\frac{P_{Ht}(i)}{P_{Ht}}\right)^{-\epsilon}\frac{1}{P_{Ht}}Y_t(i) - \xi\left(\frac{P_{Ht}(i)}{P_{H,t-1}(i)} - 1\right)\frac{1}{P_{H,t-1}(i)}Y_t(i) \\ + \mu_t\epsilon P_{Ht}(i)^{-\epsilon-1}\left(\frac{1}{P_{Ht}}\right)^{-\epsilon} Y_t(i) + \mathbb{E}_t\left[\Lambda_{t+1}\xi\left(\frac{P_{H,t+1}(i)}{P_{Ht}(i)} - 1\right) Y_{t+1}(i)\left(\frac{P_{H,t+1}(i)}{P_{Ht}(i)^2}\right)\right] = 0\end{aligned} \tag{A.40}$$

Imposing the symmetric equilibrium conditions $P_{Ht}(i) = P_{Ht}$ and $Y_t(i) = Y_t$, derive the New Keynesian Philips Curve (NKPC):

$$(1-\epsilon) - \xi\left(\Pi_{Ht} - 1\right)\Pi_{Ht} + \mu_t\epsilon + \beta\mathbb{E}_t\left[\xi\left(\Pi_{H,t+1} - 1\right)\Pi_{H,t+1}\frac{Y_{t+1}}{Y_t}\right] = 0 \tag{A.41}$$

[39] The Lagrange multiplier on the demand curve μ_t^{nom} is the nominal marginal cost.
[40] The Lagrange multiplier on the demand curve μ_t is the real marginal cost.

where $\Pi_{Ht} = \left(\frac{P_{Ht}(i)}{P_{Ht}}\right)$ is inflation of the Home-produced good.
Aggregate price adjustment costs:

$$FC_t = \int_0^1 FC_t(i)di \tag{A.42}$$

Aggregate nominal profits:

$$D_t = P_{Ht}Y_t\left(1 - FC_t\right) - W_tN_t - P_{Et}E_t^f \tag{A.43}$$

A.3 Summary of model equations

Relative prices

$$P_{Ot} = \left[(1-\alpha_I)P_{Ht}^{1-\gamma} + \alpha_I P_{Ft}^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A.44}$$

$$P_{Ot}^* = \left[\alpha_I^* P_{Ht}^{1-\gamma} + (1-\alpha_I^*)P_{Ft}^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A.45}$$

$$P_t = \alpha_E \log P_{Et} + (1-\alpha_E)\log P_{Ot} \tag{A.46}$$

$$P_t^* = \alpha_E \log P_{Et}^* + (1-\alpha_E)\log P_{Ot}^* \tag{A.47}$$

$$S_t = \frac{P_{Ft}}{P_{Ht}} \tag{A.48}$$

$$P_t^{rel,EO} = \frac{P_{Et}}{P_{Ot}} \tag{A.49}$$

$$P_t^{rel,EO*} = \frac{P_{Et}^*}{P_{Ot}^*} \tag{A.50}$$

$$P_{Et} = P_{Et}^* \tag{A.51}$$

Households.

$$C_t = E_t^h + C_{Ot} \tag{A.52}$$

$$C_t^* = E_t^{h*} + C_{Ot}^* \tag{A.53}$$

$$C_{Ot} = \left[(1-\alpha_I)^{1/\gamma}\left(C_{Ht}\right)^{(\gamma-1)/\gamma} + (\alpha_I)^{1/\gamma}\left(C_{Ft}\right)^{(\gamma-1)/\gamma}\right]^{\gamma/(\gamma-1)} \tag{A.54}$$

$$C_{Ot}^* = \left[(1-\alpha_I^*)^{1/\gamma}\left(C_{Ft}^*\right)^{(\gamma-1)/\gamma} + (\alpha_I^*)^{1/\gamma}\left(C_{Ht}^*\right)^{(\gamma-1)/\gamma}\right]^{\gamma/(\gamma-1)} \tag{A.55}$$

$$\frac{C_{Ht}}{C_{Ft}} = \frac{1-\alpha_I}{\alpha_I}\left(\frac{P_{Ht}}{P_{Ft}}\right)^{-\gamma} = \frac{1-\alpha_I}{\alpha_I}S_t^{\gamma} \tag{A.56}$$

$$\frac{C_{Ht}^*}{C_{Ft}^*} = \frac{1-\alpha_I^*}{\alpha_I^*}\left(\frac{P_{Ht}}{P_{Ft}}\right)^{-\gamma} = \frac{1-\alpha_I^*}{\alpha_I^*}S_t^{\gamma} \tag{A.57}$$

$$C_{Ot} = \frac{[1-\alpha_E\varpi_t]}{\alpha_E\varpi_t}P_t^{rel,EO}E_t^h \tag{A.58}$$

$$C_{Ot}^* = \frac{[1-\alpha_E\varpi_t^*]}{\alpha_E\varpi_t^*}P_t^{rel,EO*}E_t^{h*} \tag{A.59}$$

$$\varpi_t = \left(\frac{P_{Ot}}{exp_t}\right)^{\varepsilon_1}\left(\frac{P_{Et}}{P_{Ot}}\right)^{\varepsilon_2} = \left(exp_t^{rel}\right)^{-\varepsilon_1}\left(P_t^{rel,EO}\right)^{\varepsilon_2} \tag{A.60}$$

$$\varpi_t^* = \left(\frac{P_{Ot}^*}{exp_t^*}\right)^{\varepsilon_1}\left(\frac{P_{Et}^*}{P_{Ot}^*}\right)^{\varepsilon_2} = \left(exp_t^{rel*}\right)^{-\varepsilon_1}\left(P_t^{rel,EO*}\right)^{\varepsilon_2} \tag{A.61}$$

$$exp_t^{rel} = P_t^{rel,EO}E_t^h + C_{Ot} \tag{A.62}$$

$$exp_t^{rel*} = P_t^{rel,EO*}E_t^{h*} + C_{Ot}^* \tag{A.63}$$

$$N_t = \bar{N} \tag{A.64}$$

$$N_t^* = \bar{N} \tag{A.65}$$

$$\left(\frac{\mathbb{E}_t\left[exp_{t+1}^{rel}\right]}{exp_t^{rel}}\right)^{1-\varepsilon_1} = \beta\frac{R_t}{1+P_{Ot}\tilde{\nu}(b_t-\bar{b})}\mathbb{E}_t\left[\Pi_{O,t+1}^{-1}\right] \tag{A.66}$$

$$\left(\frac{\mathbb{E}_t\left[exp_{t+1}^{rel*}\right]}{exp_t^{rel*}}\right)^{1-\varepsilon_1} = \beta\frac{R_t}{1+P_{Ot}^*\tilde{\nu}(b_t^*-\bar{b})}\mathbb{E}_t\left[\left(\Pi_{O,t+1}^*\right)^{-1}\right] \tag{A.67}$$

Firms.

$$Y_t = A_t \left[\left(\alpha^f\right)^{1/\theta^f} \left(E_t^f\right)^{(\theta^f-1)/\theta^f} + \left(1-\alpha^f\right)^{1/\theta^f} \left(N_t\right)^{(\theta^f-1)/\theta^f} \right]^{\theta^f/(\theta^f-1)} \tag{A.68}$$

$$Y_t^* = A_t^* \left[\left(\alpha^f\right)^{1/\theta^f} \left(E_t^{f*}\right)^{(\theta^f-1)/\theta^f} + \left(1-\alpha^f\right)^{1/\theta^f} \left(N_t^*\right)^{(\theta^f-1)/\theta^f} \right]^{\theta^f/(\theta^f-1)} \tag{A.69}$$

$$\ln(A_t) \equiv \hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_t^a \tag{A.70}$$

$$\ln(A_t^*) \equiv \hat{a}_t^* = \rho_a \hat{a}_{t-1}^* + \varepsilon_t^{a*} \tag{A.71}$$

$$\frac{W_t}{P_t} = \left(1-\alpha^f\right)^{1/\theta^f} \mu_t \left(\frac{Y_t}{N_t}\right)^{1/\theta^f} A_t^{(\theta^f-1)/\theta^f} \tag{A.72}$$

$$\frac{W_t^*}{P_t^*} = \left(1-\alpha^f\right)^{1/\theta^f} \mu_t^* \left(\frac{Y_t^*}{N_t^*}\right)^{1/\theta^f} \left(A_t^*\right)^{(\theta^f-1)/\theta^f} \tag{A.73}$$

$$\frac{P_{Et}}{P_t} = \left(\alpha^f\right)^{1/\theta^f} \mu_t \left(\frac{Y_t}{E_t^f}\right)^{1/\theta^f} A_t^{(\theta^f-1)/\theta^f} \tag{A.74}$$

$$\frac{P_{Et}}{P_t^*} = \left(\alpha^f\right)^{1/\theta^f} \mu_t^* \left(\frac{Y_t^*}{E_t^{f*}}\right)^{1/\theta^f} \left(A_t^*\right)^{(\theta^f-1)/\theta^f} \tag{A.75}$$

$$\left(\Pi_{Ht}-1\right)\Pi_{Ht} = \frac{\epsilon}{\xi}(\mu_t - \bar{\mu}) + \beta \mathbb{E}_t \left[\left(\Pi_{H,t+1}-1\right)\Pi_{H,t+1} \frac{Y_{t+1}}{Y_t} \right] \tag{A.76}$$

$$\left(\Pi_{Ft}-1\right)\Pi_{Ft} = \frac{\epsilon}{\xi}(\mu_t^* - \bar{\mu}) + \beta \mathbb{E}_t \left[\left(\Pi_{F,t+1}-1\right)\Pi_{F,t+1} \frac{Y_{t+1}^*}{Y_t^*} \right] \tag{A.77}$$

Goods market clearing.

$$Y_t = (1-\alpha_I)\left(P_{Ht}^{rel}\right)^{-\theta} C_{Ht} + \alpha_I \left(P_{Ht}^{rel*}\right)^{-\theta} C_{Ht}^* + AC_t + FC_t + T_t \tag{A.78}$$

$$Y_t^* = \alpha_I \left(P_{Ft}^{rel}\right)^{-\theta} C_{Ft} + (1-\alpha_I)\left(P_{Ft}^{rel*}\right)^{-\theta} C_{Ft}^* + AC_t^* + FC_t^* \tag{A.79}$$

Energy market clearing.

$$E_t = E_t^h + E_t^{h*} + E_t^f + E_t^{f*} \tag{A.80}$$

$$E_t = E_{t-1}^{\rho_e} \bar{E}^{1-\rho_e} \exp(\varepsilon_t^e) \tag{A.81}$$

Bonds market clearing.

$$CA_t = r_{t-1} b_{t-1}^h + P_{Ht} Y_t \left(1 - FC_t\right) - P_{Ot} C_{Ot} - HC_t \tag{A.82}$$

$$CA_t^* = r_{t-1} b_{t-1}^{h*} + P_{Ft} Y_t^* \left(1 - FC_t^*\right) - P_{Ot}^* C_{Ot}^* - HC_t^* \tag{A.83}$$

$$\left(CA_t\right)^{\Theta} = -\left(CA_t^*\right)^{1-\Theta} \tag{A.84}$$

$$\left(b_t^h\right)^{\Theta} = -\left(b_t^{h*}\right)^{1-\Theta} \tag{A.85}$$

Monetary policy.

$$R_t = \frac{1}{\beta}\left(\frac{\Pi_t^W}{\bar{\Pi}^W}\right)^{\phi_\pi}\left(\frac{Y_t^W}{\bar{Y}_t^W}\right)^{\phi_y}\exp(\nu_t) \tag{A.86}$$

$$\nu_t = \rho^\nu \nu_{t-1} + \varepsilon_t^\nu \tag{A.87}$$

Fiscal policy.

$$P_{Et}^{eff} = P_{Et} - CAP_t \tag{A.88}$$

$$CAP_t = P_{Et} - \bar{P}_E \tag{A.89}$$

$$CAP_t(E_t^h + E_t^f) = T_t \tag{A.90}$$

$$CAP_t^{exp} = \frac{CAP_t\left(E_t^h + E_t^f\right)}{Y_t} \tag{A.91}$$

A.4 Steady state

This section characterizes the steady state of the Home economy. The Foreign economy is identical. In steady state, the prices are constant. Hence, the inflation rates are all equal to unity.

$$\bar{\Pi} = 1 \tag{A.92}$$

$$\bar{\Pi}_E = 1 \tag{A.93}$$

$$\bar{\Pi}_O = 1 \tag{A.94}$$

I take $\bar{P}_O = 1$ as the numeraire. With the below calculations, I get the exogenous level of energy $\bar{E}$ which sets the steady-state price of energy also equal to unity, so $\bar{P}_E = 1$.

Demand side. Taking the Euler equation in steady state, I can express the steady state nominal interest rate as a function of the discount factor:

$$\bar{R} = \frac{1}{\beta} \tag{A.95}$$

Moreover, I assume that the energy expenditure wedge ϖ_t is unity in steady state, so that the expenditure shares of energy and the other consumption goods are the same as in the benchmark Cobb-Douglas case:

$$\bar{\varpi} = 1 \tag{A.96}$$

Then, since prices are equal to unity in steady state, I obtain that steady-state total expenditure of the household from the food expenditure wedge equation:

$$e\bar{x}p = \bar{\varpi}^{1/\varepsilon_1} \tag{A.97}$$

From the Marhsallian demands from Footnote 36, derive the steady-state values for energy and other goods consumption:

$$\bar{E}^h = \alpha_E e\bar{x}p\bar{\varpi} \tag{A.98}$$

$$\bar{C}_O = (1 - \alpha_E\bar{\varpi})e\bar{x}p \tag{A.99}$$

Then, from the goods market clearing condition, get the steady-state output value:

$$Y = (1 - \alpha_I)\bar{C}_O + \alpha_I^*\bar{C}_O^* \tag{A.100}$$

Supply side. From the price-setting equation of the firms, get the steady-state real marginal cost:

$$\bar{\mu} = \frac{\epsilon - 1}{\epsilon} \tag{A.101}$$

Since $\exp(\bar{a})$ scales the economy, I set the total factor productivity $\bar{a}$ such that $\exp(a) = 1$:

$$\bar{a} = 0 \tag{A.102}$$

From the energy demand equation of the firms, get the steady-state value for the firms' energy use:

$$\bar{E}^f = \alpha^f(\bar{\mu})^{\theta^f}\bar{Y} \tag{A.103}$$

Then, from the production function, obtain the steady-state value for labor:

$$\bar{N} = \left[\frac{Y - \left(\alpha^f\right)^{1/\theta^f}\left(\bar{E}^f\right)^{(\theta^f-1)/\theta^f}}{\left(1-\alpha^f\right)^{1/\theta^f}}\right]^{(\theta^f)/(\theta^f-1)} \tag{A.104}$$

Using the steady-state values for labor, output and marginal cost, get the real wage:

$$\bar{W}^{real} = \left(1 - \alpha^f\right)^{1/\theta^f}\bar{\mu}\left(\frac{\bar{Y}}{\bar{N}}\right)^{1/\theta^f} \tag{A.105}$$

The profits in steady state are:

$$\bar{D} = Y - \bar{W}^{real}\bar{N} - \bar{E}^f \tag{A.106}$$

Check supply and demand side are consistent. From the budget constraint of the household, check that the following equation holds:

$$e\bar{x}p = \bar{W}^{real}\bar{N} + \bar{D} + \bar{E}^h + \bar{E}^f \tag{A.107}$$

For the two-agent version, check that the aggregate budget constraint (constrained and unconstrained household holds combined) holds:

$$e\bar{x}p = \bar{W}\bar{N} + (1-\delta)\bar{D} + \bar{E}^h + \bar{E}^f + \lambda\tau_t^c + (1-\lambda)\tau_t^u \tag{A.108}$$

A.5 Domestic energy production sector

The oligopolistic energy firm's problem is

$$\max_{N_{Et}} P_{Et}Y_{Et} - W_t N_{Et} \tag{A.109}$$

$$\text{s.t. production fucntion } Y_{Et} = A_{Et}N_{Et}^{\eta} \tag{A.110}$$

The first-order condition gives rise to the labor demand:

$$N_{Et} = \left(\eta A_{Et}\frac{P_{Et}}{W_t}\right)^{\frac{1}{1-\eta}}, \tag{A.111}$$

which determines the energy production:

$$Y_{Et} = A_{Et}^{\frac{1}{1-\eta}}\left(\eta\frac{P_{Et}}{W_t}\right)^{\frac{\eta}{1-\eta}} \tag{A.112}$$

and the profits of the energy firm:

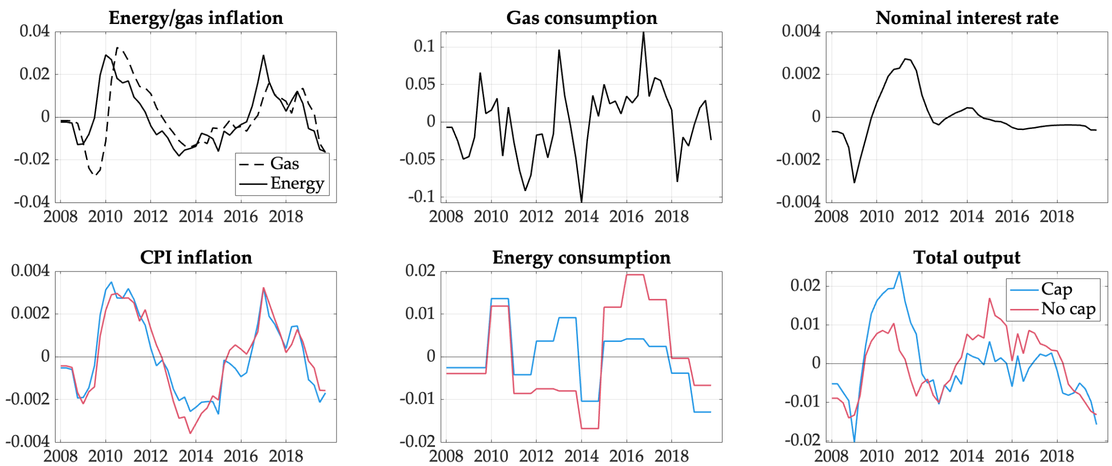
$$D_{Et} = (1-\eta)P_{Et}Y_{Et} \tag{A.113}$$

B Bayesian estimation: Details on data used and results

In this section, I describe and present the data used for Bayesian estimation. For the first estimation, to estimate the parameters, I use data from before the COVID-19 pandemic, so 2008Q1 – 2019Q4. For the second estimation, to perform a historic shock decomposition of the shock, I use data up to 2022Q4. I seasonally adjust the all data series with X-13ARIMA-SEATS. When the data is monthly, I transform the data to get quarterly equivalents. To get the aggregates for "Cap" and "No cap" countries, I take weighted averages with country weights from Eurostat Data. Finally, I detrend the data with the one-sided Hodrick-Prescott filter and demean the series to match the model variables.

Pre-pandemic data for estimating parameters. The data used for the estimation parameters are in Figure 13.[41] Since the price cap policy only took place in 2022, the energy and gas inflation in the union is the same across countries. Using gas consumption as a common variable avoids stochastic singularity. Since I assume that the countries in the union share one supply of gas, when the gas price is the same across countries the gas consumption also needs to be the same. Nominal interest is the rate that the European Central Bank sets. Energy consumption is yearly data. Hence, I allow for measurement errors in the model to capture quarterly fluctuations.

Figure 13: Data used for estimation of parameters



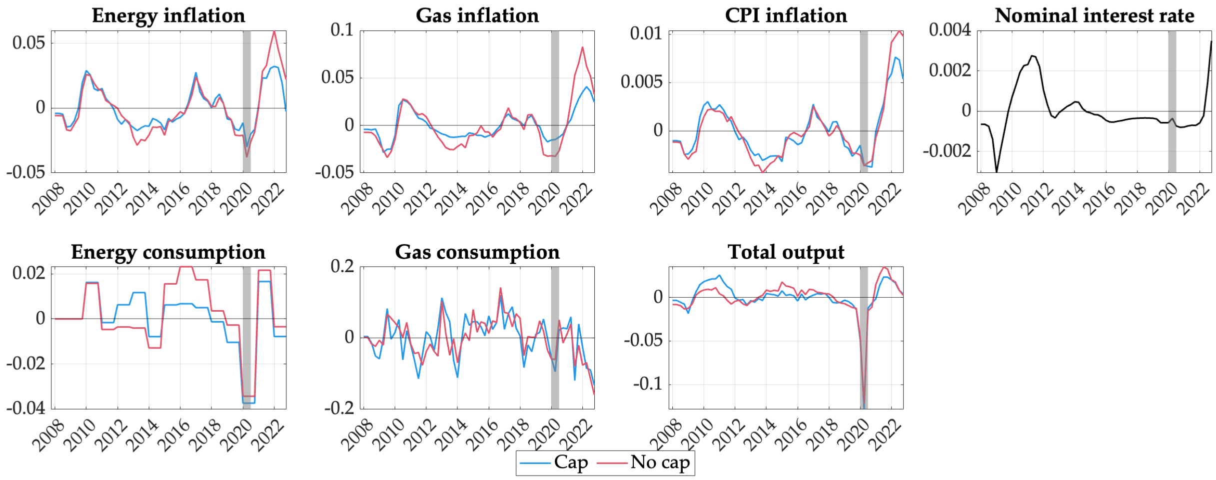
Notes: Plot of the Euro Area data used in the Bayesian estimation of the parameters. For the lower panels I separate the Euro Area countries into "Cap" and "No cap" countries, according to whether countries imposed an energy cap in 2022 or not. See Figure 2 for details.

Data for historical shock decomposition. The data used for the historical shock decomposition are in Figure 14. The data sources are identical to those for the pre-pandemic data. However, since I detrend the data over a slightly longer sample, the values are somewhat different. Moreover, I only let the energy and gas inflation diverge in 2022. Before 2022, I take the weighted average of the two blocs, since there are no price caps in place. Figure 14 shows that the energy and gas inflation rates moved very closely between "Cap" and "No cap" countries before 2022.

Estimation method. I use the Bayesian estimation approach built in Dynare Adjemian et al. (2024). For the estimation of the parameters, I use a slice optimizer to find the

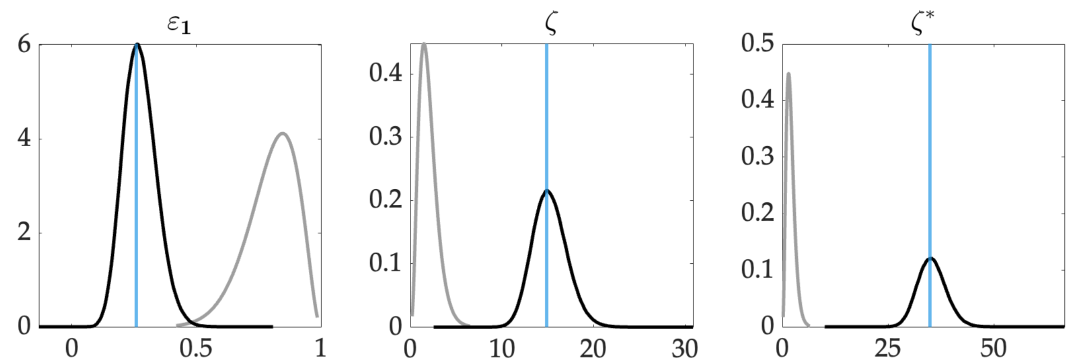
[41]Data sources: Energy, gas, and CPI inflation (Eurostat, prc_hicp_manr), gas consumption (Eurostat, nrg_cb_gasm), nominal interest rate (Eurostat, irt_st_q), total output (Eurostat, namq_10_pc), energy consumption (Our World in Data, Per capita primary energy consumption by source). When data are not per capita and they need to be, I use intrapolated population data (Eurostat, demo_pjan) to transform them to per capita variables.

Figure 14: Data used for historical shock decomposition



Notes: Plot of the data used in the historical shock decomposition. I separate the Euro Area countries into "Cap" and "No cap" countries, according to whether countries imposed an energy cap in 2022 or not. See Figure 2 for details. Grey-shaded area are 2020Q1 and Q2, the quarters most affected by the COVID-19 pandemic.

Figure 15: Prior and posterior distributions



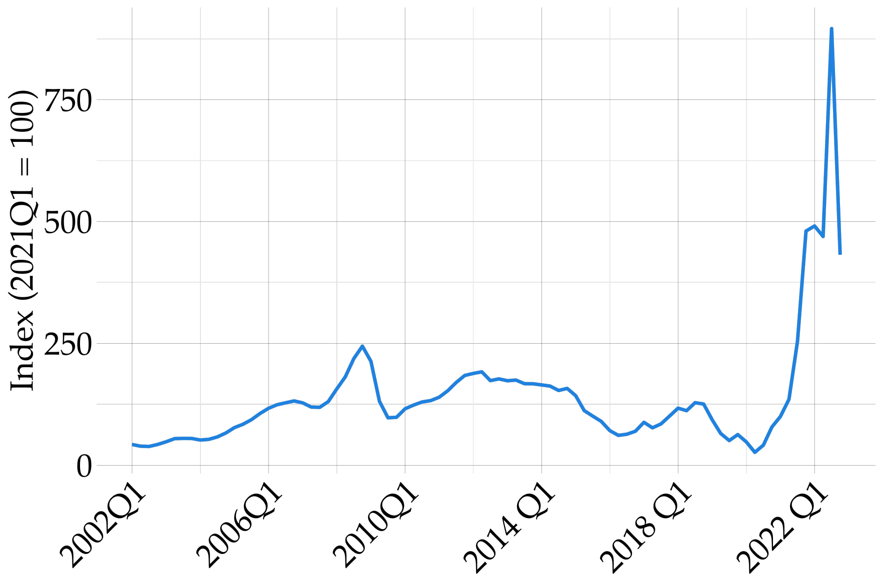
Notes: Plot of the prior distribution (gray) and the posterior distribution (black). The vertical blue line indicates the posterior mode. The y-axis displays the density of the distributions.

mode of the posterior distribution.[42] Then, the Metropolis-Hastings algorithm evaluates the marginal likelihood of the model and produces the posterior distributions. I use one million replications for each chain of the algorithm and four parallel chains. I check that the Monte Carlo Markov Chain converges and that the posterior chain for each parameter is stable. The posterior plots are in Figure 15. For the historical shock decomposition, I use the `shock_decomposition`-command in Dynare, which uses the Kalman smoother to decompose the historical fluctuations of the variables into contributions from each shock.

[42] Option 5 of the `mode_compute`-option in the `estimation`-command in Dynare.

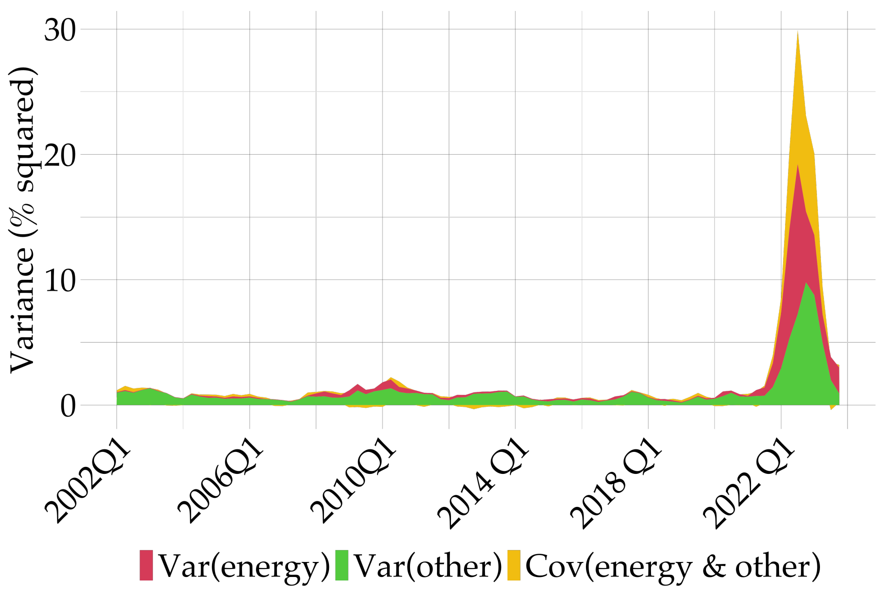
C Additional figures

Figure 16: Natural gas price in Europe



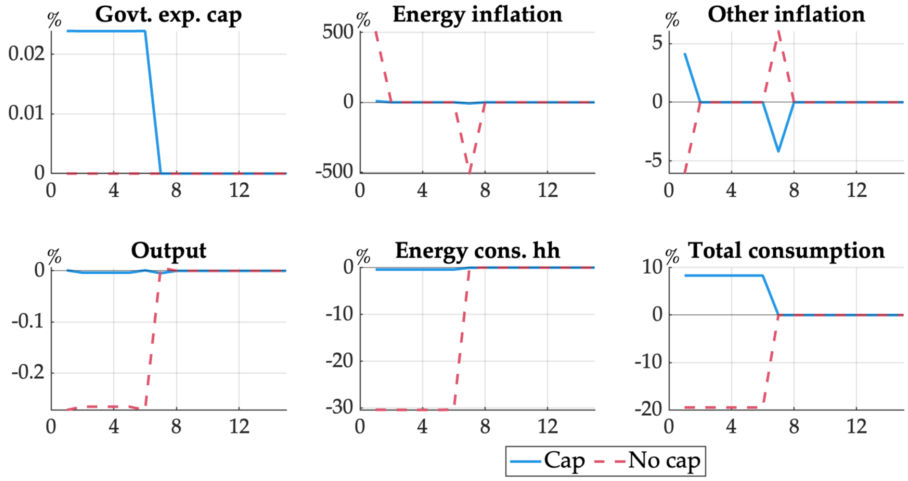
Notes: The price index of the Title Transfer Facility (TTF) gas in the Netherlands. Data source: IMF Data (2024).

Figure 17: Decomposition of the variance of headline inflation



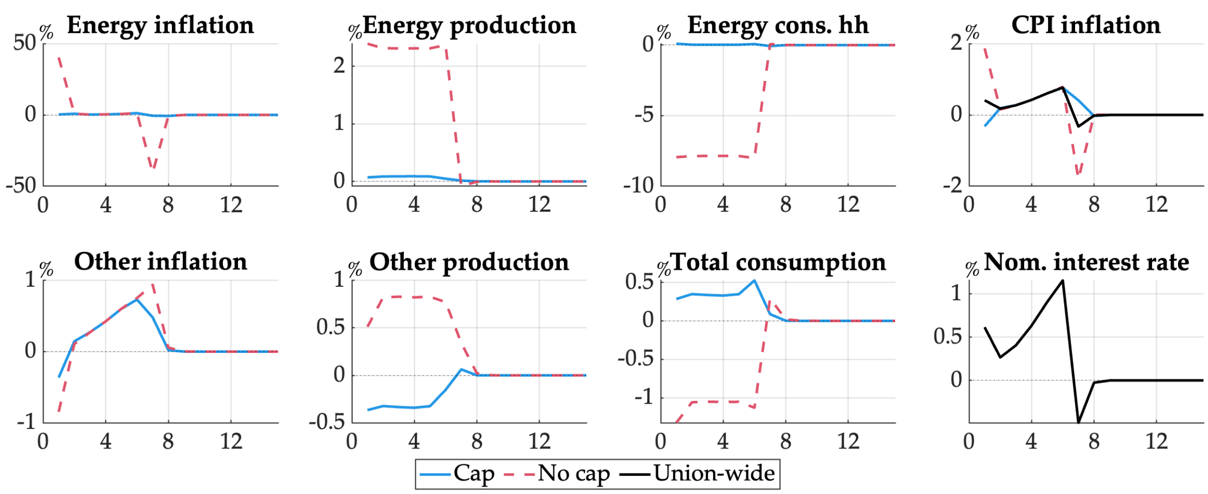
Notes: The headline inflation in country i in quarter t is $\Pi_{it} = (1-\alpha^E_{it})\Pi^O_{it} + \alpha^E_{it}\Pi^E_{it}$ where is α^{ENG} the share of energy in the consumption basket, Π^E_{it} and Π^O_{it} energy and other goods inflation. The variance decomposition is across countries for each quarter, so $Var_t(\Pi_{it}) = Var_t\left[(1-\alpha^E_{it})\Pi^O_{it} + \alpha^E_{it}\Pi^E_{it}\right]$. Data source: Eurostat.

Figure 18: Responses to an adverse energy supply shock | Cap vs. no cap under core-inflation targeting



Notes: Impulse responses to a 15% decline in energy supply, in a model in which the central bank targets other inflation (core inflation). Preferences are non-homothetic. The bigger country, of size Θ imposes a price cap on the energy price (blue, solid) and the smaller country, of size $1-\Theta$ does not (red, dashed). The black solid lines show the union-wide variables. The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

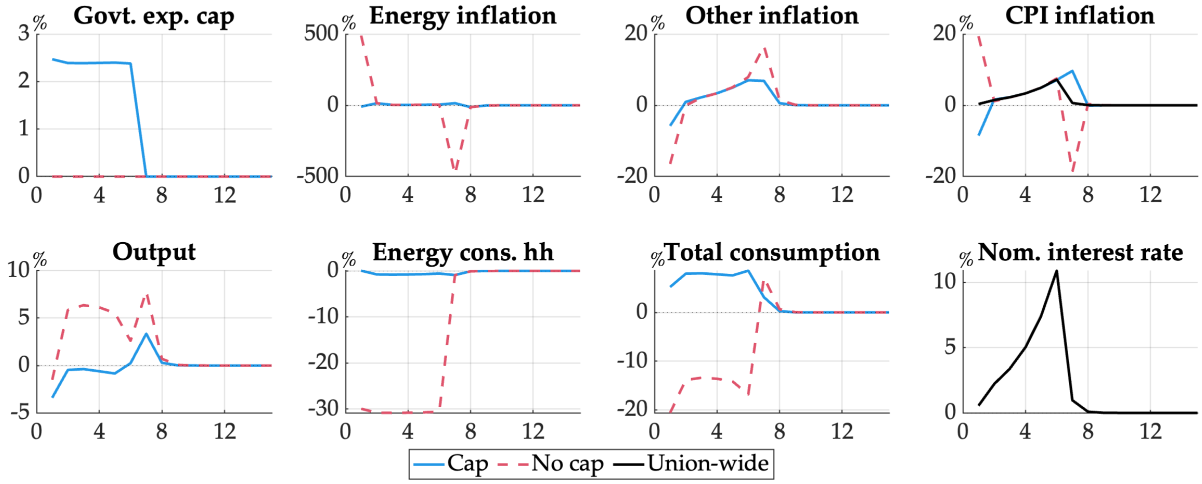
Figure 19: Responses to an adverse energy supply shock | Cap vs. no cap with TANK



Notes: Impulse responses to a 15% decline in energy supply, in the two-agent version of the model. Preferences are non-homothetic. The bigger country, of size Θ imposes a price cap on the energy price (blue, solid) and the smaller country, of size $1-\Theta$ does not (red, dashed). The black solid lines show the union-wide variables. The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

C.1 Results under elastic labor supply

Figure 20: Responses to an adverse energy supply shock | Cap vs. no cap with elastic labor supply



Notes: Impulse responses to a 15% decline in energy supply, in a model with elastic labor supply. Preferences are non-homothetic. The bigger country, of size Θ imposes a price cap on the energy price (blue, solid) and the smaller country, of size $1 - \Theta$ does not (red, dashed). The black solid lines show the union-wide variables. Output is equal to the output gap. Government expenditure on the price cap (Govt. exp. cap) is the cost of the cap as a share of annual total output of the country (GDP). The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

Table 8: Welfare gains/losses after energy supply shock

(a) Baseline

	%	1/3 of union: Cap	1/3 of union: No cap
2/3	Cap	$(-1.04, -1.04)$	$(0.49, -1.08)$
2/3	No cap	$(-1.08, 0.42)$	$(-0.05, -0.05)$

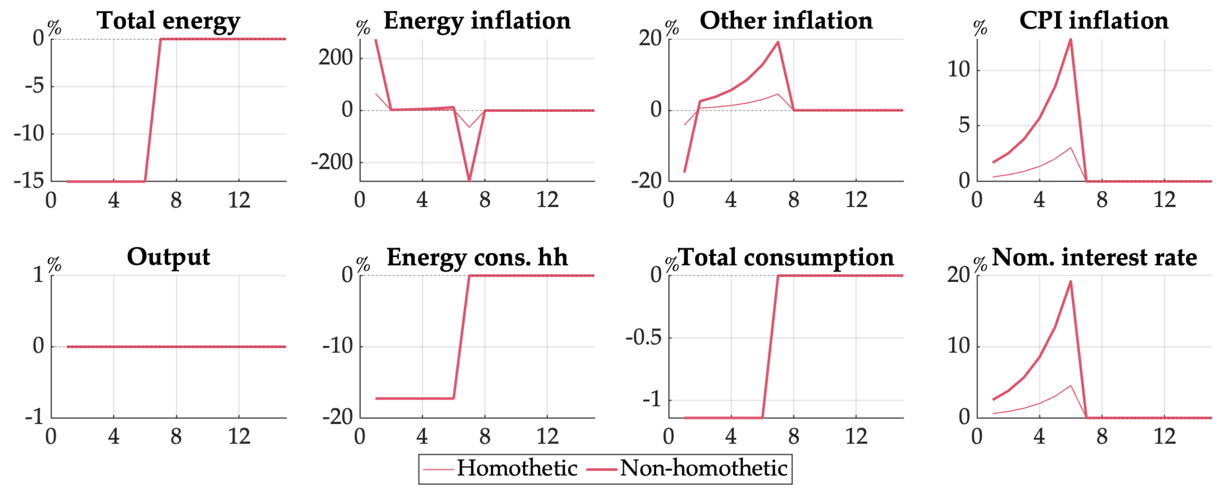
(b) Elastic labor supply

	%	1/3 of union: Cap	1/3 of union: No cap
2/3	Cap	$(-0.86, -0.86)$	$(0.40, -0.72)$
2/3	No cap	$(-0.97, 0.53)$	$(-0.03, -0.03)$

Notes: Welfare gains and losses after a 15% energy supply shock, in a model with elastic labor supply. The gains and losses are in terms of the consumption equivalent relative to the steady state. The circles are around the preferred policy choices (Cap or No cap) for the countries.

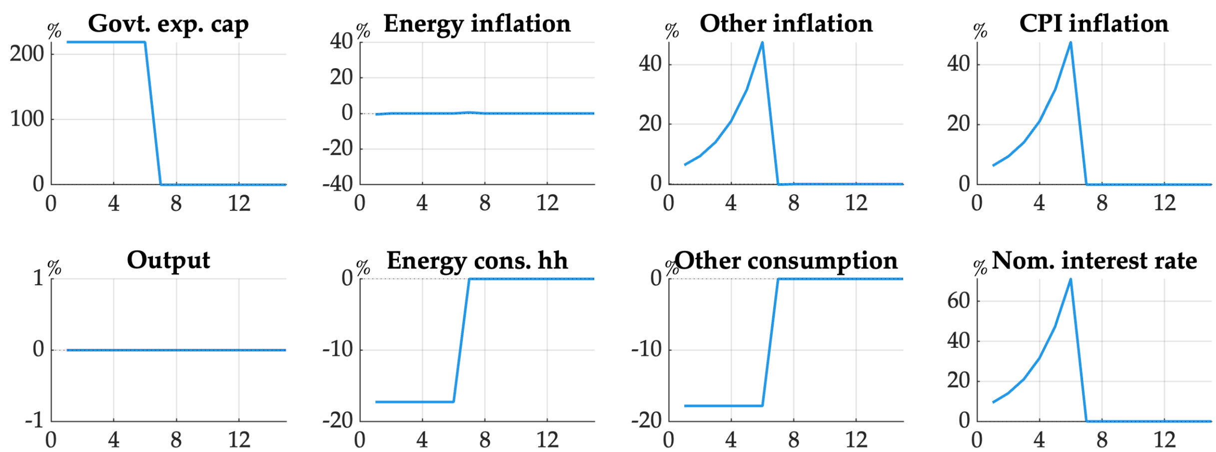
C.2 Results under flexible prices

Figure 21: Responses to an adverse energy supply shock | No price caps with flexible prices



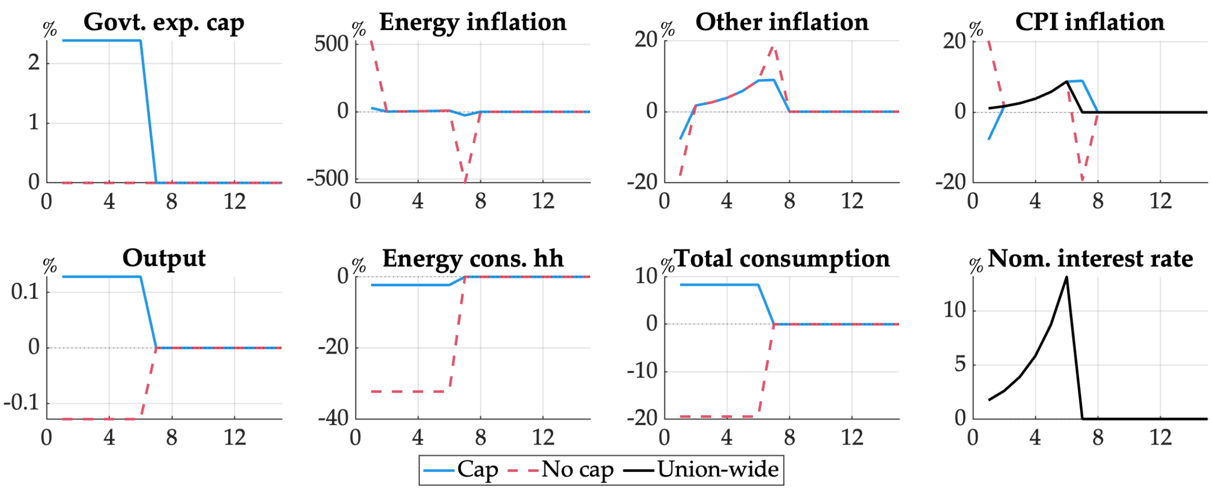
Notes: See Figure 20. Impulse responses to a 15% decline in energy supply, in a model with flexible prices.

Figure 22: Responses to an adverse energy supply shock | Price caps with flexible prices



Notes: See Figure 20. Impulse responses to a 15% decline in energy supply, in a model with flexible prices.

Figure 23: Responses to an adverse energy supply shock | Cap vs. no cap with flexible prices



Notes: See Figure 20. Impulse responses to a 15% decline in energy supply, in a model with flexible prices.

Table 9: Welfare gains/losses after energy supply shock

(a) Baseline

	%	1/3 of union: Cap	1/3 of union: No cap
2/3	Cap	(-1.04, -1.04)	(0.49, -1.08)
	No cap	(-1.08, 0.42)	(-0.05, -0.05)

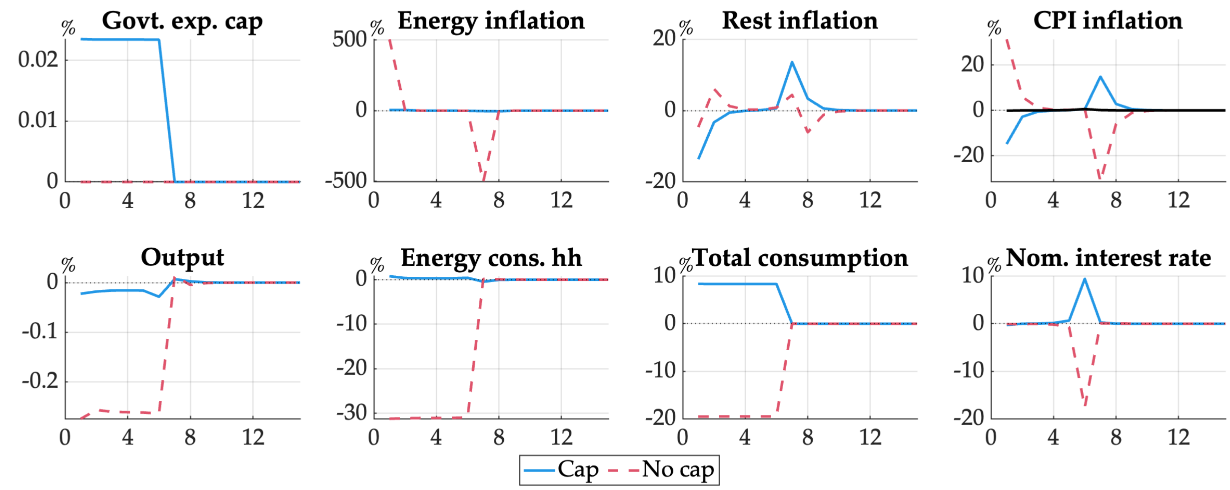
(b) Flexible prices

	%	1/3 of union: Cap	1/3 of union: No cap
2/3	Cap	(-1.04, -1.04)	(0.49, -1.08)
	No cap	(-1.08, 0.42)	(-0.05, -0.05)

Notes: See Table 8. Welfare gains and losses after a 15% energy supply shock, in a model with flexible prices.

C.3 Results under flexible exchange rates

Figure 24: Responses to an adverse energy supply shock | Cap vs. no cap in world with flexible nominal exchange rates



Notes: See Figure 20. Impulse responses to a 15% decline in energy supply, in a model with flexible nominal exchange rates.

Table 10: Welfare gains/losses after energy supply shock

(a) Baseline

	%	1/3 of union: Cap	1/3 of union: No cap
2/3	Cap	(−1.04, −1.04)	(0.49, −1.08)
	No cap	(−1.08, 0.42)	(−0.05, −0.05)

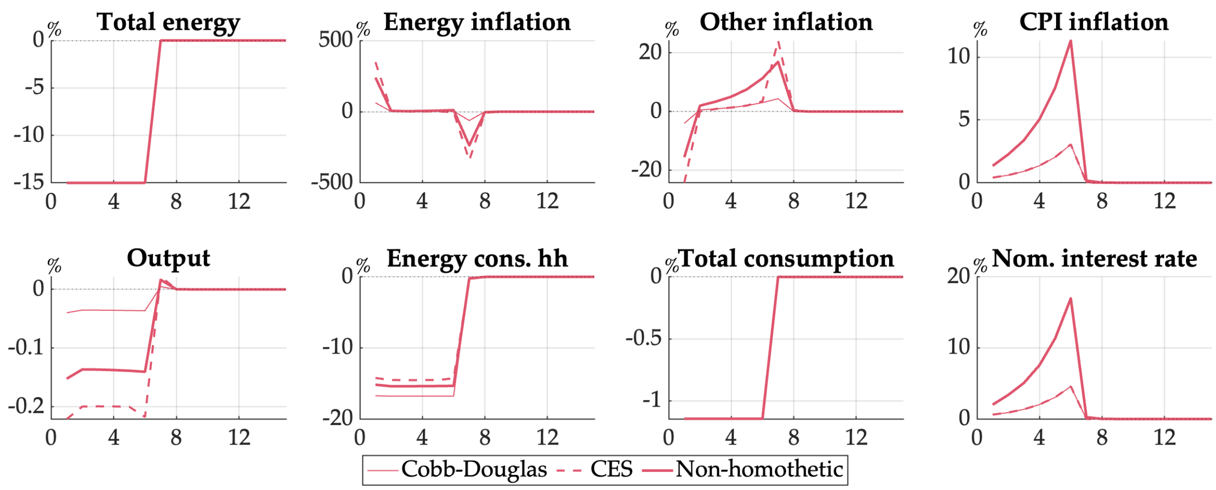
(b) Flexible nominal exchange rate

	%	1/3 of union: Cap	1/3 of union: No cap
2/3	Cap	(−1.04, −1.04)	(0.49, −1.08)
	No cap	(−1.07, 0.42)	(−0.05, −0.05)

Notes: See Table 8. Welfare gains and losses after a 15% energy supply shock, in a model with flexible nominal exchange rates.

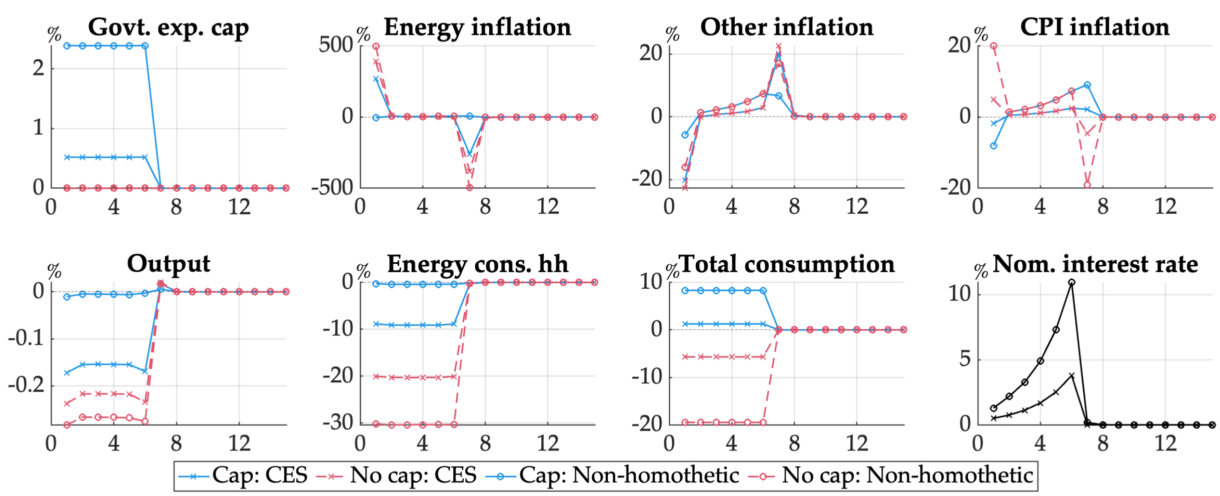
C.4 Results under CES preferences

Figure 25: Responses to an adverse energy supply shock | No caps with CES preferences



Notes: Impulse responses to a 15% decline in energy supply. The graph compares three types of preferences: Cobb-Douglas (solid, thin), Constant Elasticity of Substitution (CES) (dashed), and non-homothetic preferences (solid, bold). Output is equal to the output gap. The y-axis is in terms of percentage deviations from steady state. The x-axis is in quarters. Inflation and interest rates are annualized.

Figure 26: Responses to an adverse energy supply shock | Cap vs. no cap with CES preferences



Notes: See Figure 20. Impulse responses to a 15% decline in energy supply, in a model with CES preferences.