Can Energy Subsidies Help Slay Inflation?*

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Abstract

Many countries have used energy subsidies to cushion the effects of high energy prices on households and firms. We use a New Keynesian DSGE modeling framework to identify the conditions under which these policies can curb inflation that draws on empirical evidence about energy shock transmission from proxy VARs. We show formally that, when implemented globally or in segmented energy markets, a consumer energy subsidy is equivalent to taxing energy use by firms; moreover, it is counterproductive in fighting inflation under empirically plausible characterizations of wage-setting. We find more scope for energy subsidies to reduce core inflation and stimulate demand if introduced by a small group of countries which collectively do not have much influence on global energy prices. However, even here the subsidies boost external debt and weaken the exchange rate, and can be counterproductive for inflation. We also show that targeted transfers are more efficient than subsidies if the aim is to shield vulnerable households.

JEL: E32, E52, E64, H23, Q43

Keywords: energy prices, energy subsidies, monetary policy, international spillovers

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1 Introduction

Central banks have tightened monetary policy aggressively to combat high inflation, which surged to multi-decade peaks in many economies. While the inflation runup has been driven by a number of factors, including supply disruptions and massive fiscal and monetary stimulus, sharp increases in energy prices have been a major catalyst. Many countries responded by using various forms of energy subsidies, often targeted mainly to households, to help curb inflation as well as to cushion the effects on household purchasing power (Arregui et al., 2022; Sgaravatti et al., 2023). Energy subsidies are viewed by many policymakers as helpful in the fight against inflation on the grounds that they are likely to limit both first and second round effects, including by reducing passthrough to wages.

But there are many open questions about the conditions under which energy subsidies are actually likely to be effective in lowering inflation, or, conversely, when they may be counterproductive. While wage stickiness has long been recognized as pivotal in the transmission of energy shocks to overall price inflation (e.g., Blanchard and Gali, 2007), there has been little analysis of how the effects of energy subsidies on inflation depend on the modalities of wage-setting, including the degree of indexation. Similarly, it is unclear how the effects of subsidies depend on the structure of the energy market: could insulating consumers from the effects of higher prices in a highly segmented market – such as the one for natural gas in Europe (see Albrizio et al., 2023) – hurt firms enough to cause core inflation to rise? And how do the effects of subsidies depend on whether they are used by a single "small economy" or a broad set of countries?

In this paper, we use a New Keynesian modeling framework to help analyze these questions, but first seek empirical grounding by estimating how oil shocks transmit to the economy in the United States (US) and euro area (EA). Specifically, we use a proxy SVAR approach where the instrument is given by surprise changes in oil prices following the announcement of OPEC meeting decisions. The series of surprises is adopted from Känzig (2021) and aggregated to quarterly frequency over the 1983 to 2019 sample period. For these identified shocks, we find that a negative oil supply shock which drives up the price of oil leads to higher core and headline inflation, lower GDP, and higher policy rates initially in both the US and the euro area. Importantly, we find significant differences in the transmission to wages between these two economies, with oil price hikes having small effects on nominal wages in the US – so that real wages fall notably – whereas they tend to boost nominal wages enough in the euro area that the real (product) wage actually rises. These differences in wage transmission turn out to have critical bearing on how energy subsidies affect inflation.

Turning to our theoretical framework, we begin by considering a simple workhorse closed economy model with nominal wage and price stickiness that builds on Bodenstein et al. (2011). As in that model, we assume the economy has an endowment of energy that is utilized both in production and consumption, but enrich the supply block by allowing for alternative forms of dynamic wage indexation where wages may adjust to either core or headline inflation. We also incorporate energy subsidies that are proportional to energy use, thus resembling the dominant type of subsidies introduced in many countries, including the US and Europe.

Using this model, we demonstrate formally that providing energy subsidies to consumers is essentially equivalent to taxing energy use by firms: both policies decrease the effective energy cost to households while increasing that faced by firms, thus resulting in the same allocations.[1] The implication is that while consumer energy subsidies can be designed to shield households from a rise in the relative price of energy (say due to a supply shock), such a policy is essentially a tax on firms that drives up their marginal costs of production.

We show how a log-linearized version of the model with energy can be expressed in a form isomorphic to that of Erceg et al. (2000), and use this formulation to derive a striking analytical result. In particular, we show that energy subsidies to consumers necessarily boost core price inflation if monetary policy keeps employment at potential and wages are indexed to core inflation (either fully or partially, including the special case of no indexation). This result holds for any configuration of parameters assuming that very weak conditions are satisfied (i.e., implying that adverse energy shocks reduce the potential real wage). Intuitively, while consumer subsidies damp the initial rise in headline inflation, the subsidies drive up the energy prices faced by producers, which they pass along gradually through raising product prices. Hence, these subsidies make inflation – both core and headline – more persistent.

The closed economy model is relevant for considering the likely effects of consumer energy subsidies in the global economy when all countries pursue similar policies, or in a highly segmented energy market (such as for natural gas in Europe). In short, we find using quantitative simulations of our model that even a high degree of indexation to headline consumer price inflation – well above what we find empirically for the US, or even the euro area – is not enough for consumer energy subsidies to reduce core inflation. These subsidies indeed reduce first-round effects on headline inflation in response to an energy price spike and this reduces upward pressure on wages, but they also cause the pre-subsidy energy price faced by firms to rise enough that the "all-in" effect is a rise in core inflation. Welfare analysis using the usual utility-based metric confirms that consumer energy subsidies lower welfare.

While our workhorse model casts strong doubt on the ability of consumer subsidies to lower inflation when applied globally, it still might be expected that a small open economy – or group of countries too small to affect global energy prices – might be able to use subsidies to lower inflation. To explore this, we use a two-country extension with incomplete asset markets. This variant allows for the transmission of energy supply shocks to differ substantially across energy-importers and exporters, and also depend on the depth of the

[1] These alternative approaches do have different implications for the pre-subsidy energy price, with the consumer subsidy driving up the energy price, and the tax on firms driving it down (hence, allocations would be affected in a setting with endogenous oil production).

foreign exchange market which heavily influences the exchange rate response.

Focusing on the small open economy case, we find more scope for consumer energy subsidies to reduce core inflation than in the closed economy model. This seems intuitive: such subsidies should "choke off" first round effects and thus limit the scope for second round effects to materialize, including through wage indexation. And firms should not be "bitten" by higher global energy prices given the home country's small share in the global energy market.

Even so, the conditions under which subsidies reduce core inflation still turn out to be surprisingly restrictive. Although subsidies have essentially no effect on global energy prices, they cause the trade balance to deteriorate and exchange rate to depreciate. This exchange rate channel can be big enough that subsidies can cause core inflation to rise, unless wage indexation to consumer prices is sufficiently high.[2] The depreciation effect is larger the more persistent the subsidy (which typically is linked to the persistence of the underlying shock to energy supply) and is larger in economies with shallow foreign exchange markets, as is the case in many emerging market economies.

The policy implication is that consumer energy subsidies may help reduce core inflation if implemented by countries that are a relatively small share of the global energy market but well connected to it; if the subsidies are temporary; if wage indexation to consumer prices is high (so that second round effects would be large in the absence of subsidies); and if the actions are taken by economies with well-developed financial markets and modest debt levels.[3] We also show that a package of energy subsidies to firms as well as households may be attractive for a small "energy-price taking" economy – supporting aggregate demand while lowering inflation. But as foreshadowed by the closed economy results, our two country model highlights how consumer subsidies are less likely to be effective in reducing inflation as their use becomes more widespread. The pre-subsidy energy price rises by more, making it more likely that subsidies boost inflation. Moreover, our model highlights the adverse spillovers to other energy importers – the latter experience bigger trade deficits, currency depreciation, and upside inflation pressure. The spillovers are particularly acute for vulnerable emerging economies with thin foreign exchange markets.

While our focus is largely on aggregate supply, consumer energy subsidies also have demand side effects that may vary significantly across households, and which are not well-captured by our framework. Indeed, our welfare results in particular may be viewed as unduly biased against such subsidies insofar the model does not allow for how subsidies may shield poorer and liquidity-constrained households from major hits to their purchasing power and consumption arising from energy shocks – which was clearly a key aim of policymakers

[2] Energy subsidies tend to be helpful under these conditions by choking off first-round effects that would otherwise exert large pass through to core.

[3] Dao et al. (2023) found that energy subsidies were helpful in mitigating both headline and core inflation pressures in the euro area during the 2022 surge in energy prices which proved to be temporary.

in addition to restraining overall inflation.

To explore this, we incorporate hand-to-mouth households into our closed economy model as in the two-agent New Keynesian (TANK) setup developed by Gali et al. (2007) and Bilbiie (2008), and show that our results are largely robust even when capturing the demand-side effects of energy shocks.[4] Interestingly, we show that consumer energy subsidies could improve welfare in our TANK framework by reducing consumption inequality across households (i.e., permanent income versus hand-to-mouth). However, targeted transfers to hand-to-mouth households are more efficient as they can achieve this goal at lower fiscal cost and with a better inflation-output tradeoff. The main advantage of such transfers over energy subsidies is that they do not distort relative energy prices faced by households, and hence preserve their incentive to conserve energy. This limits the increase in the pre-subsidy energy price faced by firms, and hence lowers inflation pressure.

Our paper is closely related to an insightful recent paper by Auclert et al. (2023) which explores the transmission of oil shocks in an open economy HANK model, and the effects of consumer energy subsidies. These authors also show how subsidies may be beneficial in reducing inflation and boosting consumption for an individual "small" country, but can have counterproductive effects if deployed by a broad set of countries. Our paper differs from their work in several important aspects. First, their paper focuses heavily on heterogeneity across households in a HANK framework and associated distributional effects, whereas our study devotes much more attention to the supply side (different wage indexation schemes rather than assuming full indexation of wages to consumer prices). Second, we incorporate features aimed at capturing financial vulnerabilities (such as thin FX markets) that influence how subsidies operate through open economy channels. Third, we assume the central bank follows optimal policy or uses a Taylor-style reaction function that provides a good approximation. This turns out to have important implications for the pass-through of energy price shocks and subsidies. All told, our paper is more pessimistic in the ability to use consumer energy subsidies successfully to reduce inflation, even in the case of a small group of countries (e.g., showing how subsidies can be counterproductive through trade channels).

Our paper also draws on the extensive earlier literature studying the transmission of energy price shocks. Key empirical contributions include Hamilton (1983), Hamilton (2003), Barsky and Kilian (2004), Blanchard and Gali (2007), Kilian (2009), Baumeister and Hamilton (2019), and Känzig (2021). We use energy supply shocks identified in this last paper to analyze the reaction of wages. A number of papers incorporate energy into structural macroeconomic models, but do not study the effects of energy subsidies, see Kim and Loungani (1992), Backus and Crucini (2000), Leduc and Sill (2004), Bodenstein et al. (2011), Blanchard and Riggi (2013), Bodenstein et al. (2018), Baqaee and Farhi (2019), Gagliardone

[4] Debortoli and Gali (2018) argue that a simple two-agent New Keynesian (TANK) model can be a good approximation of heterogeneous agent New Keynesian (HANK) models regarding the transmission of aggregate shocks to macroeconomic variables.

and Gertler (2023), and Pieroni (2023), among others. Similarly to Auclert et al. (2023), the last paper uses a HANK setup while we opt for a more parsimonious TANK model as an extension to capture household heterogeneity and analyze the scope for transfers. By looking at the interactions between price and nominal wage rigidity within New Keynesian models, our work is related to the literature originated by Blanchard (1986) and draws particularly on Erceg et al. (2000) and Bodenstein et al. (2008). A recent contribution in this line by Lorenzoni and Werning (2023) considers both the transmission of supply and demand shocks and optimal policy in a continuous time framework (with inflation interpreted as arising from conflict between firms and workers over wages).

The paper is structured as follows. Section 2 discusses the empirical evidence on the effects of energy price shocks, with a special focus on the response of wages. Section 3 presents a simple closed economy model with energy. Section 4 offers analytical insights on the transmission of energy price shocks and subsidies. These are complemented with quantitative simulations described in Section 5. Section 6 presents the version of the model with hand-to-mouth agents and is followed by an open economy extension in Section 7. Section 8 concludes.

2 Empirical Evidence on Oil Shocks and Wage Adjustment

In this section, we provide empirical evidence on the response of wages and consumer prices to oil price shocks in the United States and the euro area.

First, we identify a source of oil price movements that is not correlated with other fundamental shocks to avoid reverse causality or a omitted variable bias. To do so, we rely on Känzig (2021) who identifies surprise changes in oil futures prices related to OPEC's meetings decisions about production targets. As Känzig measures these changes in a tight window around the announcements,[5] it is likely that they can isolate the impact on oil prices of the unexpected component of OPEC's deliberations – analogously to the literature that identifies monetary policy shocks (e.g., Gurkaynak et al., 2005; Gertler and Karadi, 2015; Nakamura and Steinsson, 2018, among others). Since markets pay close attention to OPEC's decisions, a reverse causality of the global economic outlook should plausibly be ruled out because it should already be priced in at the time of the announcement. OPEC's decisions are not random events but as the Känzig shocks measure only the component not anticipated by markets, their immediate impact on prices should reflect the element of the decision that surprised market participants.[6] A distinct advantage of using these shocks relative to the

[5]The window is taken to be one day, using WTI crude futures starting in 1983 traded at the New York Mercantile Exchange (NYMEX), which is one of the most liquid and largest market for crude oil. For further details, see Känzig (2021).

[6]Nazer and Pescatori (2022) show that it is the surprise component of the OPEC (or OPEC+) decisions that affects the market since the same decision can induce price responses of different sign.

standard approach pioneered by Kilian (2009) is to bypass the difficulties of disentangling oil demand and oil production shocks. Even so, we will show that our results also hold when using shocks measured by Baumeister and Hamilton (2019).

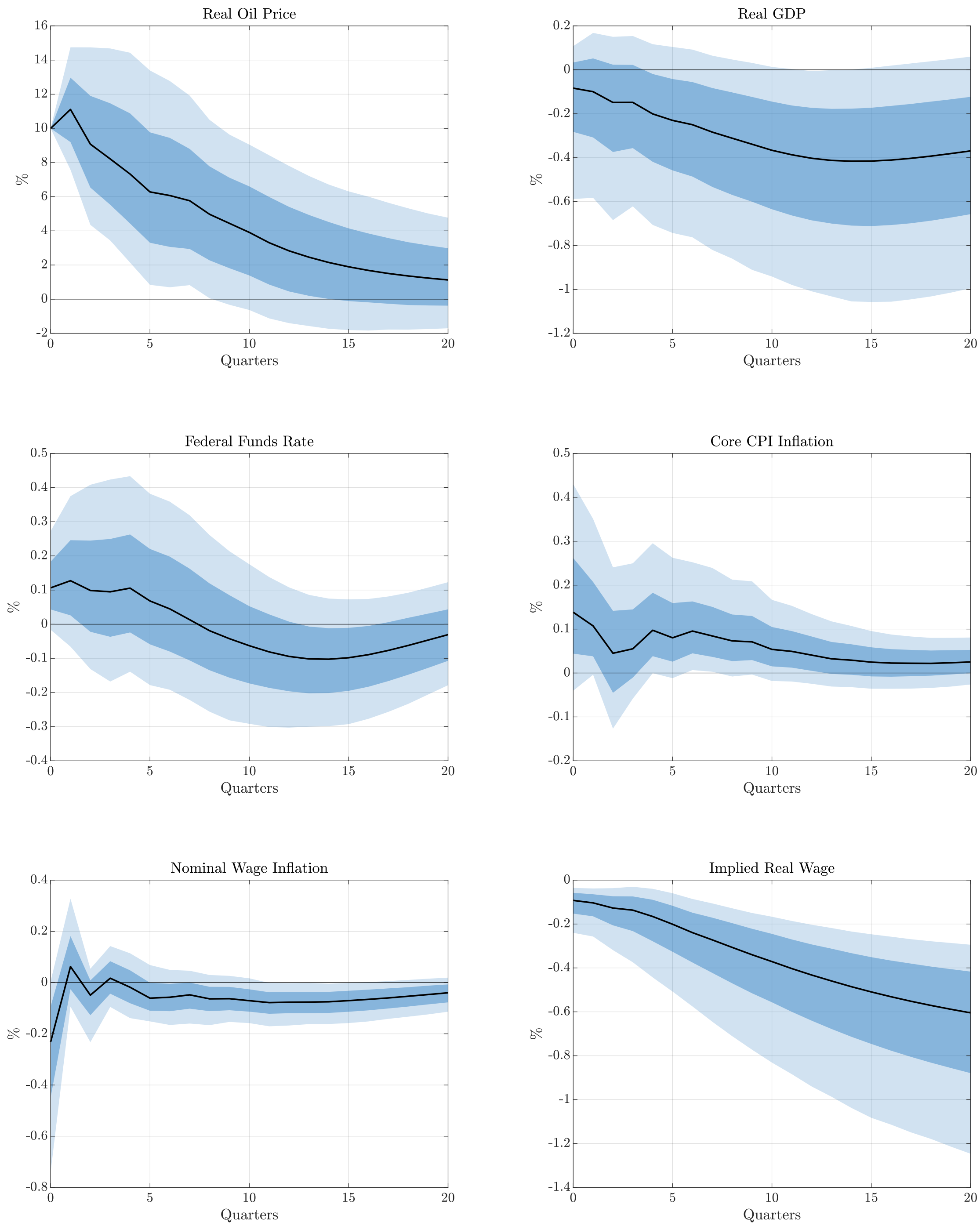
The series of oil price surprises spanning from 1983 to 2019 are aggregated at quarterly frequency and used as an instrument in an SVAR model. In addition to the standard oil market variables such as real oil prices (deflated by either core or headline prices), oil production, and global industrial production, our proxy SVAR model also includes real GDP, core or headline CPI inflation, the short-term policy rate, as well as nominal wage inflation. All quantities and relative prices are in logs, the policy rates in percentage points, while price and wage inflation are measured as log differences. We use identical SVAR specifications for the US and the euro area. Appendices A.1 and A.2 contain additional details on the proxy SVAR and data definitions.

Our baseline results are reported in Figures 1 and 2 for the US and euro area, respectively. According to the proxy SVAR for the US, an increase in oil prices driven by an oil supply news shock leads to a decline in nominal and real wages.[7] More concretely, an oil supply-driven 10 percent increase in oil prices with a 2-year half life increases core inflation by about 0.1 percentage point for a few quarters and reduces the nominal wage by about 0.2 percent on impact. Consequently, the implied producer real wage – calculated by accumulating the nominal wage growth impulses and subtracting the accumulated core inflation impulses – falls by roughly 0.3 percent over the first 2 years and by nearly 0.6 percent after 5 years. The reduction in real wages is in line with an oil supply shock transmitting similarly to an adverse TFP shock, with real GDP falling by more that 0.4 percent after 2 years. Crucially for our further analysis, these results suggests that the ability of US households and labor unions to achieve compensation for higher prices through higher wages is very limited.

The impact on the euro area is shown in Figure 2. While the oil price path is almost identical to that obtained in the SVAR for the US, the transmission to other key macro variables differs notably. Most notably, nominal wage growth persistently increases. This finding is possibly driven by more centralized wage bargaining and higher unionization in the euro area than in the US, leading to a higher degree of (explicit or implicit) indexation (Baba and Lee, 2022). Increasing wages put some upward pressure on core inflation and so the ECB raises the interest rate significantly. The tighter policy stance implies that the associated output contraction is about the same as in the US, although the euro area economy is less dependent on oil. Turning to the implied real producer wage, the point estimate of its impulse response is modestly positive, but not significantly so. We interpret this finding as only mild evidence in favor of some indexation mechanisms in European wage setting that compensates households for the loss of purchasing power due to energy price shocks.

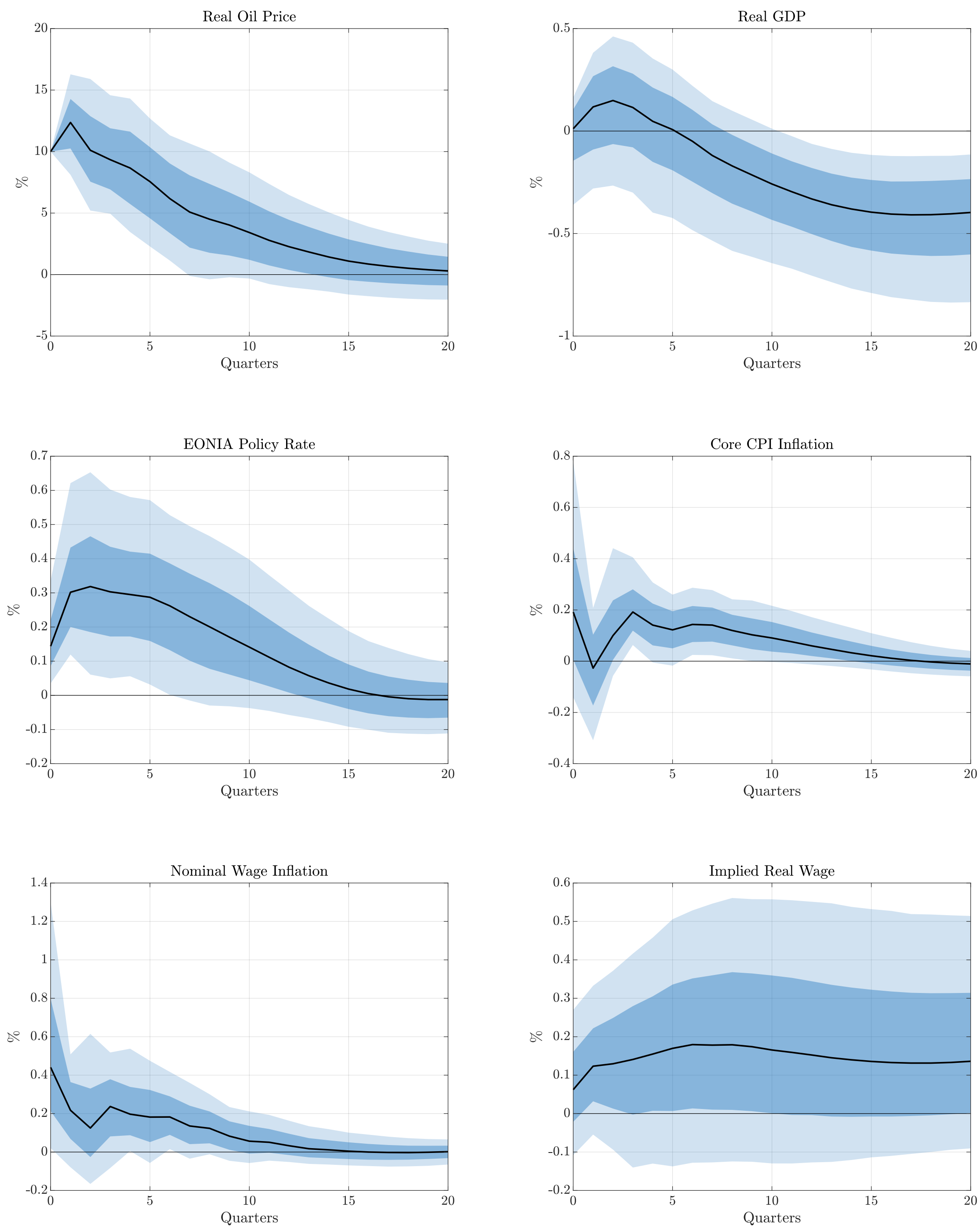
[7] The confidence bands are computed using a moving block bootstrap, as proposed by Jentsch and Lunsford (2019). This method produces asymptotically valid confidence bands under fairly mild alpha-mixing conditions. The block size is set to 24 and deals with the difference in the estimation and identification samples.

Figure 1: US Proxy-VAR Evidence: Oil Price Shocks



Notes: All variables are expressed in percent deviations, real oil prices are deflated with core CPI, implied real wage is defined as accumulated nominal wage inflation minus core inflation. The confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

Figure 2: EA Proxy-VAR Evidence: Oil Price Shocks



Notes: All variables are expressed in percent deviations, real oil prices are deflated with core CPI, implied real wage is defined as accumulated nominal wage inflation minus core inflation. The confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

As shown in Appendix A.3, the impact of an oil supply shock on headline inflation is notably stronger on impact in both the US and the euro area, up to 1 (0.5) percent in the same quarter but much less persistent – consistently with oil prices reverting to their pre-shock levels. Even so, the implied consumer real wage, i.e. nominal wage divided by headline CPI, falls notably more initially than the producer real wage in Figure 1. The smaller pass-through to headline inflation relative to core inflation in the euro area than in the US can be at least partially explained by higher excise taxes on liquid fuels and a downstream oil industry that tends to have more rigid retail prices (Ahn, 2024). Importantly for our further analysis, regardless if we work with core or headline inflation in the SVAR, we find that the implied real wage in the euro area falls less than in the US.

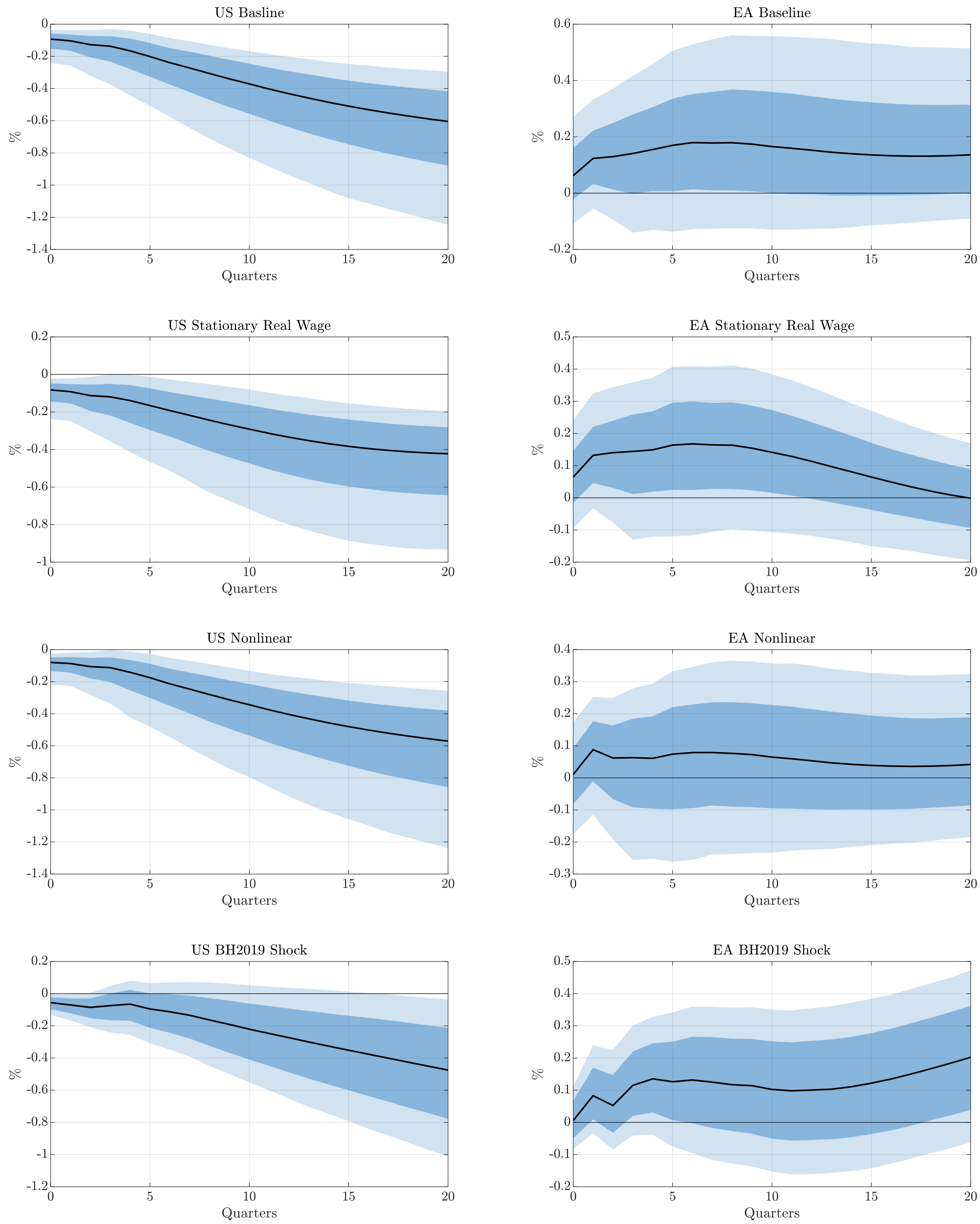
We have examined the robustness of our results for a number of alternative SVAR specifications. Figure 3 presents the impulse responses for the implied producer real wage (US in the left column and euro area in the right), while Appendix A.3 reports the results for all variables included in each of the considered alternatives. The first row in the figure just restates our baseline results from Figures 1 and 2. The second row reports an alternative where we impose mean reversion of the real wage impulse responses by introducing this variable directly in the SVAR instead of nominal wage growth and imposing stability conditions. As can be seen, real producer wages in the US still decline significantly in response to an energy supply shock while they rise somewhat (although not significantly at the 90 percent confidence level) in Europe.

We also tested for possible non-linearities in tracing the effects of oil price shocks on wages and inflation by excluding shocks smaller than one standard deviation from the sample. The third row in Figure 3 reports our estimates, with the impulses scaled to imply the same initial oil price reaction as in our baseline specification. By comparing the large shock results with our baseline findings in the first row, we find no evidence that the size of oil supply shocks matters for their transmission to real wages.

Finally, as can be seen from the full set of responses reported in Appendix A.3, the oil price shocks estimated by Känzig do not necessarily lead to an immediate reduction in oil and global industrial production, which actually rise somewhat initially. This suggests that the identified shocks may not reflect only supply forces, but also have a demand component.[8] Therefore, the final row in Figure 3 reports the results for an alternative identification scheme with sign restrictions following Baumeister and Hamilton (2019), where oil production declines strongly on impact. As can be seen from the figure, the impact on real wages remains robust.

[8] To the extent this is indeed is the case, it further strengthens the interpretation of our evidence as lending little support for strong indexation of wage formation to headline inflation.

Figure 3: Implied Real Wage in Different SVAR Specifications



Notes: Implied real wage is defined as accumulated nominal wage inflation minus core inflation. The confidence bands are the 90 and 68 percent level bands based on 10,000 bootstrap replications.

3 Simple Closed Economy Model with Energy

3.1 Households

There is a continuum of households indexed by h, each of whom maximizes

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left(\frac{\left(C_{t+s}\left(h\right) - \varkappa C_{t+s-1}(h)\right)^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} - \chi_0 \frac{N_{t+s}\left(h\right)^{1+\chi}}{1+\chi} \right), \tag{1}$$

where $0 \leq \beta, \varkappa < 1$ and $\sigma, \chi, \chi_0 > 0$, whereas C_t and N_t denote current consumption and hours of labor, respectively. Household h faces a flow budget constraint in period t

$$P_{C,t}C_t\left(h\right) + B_t(h) + T_t = (1+\tau_w)W_t(h)N_t\left(h\right) + R_{K,t}K + I_{t-1}B_{t-1}(h) + D_t + \Xi_t(h), \tag{2}$$

where B_t denotes bond holdings that pay gross nominal interest I_t from t to $t+1$. Each household has a fixed stock of capital K, which is leased to firms at the rental rate $R_{K,t}$, pays lump sum taxes T_t to the government, and receives an aliquot share D_t of the profits of all types of firms.

We assume that labor supplied by individual households is differentiated, with a constant elasticity of substitution between individual varieties controlled by parameter $\theta_w > 0$. The aggregate labor supply is then given by the following formula

$$N_t = \left(\int_0^1 N_t(h)^{\frac{1}{1+\theta_w}} dh \right)^{1+\theta_w}. \tag{3}$$

Wages are set by households in a Calvo-style staggered fashion. Each period, household h faces a fixed probability $1-\xi_w$ of being able to reoptimize her wage, while the remaining fraction of households mechanically index their wages according to factor $\tilde{\Pi}_{W,t}$

$$\tilde{\Pi}_{W,t} = \Pi_{Y,t}^{\iota_y} \Pi_{C,t}^{\iota_c} \Pi^{1-\iota_y-\iota_c}, \tag{4}$$

where $0 \leq \iota_y, \iota_c \leq 1$ and $\iota_y + \iota_c \leq 1$, whereas $\Pi_{Y,t}$ and $\Pi_{C,t}$ are the (gross) rate of change in the producer and consumer price index, respectively, with Π denoting their steady state level. For tractability, we assume the existence of perfect insurance schemes against idiosyncratic income risk associated with staggered wage setting, denoting the associated payments (equal to zero in aggregate) as Ξ_t. This ensures that all households make the same consumption and asset choices. We also assume a static subsidy to labor income $\tau_w \equiv (1+\theta_w)/\theta_w$ that eliminates the steady state distortion associated with the labor market being imperfectly competitive.

3.2 Firms

3.2.1 Final goods producers

Final consumption goods are produced by perfectly competitive firms indexed by j, which combine non-energy inputs Y_t and energy component $O_{C,t}$ according to:

$$C_t(j) = \left((1-\omega_c)^{\frac{1}{\eta_c}} Y_t(j)^{\frac{\eta_c-1}{\eta_c}} + \omega_c^{\frac{1}{\eta_c}} O_{C,t}(j)^{\frac{\eta_c-1}{\eta_c}} \right)^{\frac{\eta_c}{\eta_c-1}}, \tag{5}$$

where $0 < \omega_c < 1$ and $\eta_c > 0$. They maximize

$$P_{C,t}C_t(j) - P_{Y,t}Y_t(j) - (1-\tau_{C,t})P_{O,t}O_{C,t}(j), \tag{6}$$

where $\tau_{C,t}$ is a proportional net subsidy to energy consumption by households.

3.2.2 Non-energy goods producers

Non-energy component in the consumption basket is produced by perfectly competitive firms that combine intermediate inputs f according to

$$Y_t = \left(\int_0^1 Y_t(f)^{\frac{1}{1+\theta}} df \right)^{1+\theta}, \tag{7}$$

where $\theta > 0$ is a constant elasticity of substitution between individual varieties. They maximize

$$P_{Y,t}Y_t - \int_0^1 P_{Y,t}(f)Y_t(f)df. \tag{8}$$

3.2.3 Intermediate goods producers

Non-energy goods are produced by monopolistically competitive firms indexed by f, which combine energy input $O_{Y,t}$ with a capital-labor bundle V_t

$$Y_t(f) = \left((1-\omega_y)^{\frac{1}{\eta_y}} V_t(f)^{\frac{\eta_y-1}{\eta_y}} + \omega_y^{\frac{1}{\eta_y}} O_{Y,t}(f)^{\frac{\eta_y-1}{\eta_y}} \right)^{\frac{\eta_y}{\eta_y-1}}, \tag{9}$$

where $0 < \omega_y < 1$ and $\eta_y > 0$, and where V_t is given by the standard Cobb-Douglas formula

$$V_t(f) = K_t(f)^{\alpha} N_t(f)^{1-\alpha}, \tag{10}$$

with $0 < \alpha < 1$. Firms generate period profits

$$(1+\tau)P_{Y,t}(f)Y_t(f) - R_{K,t}K_t(f) - W_tN_t(f) - (1-\tau_{Y,t})P_{O,t}O_{Y,t}(f), \tag{11}$$

where $\tau_{Y,t}$ is a proportional net subsidy to energy use in production and $\tau \equiv (1+\theta)/\theta$ is a static subsidy to production that eliminates the steady state distortion associated with monopolistic competition. This type of firms set their prices in Calvo-style staggered contracts. In particular, each firm faces a constant probability $1-\xi$ of being able to reoptimize the price it charges. Non-optimizing producers index their prices according to factor $\tilde{\Pi}_{Y,t}$

$$\tilde{\Pi}_{Y,t} = \Pi_{Y,t-1}^{\iota} \Pi^{1-\iota}, \tag{12}$$

where $0 \leq \iota \leq 1$.

3.2.4 Energy supply

Energy goods are modeled as an exogenous endowment $Y_{O,t}$ and hence generate revenue to households equal to $P_{O,t} Y_{O,t}$.

3.3 Monetary and fiscal authorities

To characterize monetary policy, we posit a simple Taylor-type instrument rule

$$I_t = I + \psi_\pi \left(\Pi_{Y,t} - \Pi\right) + \psi_y \left(\frac{Y_t}{Y_t^{pot}} - 1\right), \tag{13}$$

where $\psi_\pi > 1$, $\psi_y \geq 0$, and Y_t^{pot} is the level of output when prices and wages are fully flexible, which corresponds to setting $\xi = \xi_w = 0$.

There are two things to note about this rule. First, the central bank is assumed to respond to producer price (i.e. core) inflation $\pi_{Y,t}$ rather than to headline inflation $\pi_{C,t}$.[9] This corresponds to common central bank practice in economies with well-anchored inflation expectations so that monetary policy can "look through" the consumer price fluctuations caused by transitory commodity price shocks. Moreover, perfect stabilization of core inflation would be the optimal policy in our model if wages were fully flexible. Second, as the inefficiency associated with nominal wage rigidities can be reasonably well approximated with deviations of output from its flexible price and wage level (see, e.g., Debortoli et al., 2019), the monetary policy rule (13) also includes the appropriately defined output gap term.

The fiscal authority levies lump sum taxes T_t or issues debt $B_{G,t}$ to finance subsidies to energy use in consumption and production. The government intertemporal budget constraint

[9] In our model, we define headline inflation as the change in the effective price of the consumption basket, and so it can be thought of as a measure of the cost of living. The headline inflation rate reported by the statistical offices is closely related to this concept if subsidies supporting households are introduced in a way that directly affects retail energy prices, for example if the fiscal authority lowers indirect taxes levied on energy purchases. If instead subsidies are paid directly to households, the official measure of headline inflation may deviate from the one we use in the model as subsidies will not be reflected in retail energy prices.

is then

$$B_{G,t} = I_{t-1}B_{G,t-1} + \tau_{Y,t}P_{O,t}O_{Y,t} + \tau_{C,t}P_{O,t}O_{C,t} - T_t. \tag{14}$$

As Ricardian equivalence holds in the model, the particular sequence of taxes that ensures the long-run stability of government debt is irrelevant for the equilibrium, as long as the associated transversality condition is satisfied.

3.4 Market Clearing

We impose a standard set of market clearing conditions. In particular, the energy market needs to clear

$$Y_{O,t} = O_{C,t} + O_{Y,t}. \tag{15}$$

The definition of equilibrium is straightforward, and the full list of equations defining it can be found in Appendix A.4.

4 Transmission of Energy Shocks and Subsidies: Analytical Insights

The model presented above is simple enough to allow us to prove some of our key results analytically.

4.1 Equivalence Results

We start by showing that, even though energy subsidies to firms and households are conceptually different policy instruments, their effects on real allocations are tightly linked. We can formalize this relationship in the following proposition.

Proposition 1. *In a New Keynesian model with energy, any sequence of subsidy pairs* $\{\tau_{C,t}, \tau_{Y,t}\}_{t=0}^{\infty}$ *yields identical equilibrium allocations as an alternative sequence* $\{\mathring{\tau}_{C,t}, \mathring{\tau}_{Y,t}\}_{t=0}^{\infty}$ *if and only if* $\frac{1-\tau_{C,t}}{1-\tau_{Y,t}} = \frac{1-\mathring{\tau}_{C,t}}{1-\mathring{\tau}_{Y,t}}$ *for all* $t = 0, 1, ...$

The proof can be found in Appendix A.5. One immediate implication is that energy subsidies work only if they are differentiated between households and firms, so that these two types of agents end up facing a different energy price. In particular, if energy use by households and firms is subsidized at exactly the same rate, the subsidy has no effect on allocations.

The following corollary, which holds in the linearized version of the model, makes another key implication of Proposition 1 immediately clear: an energy subsidy to consumers is akin to an energy tax on firms.

Corollary 1. *In a linearized New Keynesian model with energy, subsidizing energy use by households is equivalent to taxing energy use by firms at the same rate.*

These results may appear surprising, especially because they hold independently on the model parametrization. The key insight is that what matters for allocations is not the pre-subsidy energy price $P_{O,t}$, but the effective energy cost for households and firms, or $(1 - \tau_{C,t})P_{O,t}$ and $(1 - \tau_{Y,t})P_{O,t}$, respectively. This can be seen by inspecting the model equilibrium conditions, in which $P_{O,t}$ never shows up independently. Suppose, then, that the government introduces subsidies to households but no subsidies to firms, which results in an endogenously determined pre-subsidy paths of energy price $P_{O,t}$ and other allocations. Then the model equilibrium conditions are also consistent with some path of energy subsidies to firms, no subsidies to households, some pre-tax energy price path $\mathring{P}_{O,t}$, and exactly the same real allocations, as long as the following two conditions hold for all t

$$(1 - \tau_{C,t})P_{O,t} = \mathring{P}_{O,t}, \tag{16}$$

$$P_{O,t} = (1 - \tau_{Y,t})\mathring{P}_{O,t}, \tag{17}$$

which simply imposes that the effective real energy price paid by households and firms is the same under these two alternative policies. To first order, these conditions imply $\tau_{C,t} = -\tau_{Y,t}$.

Note that the equivalence results above apply to allocations, but also to all prices except for the pre-subsidy energy price. As a matter of fact, endogenous adjustment of the pre-subsidy price is exactly what makes the equivalence work. For example, subsidies to households decrease the effective price they pay for energy use, but endogenously drive the pre-subsidy energy price up, thus increasing the unit energy cost to firms. Hence, subsidies to households act like a tax on energy use by firms, though an actual tax on firms would depress the pre-subsidy energy price, which in turn would stimulate household demand in a manner akin to a subsidy.

This equivalence result is admittedly derived in a fairly simple model of a closed economy in which the energy endowment is exogenous and Ricardian equivalence holds.[10] A consumer energy subsidy would not induce the same "one-to-one" crowding out of firm energy demand if the induced rise in energy prices caused energy production to rise. And, in an open economy setting, there would be little crowding out of firm energy demand if a small country increased its energy subsidy unilaterally (as the consumer subsidy would have a de minimis effect on global oil prices, and hence the oil price faced by domestic firms). Even so, this analysis provides helpful intuition for understanding the effects of a consumer subsidy if deployed by many countries simultaneously, especially in the short-run in which global energy supply is

[10] If the government does not have access to lump sum transfers and taxes, energy subsidies to households and energy taxes on firms will imply different paths of other distortionary fiscal instruments, breaking the equivalence.

plausibly very inelastic: such a broad-based subsidy would act like a global energy tax on firms, as we will illustrate more concretely in the next section.

4.2 Log-linearized Model with Full Price Flexibility

We next turn to the log-linearized model and begin by focusing on how energy shocks and energy subsidies transmit in the flexible price and wage equilibrium. Because we assume that the effects of monopolistic competition in intermediate goods production and labor market are eliminated with appropriate subsidies, this equilibrium coincides with the first-best allocation provided that energy subsidies are not utilized. To facilitate the exposition and to derive analytical results, we momentarily abstract from habit persistence in consumption and the dynamic component of price indexation by setting $\varkappa = \iota = 0$, though we will reintroduce these features in the numerical simulations considered in the next subsection. Throughout, we use smaller case letters to indicate log-deviations of variables from their steady state values, with all real prices normalized by the producer price index $P_{Y,t}$. We also adopt the convention of using superscript f to indicate flexible price equilibrium allocations and prices, and refer to their values as "potential" levels.

We show in Appendix A.7 that if both prices and wages can freely adjust, the energy market clearing condition can be written as

$$-y_{O,t} = \Psi_{oc}\left(p^f_{O,t} - \tau_{C,t}\right) + \Psi_{oy}\left(p^f_{O,t} - \tau_{Y,t}\right), \tag{18}$$

where $\Psi_{oc}, \Psi_{oy} > 0$.[11] A useful feature of equation (18) is that the potential price of energy $p^f_{O,t}$ is the only endogenous variable. Clearly, a fall in the energy endowment or an increase in either type of energy subsidy boosts the potential pre-subsidy energy price.

The effects of subsidies on the labor market, and especially on the product real wage, are of crucial significance in our subsequent analysis. Under full price and wage flexibility, the "demand" real wage of producers w^f_t – what firms would be willing to pay to hire a given quantity of labor – is determined by the equality of the product real wage and marginal product of labor schedule. The product real wage declines in hours worked n^f_t and in the real price of energy net of the producer subsidy $p^f_{O,t} - \tau_{Y,t}$

$$w^f_t = -\frac{\omega_y}{1-\omega_y}\left(p^f_{O,t} - \tau_{Y,t}\right) - \alpha n^f_t. \tag{19}$$

The "supply" real wage of households is determined by the equality between the household's marginal rate of substitution and the consumer real wage. Specified in terms of the product

[11] Throughout this section, we use composite parameters Ψ with different sub- and superscripts to save space. Their exact links to the structural parameters can be found in Appendix (A.7) and (A.9).

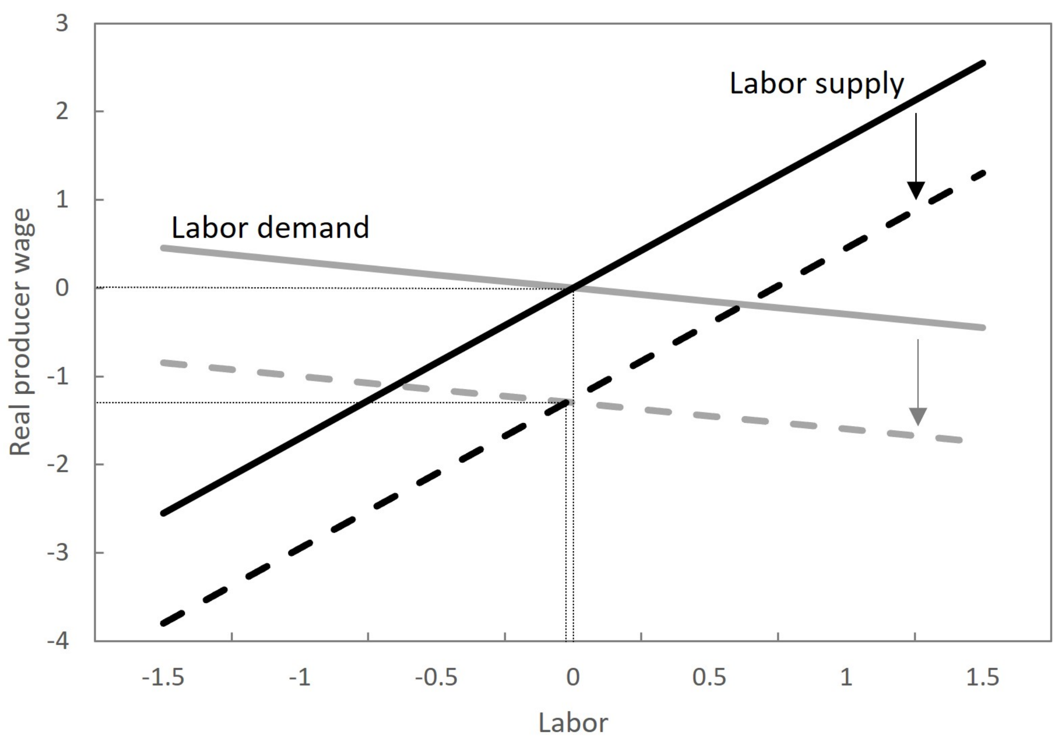
real wage w_t^f, the real wage that households demand to work n_t^f hours is given by

$$w_t^f = \chi n_t^f + \omega_c \left(p_{O,t}^f - \tau_{C,t} \right) + \frac{1}{\sigma} c_t^f, \tag{20}$$

where the first term captures the disutility from working, the second the wedge between consumer and producer prices, and the last term the wealth effect.

To gauge the effect of a consumer energy subsidy $\tau_{C,t}$, it is helpful to abstract from the wealth effect. Since such a subsidy reduces the net energy price to households, it shifts the labor supply curve outward as illustrated in Figure 4, while shifting the labor demand curve down (insofar as it raises the energy price paid by firms). Hence, the subsidy would invariably depress the equilibrium product real wage, as shown in the figure, while having ambiguous effects on hours worked.

Figure 4: Labor Market Effects of Consumer Energy Subsidies under Flexible Prices and Wages



Allowing for wealth effects, it turns out that the (equilibrium) product real wage necessarily declines in response to a consumer energy subsidy if value added production is linear in labor (so $\alpha = 0$). In the more general case in which there are diminishing returns to labor, consumption c_t^f could in principle rise enough to shift in labor supply. This reflects that consumption depends on domestic non-energy production, which falls, but also on household energy consumption, which rises. Nevertheless, even if the latter effect is big enough to shift labor supply inward, the fall in labor demand dominates under any reasonable calibration, so that the product real wage goes down in reaction to a consumer energy subsidy. More formally, we show in Appendix A.7 that the product real wage must decline provided that

$$\omega_c \left(1 - \frac{1}{\sigma}\eta_c\right) \Psi_{oy} + \frac{\omega_y}{1-\omega_y} \left[\left(\frac{1}{\alpha} - 1\right)\left(\chi + \frac{1}{\sigma}\right) + \frac{1}{\sigma}\eta_y\right] \Psi_{oc} > 0. \tag{21}$$

A sufficient condition for this restriction to hold is $\eta_c < \sigma$, implying that energy and non-energy goods are (Pareto-Edgeworth) complements in household preferences. Complementarity implies that households want to increase their consumption of both energy and non-energy goods when energy becomes cheaper due to subsidies, which reduces their wealth effect on labor supply.

4.3 Log-linearized Model

To highlight the key channels through which energy supply shocks and energy subsidies transmit in our model economy, it is helpful to consider the supply block of the model in log-linearized form. A full list of linearized equilibrium conditions can be found in Appendix A.6 with the implications for aggregate demand discussed in Appendix A.8. In light of the equivalence between consumer energy subsidies and energy taxes on firms highlighted in Proposition 1, we confine our attention to the former.

Headline inflation $\pi_{C,t}$ is defined as a weighted average of core inflation $\pi_{Y,t}$ and consumer energy price inflation

$$\pi_{C,t} = (1-\omega_c)\pi_{Y,t} + \omega_c \left(\pi_{O,t} - \Delta\tau_{C,t}\right), \tag{22}$$

where $\pi_{O,t} \equiv \log(P_{O,t}/P_{O,t-1}) - \log(\Pi)$. Given that households consume energy directly, an increase in energy prices has a first-round effect on headline inflation. Consumer energy subsidies can reduce the impact of this first-round effect, or even offset it completely, if they are set to follow exactly the path of energy prices, i.e. $\Delta\tau_{C,t} = \Delta p_{O,t}$.

Over the medium term, inflation is mainly driven by its more sticky core part. The evolution of core inflation is governed by the price Phillips curve

$$\pi_{Y,t} = \beta\mathbb{E}_t\pi_{Y,t+1} + \kappa_p \left[\omega_y \left(p_{O,t} - \tau_{Y,t}\right) + (1-\omega_y)\left(w_t + \alpha n_t\right)\right], \tag{23}$$

where $\kappa_p \equiv \frac{(1-\xi)(1-\beta\xi)}{\xi}$ and the term in the square brackets is the real marginal cost, consisting of energy and non-energy components. As discussed above, the former clearly rises in response to a jump in the energy price (which, as we will show below, rises with a consumer energy subsidy). The reaction of core inflation will hence crucially depend on how employment and the (producer) real wage adjust. If wages are sufficiently sticky, a shock that raises the energy price will also boost core inflation.

Nominal wage dynamics in our model can be summarized by the following wage Phillips curve

$$\pi_{W,t} - \tilde{\pi}_{W,t} = \beta \mathbb{E}_t \left\{ \pi_{W,t+1} - \tilde{\pi}_{W,t+1} \right\} + \kappa_w \left[\chi n_t + \frac{1}{\sigma} c_t - w_{C,t} \right], \tag{24}$$

where $\kappa_w \equiv \frac{(1-\xi_w)(1-\beta\xi_w)}{\left(1+\frac{1+\theta_w}{\theta_w}\chi\right)\xi_w}$, $\pi_{W,t} \equiv \log(W_t/W_{t-1}) - \log(\Pi)$ is (demeaned) nominal wage inflation, $\tilde{\pi}_{W,t} = \iota_y \pi_{Y,t} + \iota_c \pi_{C,t}$ describes the wage indexation scheme, and $w_{C,t} \equiv w_t - \omega_c \left(p^f_{O,t} - \tau_{C,t} \right)$ is the real consumer wage. Energy supply shocks hence transmit into higher nominal wages via two channels. First, they open the gap between the real consumer wage, which falls due to the first-round effect of higher energy cost on consumer prices, and the marginal rate of substitution. This induces those agents who can reoptimize to increase their wages. Second, nominal wages increase via the indexation mechanism, with the transmission of energy price changes especially strong if indexation keys off of headline inflation. Accordingly, subsidies tend to be more effective in moderating wage pressures if there is a high degree of indexation to headline inflation.

4.4 The Model in "Gap" Form

The log-linearized supply block can be re-written in a simple form that depends only on the real wage gap – the gap between the real wage and its potential level – and the employment gap – the gap between employment and its potential level following an approach similar to Bodenstein et al. (2008) and Lorenzoni and Werning (2023). In concert with our result that energy subsidies to households depress the potential (producer) real wage, this reformulation turns out to be very useful in showing analytically how consumer energy subsidies affect price inflation, with strong predictions that are robust qualitatively across different calibrations. By way of notation, we will use hats to denote deviations of variables from their potential level, i.e., for any variable x_t, we define $\hat{x}_t \equiv x_t - x^f_t$. The details of the derivations below are presented in Appendices (A.7) and (A.9).

We begin by noting that the energy market clearing condition can be written as

$$y_{O,t} = v_t - \eta_y \left(\frac{O_Y}{Y_O} + \omega_y \frac{O_C}{Y_O} \right) (p_{O,t} - \tau_{Y,t} - p_{V,t}) - \eta_c \frac{O_C}{Y_O} (p_{O,t} - \tau_{C,t}) . \tag{25}$$

where $p_{V,t} \equiv \alpha r_{k,t} + (1-\alpha) w_t$ is the marginal cost of non-energy input (i.e., capital and labor) to production. This equation shows that a negative energy supply shock $y_{O,t}$ or an increase in any type of subsidies $\tau_{C,t}$ or $\tau_{Y,t}$ requires either higher pre-subsidy real energy prices, a decline in employment (noting that $v_t = (1-\alpha) n_t$), or a decline in the prices of non-energy production factors. As we will subsequently show, the endogenous increase in energy prices must be the key equilibrating force under a reasonable monetary policy response reaction, see also Appendix A.8.

Representing equation (25) in "gap" form, the deviation of the pre-subsidy energy price from its potential level $\hat{p}_{O,t}$ can be expressed as a simple function of the employment gap $\hat{n}_t$ and real wage gap $\hat{w}_t$

$$\hat{p}_{O,t} = \Psi_{on}\hat{n}_t + \Psi_{ow}\hat{w}_t, \tag{26}$$

where $\Psi_{on}, \Psi_{ow} > 0$ are explicit functions of the deep model parameters.

This allows us to write the price and wage Phillips curves (23) and (24) as follows

$$\pi_{Y,t} = \beta\mathbb{E}_t\pi_{Y,t+1} + \kappa_p\left[\Psi_n^{mpl}\hat{n}_t + \Psi_w^{mpl}\hat{w}_t\right], \tag{27}$$

$$\pi_{W,t} - \tilde{\pi}_{W,t} = \beta\mathbb{E}_t\left\{\pi_{W,t+1} - \tilde{\pi}_{W,t+1}\right\} + \kappa_w\left[\Psi_n^{mrs}\hat{n}_t + \Psi_w^{mrs}\hat{w}_t\right]. \tag{28}$$

Further assuming that non-optimized wages are indexed to core and steady state inflation, i.e. $\iota_c = 0$, which we found to be a reasonable empirical characterization based on the VAR evidence in Section 2, these equations have the same structure as in the model of Erceg et al. (2000). In that analysis – as here – monetary policymakers face tradeoffs between stabilizing price inflation, employment, and wage inflation.

4.5 Transmission of Consumer Energy Subsidies to Inflation

It is very useful to consider how consumer energy subsidies affect inflation when the monetary authority focuses exclusively on keeping non-energy output v_t – and hence employment n_t – at its potential level.[12] Under these conditions, the price Phillips curve implies that core inflation can be written as a function of the discounted sum of future wage gaps

$$\pi_{Y,t} = \kappa_p\Psi_w^{mpl}\mathbb{E}_t\sum_{j=0}^{\infty}\beta^j\hat{w}_{t+j}. \tag{29}$$

We now show that, in response to a (possibly persistent) consumer energy subsidy shock, the right-hand side of equation (29) is positive, and hence core inflation goes up. The key step is to combine equations (27) and (28) to obtain the following law of motion for the real producer wage

$$\mathbb{E}_t\left\{w_{t+1}\right\} - \left(1 + \frac{1}{\beta} + \frac{\kappa}{\beta}\right)w_t + \frac{1}{\beta}w_{t-1} = -\frac{\kappa}{\beta}w_t^f, \tag{30}$$

where $\kappa \equiv \kappa_w\left[1 - \Psi_w^{mrs}\right] + \kappa_p(1-\iota_y)\Psi_w^{mpl}$. This second-order difference equation can be solved to obtain

$$w_t = \mathcal{R}_2 w_{t-1} + (1-\mathcal{R}_2)\frac{1-\beta\mathcal{R}_2}{1-\rho\beta\mathcal{R}_2}w_t^f, \tag{31}$$

where ρ is the autoregressive coefficient in the AR(1) process driving the subsidy and $0 < \mathcal{R}_2 < 1$ is the lower of the two roots of the right-hand side of equation (30). As a last step

[12] The analysis presented below immediately generalizes to the case when the central bank targets any exogenously given path of the employment gap.

we prove that this solution implies

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \hat{w}_{t+j} = D w_t^f, \tag{32}$$

where $D < 0$.

Recall that, at least for realistic parametrization, energy subsidies to households push the potential real producer wage down. Then, combining equation (32) with the price Phillips curve (29) implies that this type of subsidies increases core inflation.[13] We can summarize these analytical derivations with the following proposition, the formal proof of which can be found in Appendix A.10

Proposition 2. *Assume that (i) energy and non-energy goods are complements in household preferences, (ii) the dynamic component of wage indexation, if present, relies on producer price inflation, (iii) the monetary authority focuses on closing the output gap. Then, in a linearized New Keynesian model with energy, an increase in energy subsidies to households leads to an increase in core inflation.*

As discussed above, the complementarity assumption (i) ensures that the real producer wage falls in response to a consumer energy subsidy, and can be replaced with a weaker restriction given by formula (21).

Equation (31) has also two other important implications regarding the consequences of consumer energy subsidies. The first one is that the more persistent the subsidy is, the more lasting increase in core inflation it generates. This can be seen by considering the limiting case of a permanent subsidy ($\rho \to 1$) as it implies that the real producer wage converges to its potential level monotonically. This means means that the wage gap, and hence the deviation of core inflation from its steady state, stays always positive before it converges to zero. The second implication is related to the pre-subsidy energy price. It follows from equation (26) that, if the central bank stabilizes employment at its potential level, energy subsidies to households lead to a rise in the energy price gap. Since we have already shown that the subsidy moves potential pre-subsidy energy prices up, it follows that they increase even more in the equilibrium with sticky prices and wages.

4.6 Key takeaways

The key insight from this part of our analysis is that, from a global perspective or in highly segmented energy markets, there exist strong general equilibrium mechanisms that make

[13] These results are intuitive based on previous research in a similar framework but without energy subsidies, including recent analysis by Lorenzoni and Werning (2023) and past work by Bodenstein et al. (2008). These papers show how a negative energy supply shock causes core inflation to rise under a monetary policy rule that keeps employment at potential. In this paper, the consumer subsidy in effect acts similarly to a negative shock to the energy supply to producers, and hence also boosts inflation.

consumer energy subsidies likely to be counterproductive. The most important one is endogenous adjustment in pre-subsidy energy prices, making the subsidy akin to a tax on energy use by firms. As a result, at least under an empirically relevant formulation of the wage indexation scheme, consumer energy subsidies actually exacerbate the policy tradeoffs arising from energy supply shocks, leading to an increase in core inflation for given output gap. Hence, for this type of subsidies to have a chance to be productive, wages need to be strongly linked to headline inflation. We explore this direction quantitatively in the next section.

5 Managing an Energy Shock: Quantitative Analysis

5.1 Calibration

The quantitative part of our analysis uses the model calibrated at a quarterly frequency, with parameter values as presented in Table 1. The crucial part of the calibration concerns the supply block of the model. To pin down the share of energy in production and consumption, we rely on data from the International Energy Agency (IEA) on energy use in the US and EA and its sectoral breakdown. To isolate direct energy consumption by households, we assign to it the following categories: total residential energy use, total motor gasoline used in transport, and one-third of diesel and light fuel oil used in transport. All the rest of energy use is assigned to firms. We convert the energy units into the barrel of oil equivalence, and then apply the price of 65 USD per barrel (2019 average) while converting to monetary units. By averaging the US and EA figures, we end up setting ω_y to 0.052 and ω_c to 0.046. Since our analysis focuses on the short run, we choose relatively low values for the elasticity of substitution between energy and non-energy inputs to production and consumption, setting both η_c and η_y to 0.1. This low elasticity is also used in a recent related paper by Auclert et al. (2023).

While parametrizing the price and wage setting, we largely rely on estimated DSGE models for the US and EA, and most notably on Smets and Wouters (2003, 2007) and Blanchard et al. (2017). Compared to the latter paper, which relies on more recent data than the first two, we allow for a bit steeper, but still quite flat wage and price Phillips curves. This choice is driven by the fact that our analysis is focused on the period of fairly high inflation, during which the Phillips curve slopes might be steeper than in normal times (Forbes et al., 2021; Ball et al., 2022). Also in line with the DSGE literature, we allow for a substantial degree of wage and price indexation. Informed by the empirical evidence discussed in Section 2, our baseline specification assumes that wages are indexed to producer price inflation, but we will also discuss how our main results change if we instead assume that indexation is based on headline inflation. As regards the price indexation parameter, we again make some upward adjustment compared to the estimated DSGE models on account of us focusing on a high inflation period, in line with the evidence on time-variation in this parameter documented by Fernandez-Villaverde and Rubio-Ramirez (2008).

Table 1: Model Parameters

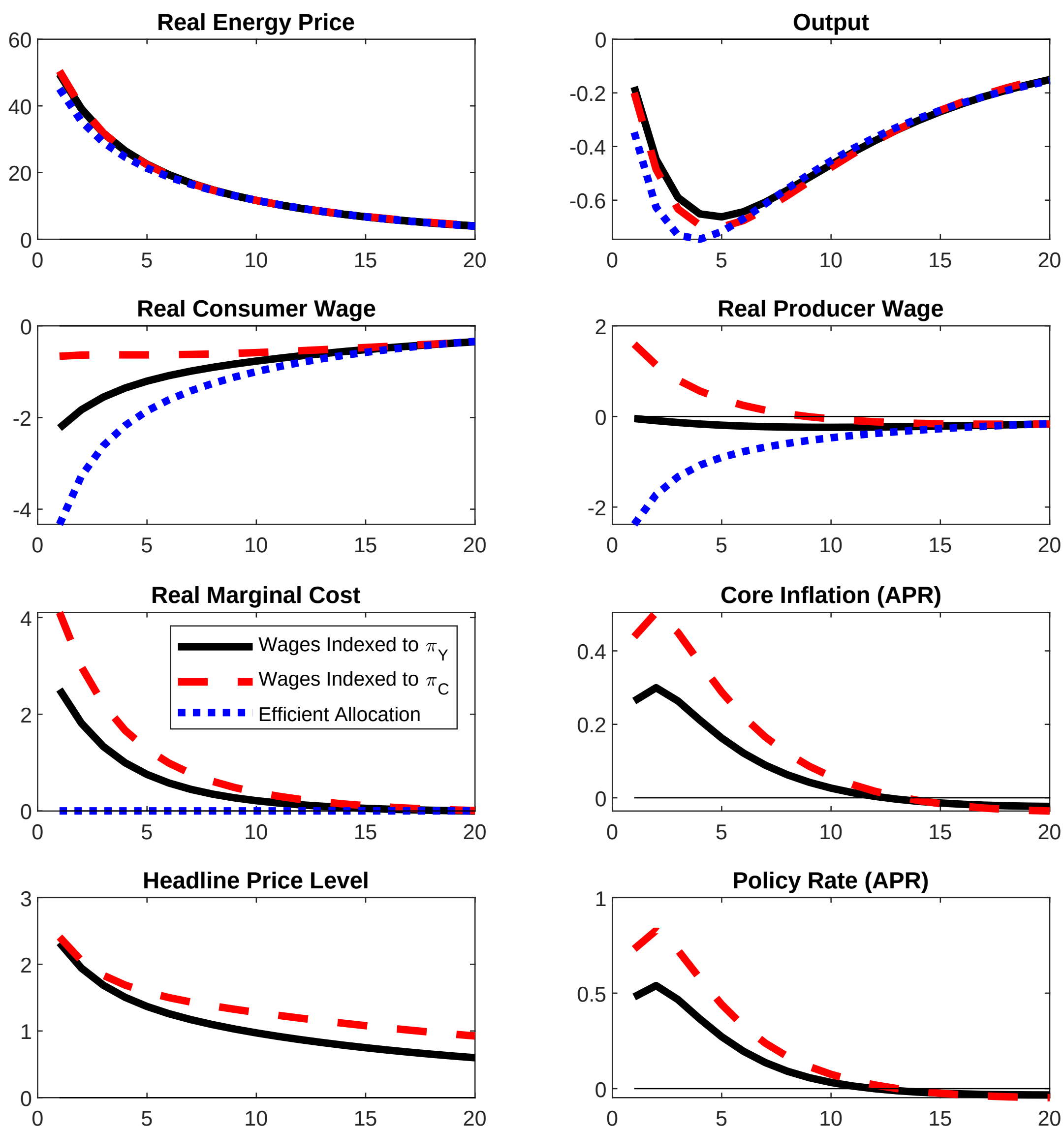
Parameter	Value
Discount factor; β	0.9963
Elasticity of intertemporal substitution; σ	1
Inv. Frisch elasticity of labor supply; φ	1
Habit persistence; $\varkappa$	0.75
Energy share (production, consumption); ω_y, ω_c	0.052, 0.046
Energy elasticity of subst. (consumption, production); η_c, η_y	0.1, 0.1
Capital share in non-energy input to production; α	0.3
Steady-state markup (production, labor market); θ, θ_w	0.2, 0.5
Calvo probability in price setting; ξ	0.92
Indexation in price setting; ι	0.4
Calvo probability in wage setting; ξ_w	0.85
Indexation in wage setting; ι_y, ι_c	0.75, 0
Steady-state inflation; Π	1.005
Monetary policy feedback coefficients; ψ_π, ψ_y	1.5, 0.125

Our calibration also implies a significant degree of habit formation in consumption, which is common in the models that follow Christiano et al. (2005) in allowing for this feature of household preferences. The rest of the parameters are set to standard values or do not have any significant impact on the presented simulations. In particular, our choices for the capital share in production, markups on the product and labor markets, intertemporal elasticity of substitution, and Frisch elasticity of labor supply all correspond to standard values chosen in the literature. The steady state values of inflation and the discount factor are set such that the model is consistent with a 2 percent annual inflation target and the long-term average real interest rate observed in the data. Finally, the Taylor rule specification also reflects typical weights on inflation and the output gap in models calibrated at a quarterly frequency.

5.2 Transmission of Energy Shocks

Figure 5 presents the responses to a persistent energy supply shock. We calibrate the size of the initial drop in energy endowment $Y_{O,t}$ such that it generates an increase in the real energy price $P_{O,t}/P_{Y,t}$ by 50 percent on impact, and then follows an AR(1) process with coefficient 0.9. We plot the outcomes assuming two alternative wage indexation schemes. Our baseline is the one in which non-optimized wages are indexed to producer price inflation, the alternative one assumes indexation to headline (consumer price) inflation. As a reference, we also show the responses in an efficient equilibrium that could be achieved if prices and wages were fully flexible, or if only either prices or wages were fully flexible and monetary policy was conducted optimally to maximize household utility.

Figure 5: Energy Supply Shock



Notes: All variables are expressed as percent deviations from their pre-shock levels. The responses of inflation and the policy rate are in annualized percentage points.

A negative energy supply shock leads to a persistent increase in real energy prices and a fall in economic activity. If wages are indexed to core inflation, the real producer wage falls, but only moderately. Comparing this response to the results presented in Section 2, the model thus generates wage dynamics in the middle ground between the empirical evidence for the US, which featured a much stronger fall in the real producer wage, and that for the EA, which pointed at some (though statistically insignificant) increase in this variable. Due to nominal wage rigidities, the real wage adjustment falls short of that implied by the efficient allocation. As a result, marginal cost and hence core inflation go up, consistently with analytical insights discussed in Section 4. Headline inflation additionally spikes on impact due to the direct energy component in the consumption basket.

The energy supply shock would be more inflationary and contractionary if wages were instead indexed to headline inflation. This type of indexation would imply that nominal wages go up to catch up with an increase in the cost of living. As a result, the real consumer wage would fall by much less while the real producer wage would actually increase, thus moving the labor market even further away from the efficient allocation. While such a description of labor market adjustment could have been a more empirically relevant case in the 1970s (Blanchard and Gali, 2007), it is inconsistent with evidence using more recent data that we discussed in Section 2, especially for the US.

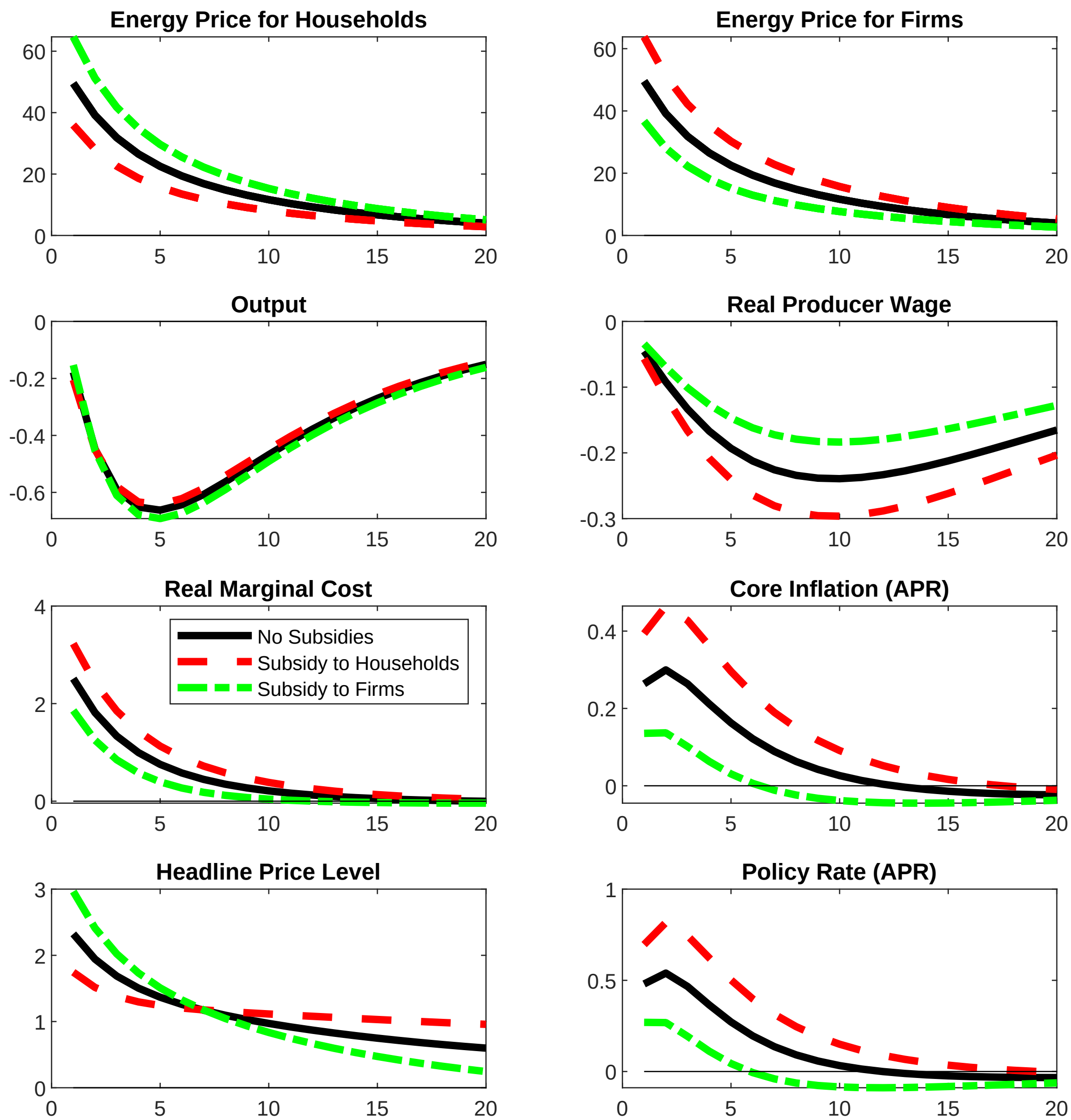
5.3 Can Energy Subsidies Reduce Inflation?

We now analyze how subsidies to energy prices could possibly improve the monetary tradeoffs during the episodes of energy supply shocks. Our model features two types of subsidies, one paid to households, the other directed to firms. Whenever we consider simulations with subsidies, we set their initial value at 17% and assume that they have the same persistence as energy shocks.[14]

The macroeconomic effects of each of the two types of subsidies are depicted in Figure 6. Energy subsidies to households have a direct mitigating effect on the increase in the cost of living faced by households due to an increase in energy prices. This shows in the panel depicting the response of the headline price level. Lower consumer prices translate into lower wage pressure, and thus the real producer wage falls. At the same time, however, the subsidy blunts households' incentive to cut their energy consumption. In consequence, the pre-subsidy energy price, which is the one reflecting energy cost faced by firms, moves up and further away from the efficient allocation. In line with the analytical results presented in the previous section, firms' marginal cost and core inflation hence increase. The endogenous reactions of the pre-subsidy energy price and core inflation also implies that the achieved reduction in headline inflation is substantially reduced and, after about two years, the cost of living index is actually higher than it would have been absent the subsidy. Another observation that can be made is that, despite amounting to about 1 percent worth of annual GDP in the first year of their deployment, subsidies have very small impact on economic activity.

[14] A 17% subsidy halves the impact of a 50% increase in the pre-subsidy energy price as faced by an atomistic subsidized agent.

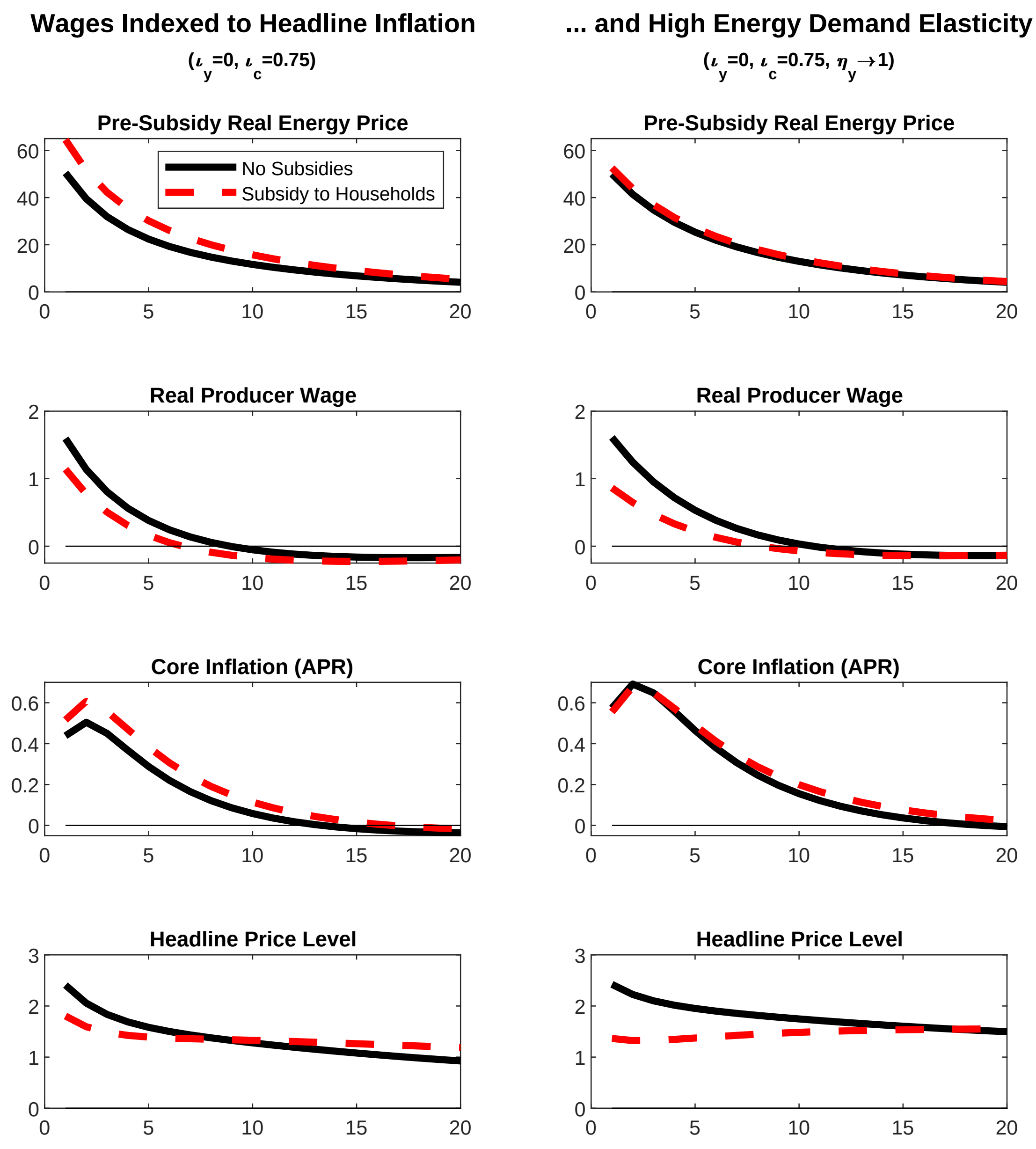
Figure 6: Energy Supply Shock with Subsidies



Notes: All variables are expressed as percent deviations from their pre-shock levels. The responses of inflation and the policy rate are in annualized percentage points.

The effects of subsidies to energy use by firms are a mirror image of those associated with consumer energy subsidies. This reflects our analytical result stated in Section 4.1, according to which there is an equivalence between subsidizing energy prices for households and taxing energy prices for by firms. Both types of subsidies drive the pre-subsidy energy price up, which essentially boils down to shifting the burden of adjustment to an energy shock from subsidized agents to non-subsidized ones. Our results thus imply that energy subsidies to firms can successfully bring core inflation down, this helping monetary policy to achieve its medium-term stabilization objectives, but this comes at a short-term cost to households, who end up paying higher prices per unit of energy consumed.

Figure 7: Energy Subsidies to Households: Different Model Calibration



Notes: All variables are expressed as percent deviations from their pre-shock levels. The responses of inflation are in annualized percentage points.

Overall, these results paint a rather pessimistic picture regarding the usefulness of energy subsidies to households in curbing inflation. We now investigate if this conclusion could change under alternative assumptions on the structural characteristics of the labor and energy markets. Figure 7 summarizes the outcomes of such experiments. To facilitate comparisons with our baseline simulations, we normalize the energy supply shock such that, absent subsidies, it generates the same increase in real energy prices of 50% in all calibration variants.

Recall that, to make our model match empirical evidence described in Section 2, in our baseline calibration we assume that nominal wages are dynamically indexed only to core inflation ($\iota_y = 0.75$, $\iota_c = 0$). Would energy subsidies to households be more effective at taming inflation if wages were instead indexed to headline inflation? To answer this question, we consider the extreme case and flip the indexation scheme in wage setting by assuming $\iota_y = 0$ and $\iota_c = 0.75$. As the left column panels in the figure show, this allows the subsidy to achieve sizable wage moderation, which is however not enough to prevent an upward pressure on producers prices. The reason is as we described before: by encouraging households to use more energy, consumer energy subsidies increase the energy price paid by firms, so that the marginal cost goes up despite lower wage pressure.

Our next counterfactual experiment considers the model variant in which, additionally to wages being indexed to headline inflation, energy can be fairly easy to substitute with capital or labor, i.e. we assume $\eta_y \to 1$. It needs to be stressed that, if anything, energy is more difficult to substitute in production than in consumption, so the only purpose of this calibration is to examine the conditions under which consumer energy subsidies could be productive. As can be seen from the right column panels, this calibration implies only a moderate increase in energy cost to firms in response to energy subsidies to households. Together with substantial wage moderation, this is sufficient to result in a fall in core inflation and keep the headline price level below the no subsidy case. However, as we stressed before, this outcome is achieved only if the two highly unrealistic assumptions on wage indexation and energy substitutability in production are simultaneously met.

5.4 Optimal Energy Subsidy

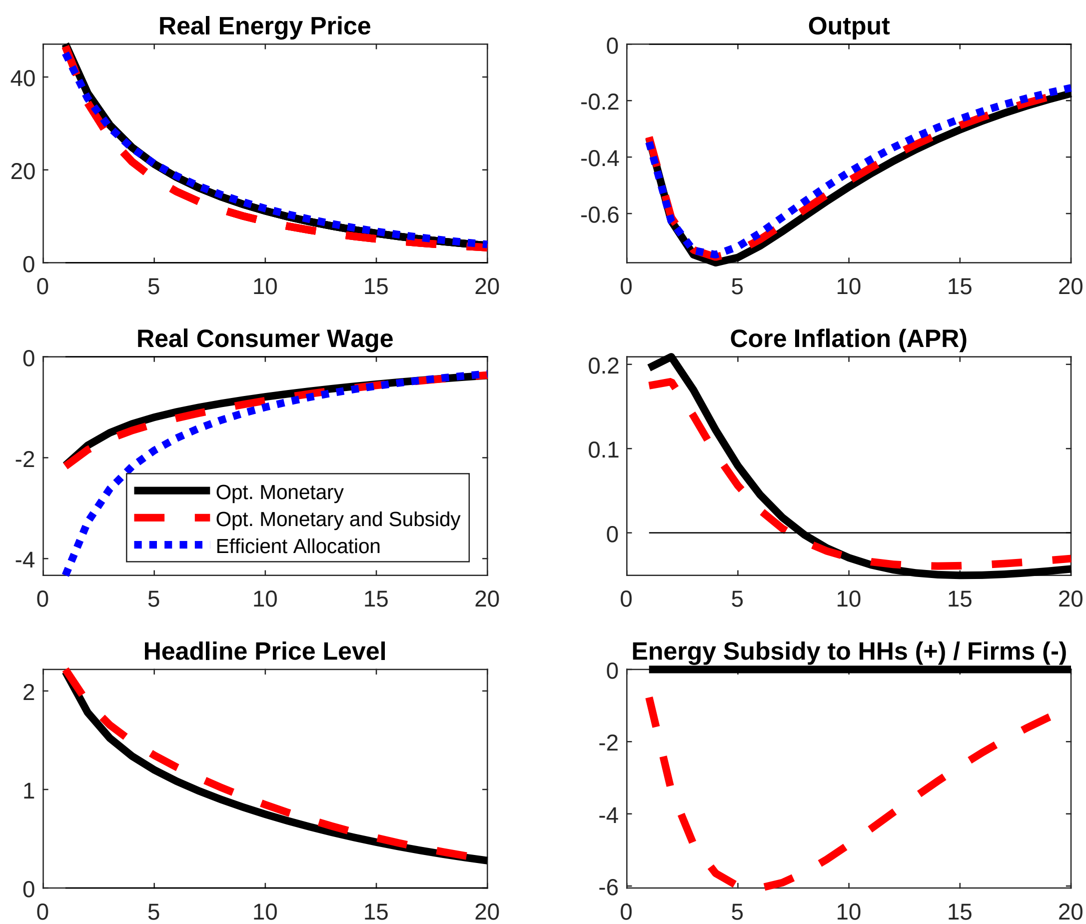
To better understand the transmission of energy subsidies, we have so far imposed them exogenously and focused on their effect on inflation. However, this type of fiscal policy is typically designed to serve broader purposes, which also include direct support to households that are particularly vulnerable to increases in energy price. The simplest version of our model is not well suited to address this type of motives and we postpone their more detailed discussion to Section 6, where we introduce hand-to-mouth households as this allows us to also capture redistributive effects of energy shocks and subsidies. However, it is still useful to start the analysis of the optimal use of this type of instruments in a simple setup that abstracts away from these additional considerations.

To this end, we now consider constrained-optimal policies that maximize social welfare

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left(\frac{\left(C_{t+s} - \varkappa C_{t+s-1}\right)^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} - \chi_0 \frac{N_{t+s}^{1+\chi}}{1+\chi} P^{\#}_{W,t+s} \right), \tag{33}$$

which aggregates individual utility 1 over the whole mass of households, and where $P^{\#}_{W,t} \equiv \int_0^1 \left(\frac{W_t(h)}{W_t}\right)^{(1+\chi)\frac{1+\theta_w}{\theta_w}} \mathrm{d}h$ is a measure of wage dispersion. Given the equivalence results established in Section 4.1, we allow the policy maker to optimally choose only one of the two subsidy types, namely the consumer energy subsidy $\tau_{C,t}$, and interpret its negative values as a subsidy to firms. To make sure that the subsidy does not try to correct suboptimality of monetary policy rule 13, we now also allow the policy maker to optimally choose also the interest rate R_t. We assume full commitment and timeless perspective (Woodford, 2003).

Figure 8: Optimal Energy Subsidies



Notes: All variables are expressed as percent deviations from the steady state. The responses of inflation are in annualized percentage points.

Figure 8 plots the optimal responses to the same energy supply shock that we considered before. If monetary policy but not subsidies can be chosen optimally, the outcomes are very similar to what we presented in Figure 5, confirming our previously made claim that equation 13 is a reasonable approximation of optimal monetary policy.[15] If subsidies are added to the set of instruments, the optimal policy is to apply them to firms rather than household. This helps contain the increase in marginal cost and hence lowers core inflation. As a result, less contraction in economic activity is needed. Overall, this part of the analysis confirms our previous conclusions that consumer energy subsidies can be quite counterproductive in stabilizing an economy that is hit by an adverse energy supply shock.

6 TANK Extension

We now consider a version of our model that includes rule-of-thumb households as it is done in the TANK (two-agent New Keynesian) literature. This extension allows us to better capture demand-side effects of energy shocks and relate our work to the growing line of papers stressing the role of household heterogeneity in the transmission of monetary and fiscal policies. While developing this version of the model, we keep its supply side intact, and hence our main conclusions regarding the impact of subsidies on the inflation-output tradeoff will still hold. However, including a second (and more vulnerable) type of households allows us to look deeper at the implications of energy subsidies for economic inequality and welfare, and also contrast their working with transfer policies.

6.1 Key model modifications

We introduce a new type of households who do not perform intertemporal optimization but instead behave in a rule-of-thumb fashion. We dub them as Keynesian, indicate them with subscript K, and denote their share in population by λ. The remaining households, which we refer to as Ricardian and whose preferences and decisions remain as in the baseline model, are indicated with superscript R. Below we describe the key elements of this model extension, relegating more detail to Appendix A.11.

Keynesian agents do not hold any assets so their nominal budget constraint is simply

$$P_{C,t}C_{K,t} = W_t N_{K,t} - P_{C,t}T_{K,t}. \tag{34}$$

They just consume their real disposable income, which consists of labor income net of taxes. We also assume that Keynesian households have no bargaining power and do not optimize

[15]The main difference is that optimal policy is more contractionary, which helps limit the increase in core inflation. The outcomes under policy rule 13 could be brought even closer to the optimal ones if one increases the interest rate responsiveness to inflation ψ_π much above the conventional value of 1.5 that we assume in our baseline calibration.

their labor effort, but simply work the same number of hours as an average Ricardian household, earning the economy-wide wage W_t. The latter is effectively determined by Ricardian agents, who do have monopolistic power on the labor market.

The presence of rule-of-thumb agents implies that the timing of lump sum taxes and their distribution across the two types of households matters. We assume that they evolve according to

$$\frac{T_{j,t} - T_j}{Y} = t_{j,t} + \phi_j \frac{B_{G,t} - B_G}{P_{Y,t} Y} \tag{35}$$

for $j = \{K, R\}$, $\phi_K = 0$, $\phi_R > 0$, and $t_j = 0$. Taxes can hence differ between Keynesian and Ricardian households due to exogenous fiscal policy decisions $t_{j,t}$. Additionally, taxes levied on Ricardian households have an endogenous component as they adjust to ensure stabilization of public debt. It is straightforward to verify that, under this formulation of transfer policies, the equivalence results described in Proposition 1 and Corollary 1 still hold.

6.2 Calibration

Table 2 lists our calibration choices concerning the TANK extension of the model. We set the share of Keynesian households to 40% and assume that their steady state consumption is half of that of Ricardian households. These numbers are consistent with evidence provided by Aguiar et al. (2020), who classify households as hand-to-mouth if they have little net worth relative to labor earnings, or have more net worth but negligible liquid assets.[16] To meet the targeted level of relative steady state consumption of Keynesian households, we appropriately calibrate the steady state distribution of taxes, for given steady state public debt. The latter is set to 2.4 times the level of output, consistently with a debt-to-annual-GDP ratio of 60%. Finally, we set the feedback coefficient in the tax rule for Ricardian agents to a low number, that is however high enough to ensure that real public debt is stationary.

Table 2: TANK Extension Parameters

Parameter	Value
Share of Keynesian households; λ	0.4
Relative consumption of Keynesian households; C_K/C_R	0.5
Steady state debt-to-output ratio; B_G/Y	2.4
Response of taxes to public debt; ϕ_K, ϕ_R	0, 0.01

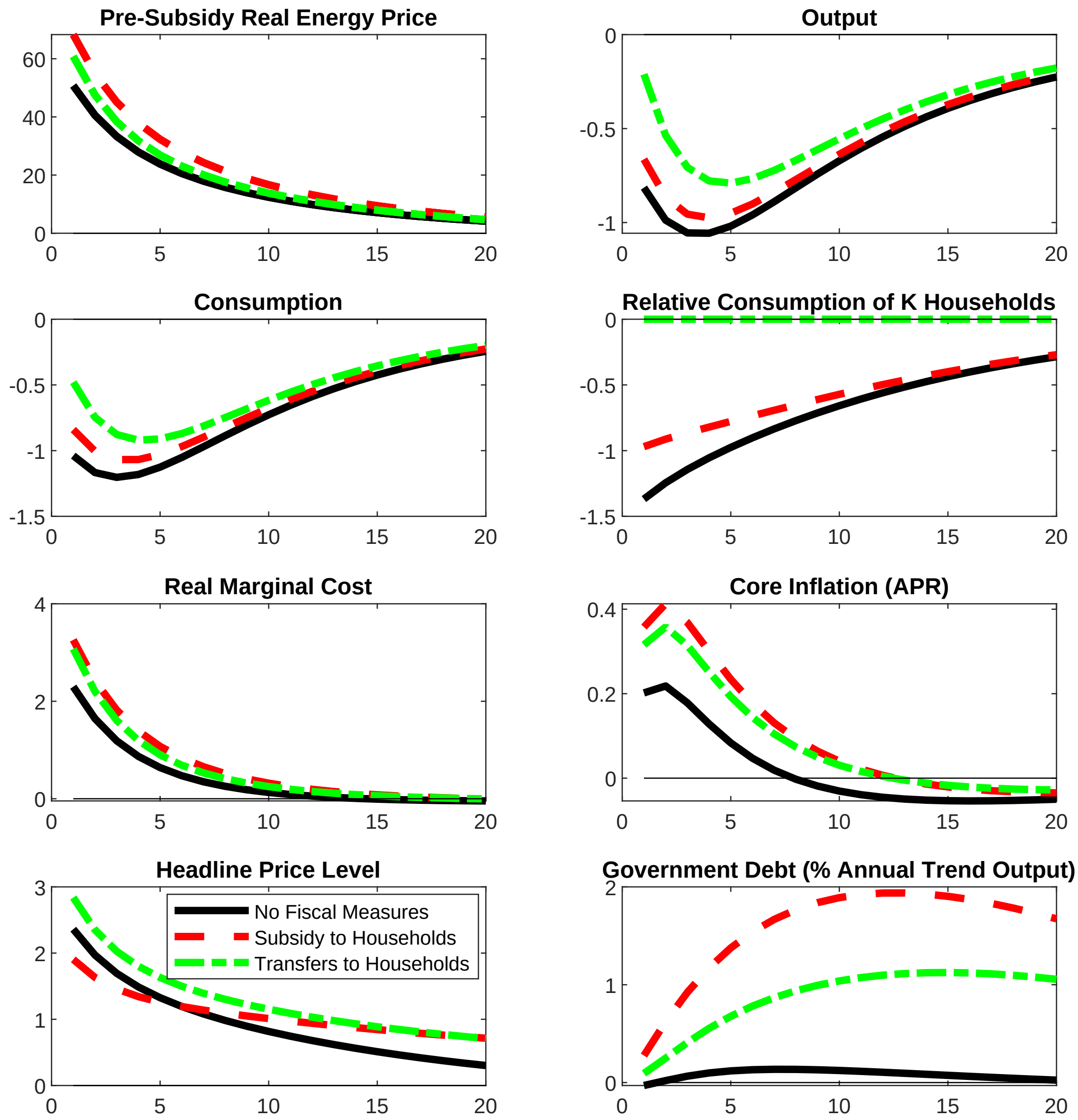
6.3 Energy Subsidies versus Transfers

We now revisit the effectiveness of consumer energy subsidies by simulating the thus modified version of our model. Figure 9 depicts the effects of an exogenous drop in energy endowment.

[16]The latter group is often referred to as ”wealthy hand-to-mouth” (Kaplan et al., 2014).

As in the simulations presented in Section 5, we scale the shock such that, absent any discretionary fiscal measures, it generates an increase in real energy price by 50% on impact, and then follows an AR(1) process with coefficient 0.9.

Figure 9: Energy Supply Shock with Subsidies and Transfers: TANK Model



Notes: All variables are expressed as percent deviations from the steady state. The responses of inflation are in annualized percentage points.

Comparing the solid black lines in Figures 9 and 5 reveals that allowing for the presence of hand-to-mouth agents amplifies aggregate demand effects of an energy price shock: the fall in output is deeper and the increase in core inflation short-lived.[17] This is because Keynesian households are much more vulnerable to changes in energy prices as they do not hold any assets that could be used to smooth consumption. As a result, consumption inequality increases. Stronger aggregate demand effects also imply that, in the TANK environment, energy subsidies turn out to be even more counterproductive in fighting core inflation than we have seen before. At the same time, they somewhat help curb an increase in consumption inequality – one of the key motives used by many countries to implement this type of unconventional fiscal measures.

However, Figure 9 also shows that, if the main policy objective is to shield vulnerable households, transfers can be much more effective than subsidies. More specifically, we now assume that the government adjusts transfers to Keynesian households $t_{K,t}$ such that they prevent any increase in consumption inequality, i.e., they ensure $C_{K,t}/C_{R,t} = C_K/C_R$. It is clear that, compared to energy subsidies, this policy is more successful at limiting the contraction in output and consumption, and is much less inflationary. The key reason is that lump sum transfers do not distort relative energy prices faced by households, and hence do not blunt so much their incentive to save energy. As a result, the pre-subsidy price of energy, and hence firms' marginal cost, increase by less.

6.4 Optimal Energy Subsidy

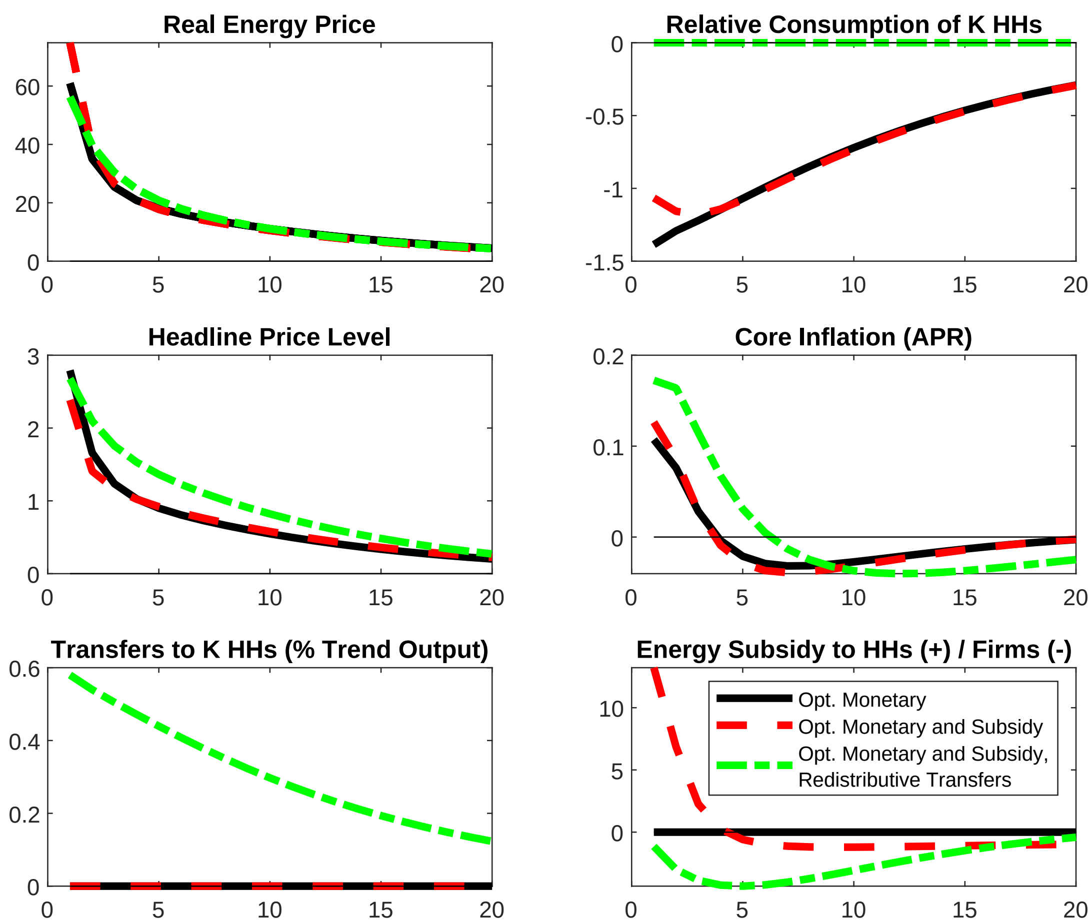
We now revisit the optimal use of subsidies by assuming that they (and the policy rate) can be chosen to maximize social welfare, defined as population-weighted average of utility of Keynesian and Ricardian agents. Starting with the case of the interest rate being the only policy instrument, we can see by comparing the black lines in Figures 10 and 9 that its optimal deployment is much more focused on keeping core inflation down compared to the policy that follows the rule given by equation 13. More generally, this benchmark monetary policy rule provides a much less accurate description of optimal policy than it was the case in the representative agent version of the model. This is not surprising as now the central bank also has to take into account the redistributive consequences of its policy. Nevertheless, using monetary policy optimally does not prevent a significant increase in consumption inequality.

Adding subsidies as an additional policy instrument helps improve this tradeoff, at least in the short term. This is achieved by a steep and short-lived increase in energy subsidy to households, which after a year is replaced with a small but persistent energy subsidy to firms. The initial increase in consumer subsidy shields Keynesian households when energy

[17] This result partially reflects the fact that the monetary policy rule given by equation 13 no longer provides a good approximation to optimal policy when some agents behave in a hand-to-mouth fashion. Compared to this rule, optimal policy would be more stimulative, making output fall shallower and inflation increase higher, but still well below the outcomes of the representative agent model. We stick here to the simple monetary policy rule nevertheless as it does not qualitatively affect our key findings on the effects of subsidies and transfers.

prices are highest, while a subsequent use of subsidies to firms exploits the forward-looking nature of the price setting and prevents a significant increase in core inflation due to higher pre-subsidy energy prices.

Figure 10: Optimal Energy Subsidies in TANK Model



Notes: All variables are expressed as percent deviations from the steady state. The responses of inflation are in annualized percentage points.

It needs to be stressed, however, that the use of consumer energy subsidies is entirely driven by inequality considerations. To demonstrate it, suppose that the social planner has also access to targeted transfers and uses them to prevent any increase in consumption inequality. As can be seen in Figure 10, in such a case it is optimal to subsidize only firms, in a way that resembles the policy in the representative agent version of the model (recall Figure 8). Even though in this experiment the transfers are not chosen optimally, welfare gains are large.

Overall, this part of our analysis suggest that there is some scope for using consumer energy subsidies to manage an energy shock due to their ability to limit the disproportionately adverse effects on more vulnerable households. However, this conclusion only holds if more effective instruments that can handle inequality, such as targeted transfers, are not available.

7 Managing an Energy Shock in an Open Economy

So far we have discussed the case of a closed economy, which gives us an idea on the macroeconomic effects of subsidies if they are implemented globally or in highly segmented markets. We now focus on uncoordinated subsidy policies and their international spillovers. To this end, we need to extent our model into an open economy setting. In this section we describe the key ingredients of this modification and refer the reader to Appendix A.12 for more detail.

7.1 Modifications to the Baseline Model

We cast the open economy extension of our model in a two-country setup. We call one country Home and the other Foreign, and indicate variables describing the latter with an asterisk. The world population is normalized to unity and the size of the Home economy is $0 < \zeta < 1$. Since both countries are isomorphic, we restrict our presentation only to the problems facing Home agents.

To allow for international trade linkages, we assume that the final consumption good is given by a similar aggregator to (5)

$$C_t(j) = \left((1-\omega_c)^{\frac{1}{\eta_c}} C_{N,t}(j)^{\frac{\eta_c - 1}{\eta_c}} + \omega_c^{\frac{1}{\eta_c}} O_{C,t}(j)^{\frac{\eta_c - 1}{\eta_c}} \right)^{\frac{\eta_c}{\eta_c - 1}}, \tag{36}$$

except that now the non-energy component combines both goods produced domestically and imports

$$C_{N,t}(j) = \left((1-\omega)^{\frac{1}{\eta}} Y_t(j)^{\frac{\eta - 1}{\eta}} + \omega^{\frac{1}{\eta}} M_t(j)^{\frac{\eta - 1}{\eta}} \right)^{\frac{\eta}{\eta - 1}}, \tag{37}$$

where $0 < \omega < 1$ and $\eta > 0$.

Intermediate goods producers sell their goods both to domestic and foreign markets. In the latter case, we assume that they set their prices in the currency of the destination market (local currency pricing), facing the probability of not being allowed to reoptimize equal to ξ_m. We also assume that energy endowments are internationally tradable so that the law of one price holds $P_{O,t} = \varepsilon_t P^*_{O,t}$, where ε_t is the nominal exchange rate, defined as Home currency units per unit of Foreign currency.

To allow for frictions in international flow of funds, we follow Gabaix and Maggiori (2015) by assuming that it is intermediated by specialized agents, whom we call financiers, and who have limited risk-bearing capacity. Each period they take symmetric nominal positions F_t in domestic currency bonds and $-F_t/\varepsilon_t$ in foreign currency bonds. After taking positions, but before shocks are realized, each financier can divert a portion $\min\left(1, \Gamma|\frac{F_t}{P_{Y,t}}|\right)$ of its assets, where $\Gamma \geq 0$. This leads to the following incentive compatibility constraint

$$V_t(k) \geq \Gamma \frac{F_t(k)^2}{P_{Y,t}}. \tag{38}$$

A representative financier k maximizes

$$V_t(k) = \frac{1}{I_t}\mathbb{E}_t\left(I_t F_t(k) - I_t^* \varepsilon_{t+1}\frac{F_t(k)}{\varepsilon_t}\right) \tag{39}$$

subject to constraint (38). After realizing profits or losses, financiers transfer them uniformly to Home and Foreign households.

7.2 Key Equilibrium Conditions and Analytical Insights

Since we assume that energy is freely tradable, its price is now determined by the world market clearing condition

$$\zeta Y_{O,t} + (1-\zeta)Y_{O,t}^* = \zeta(O_{C,t} + O_{Y,t}) + (1-\zeta)(O_{C,t}^* + O_{Y,t}^*). \tag{40}$$

This equation implies that energy prices will be affected by both countries' energy endowments and energy demand, the latter possibly affected by uncoordinated use of energy subsidies.

As we allow for cross-border flow of funds, international trade in energy and non-energy goods has implications for the net foreign assets position, which (from the Home economy's perspective) evolves according to

$$B_t = \underbrace{\left((1-\zeta)I_{t-1} + \zeta\frac{\varepsilon_t}{\varepsilon_{t-1}}I_{t-1}^*\right)B_{t-1}}_{\text{gross interest payment on foreign assets}} + \underbrace{\varepsilon_t P_{M,t}^* M_t^* - P_{M,t}M_t}_{\text{non-energy trade balance}} + \underbrace{P_{O,t}(Y_{O,t} - O_{Y,t} - O_{C,t})}_{\text{energy trade balance}}. \tag{41}$$

Finally, imperfect financial intermediation results in the following risk-augmented uncovered interest parity (UIP) condition

$$I_t = \mathbb{E}_t\left\{I_t^*\frac{\varepsilon_{t+1}}{\varepsilon_t}\right\} - \Gamma I_t \frac{B_t}{P_{Y,t}}. \tag{42}$$

This formula implies that, by affecting the net foreign assets positions, world energy prices have a direct effect on countries' risk premia. In particular, an increase in energy prices will tend to increase (decrease) the premium for net energy importers (exporters), leading to depreciation (appreciation) of their exchange rates.

As alluded to before, international trade in energy means that the equivalence result discussed in Section 4.1 no longer holds at a country level, and so energy subsidies to households and producers become distinct, and hence potentially complementary policy instruments. The reason why the equivalence breaks is that energy supply is not fixed for any individual country as it can also be imported from abroad, and so subsidizing households in one economy shifts the burden of higher energy cost not only to domestic firms, but also to foreign firms and households. In the limiting case of a small open economy ($\zeta \to 0$), pre-subsidy energy price (expressed in foreign currency) does not depend on the subsidies this country implements.

However, an open economy setting introduces additional transmission channels of energy subsidies. One is the exchange rate channel, reflecting equilibrium adjustments to external imbalances arising from changes in energy demand. In particular, as subsidies to firms or households increase domestic use of energy, they negatively affect the country's energy trade balance, triggering exchange rate depreciation, especially if FX markets are shallow (Γ is high). In this way, and similarly to the closed economy case, a consumer energy subsidy ends up increasing domestic currency energy cost to firms, even if this policy does not affect the pre-subsidy energy price expressed in foreign currency. Since a weaker exchange rate also increases the price of non-energy imports, this channel can thus significantly weaken the efficacy of subsidies in fighting energy price-driven inflation.

Finally, an open economy extension allows us to study the effects of subsidies introduced by foreign countries, especially if they form a group that is big enough to influence the world energy price. Again, international imbalances and the associated exchange rate response are the key determinants of the transmission of such policies on domestic inflation. Unless the country runs a big surplus in energy trade, subsidies introduced in the rest of the world will amplify domestic inflation pressure by driving energy prices up. However, for net energy exporters, the effect of higher world energy prices can be more than offset by the exchange rate appreciation, and thus foreign energy subsidies may end up leading to lower domestic inflation.

7.3 Calibration

We will demonstrate the quantitative implications of these insights by using model simulations. Our calibration choices regarding the additional parameters showing up in the open economy extension of our model are presented in Table 3.

Table 3: Open Economy Extension Parameters

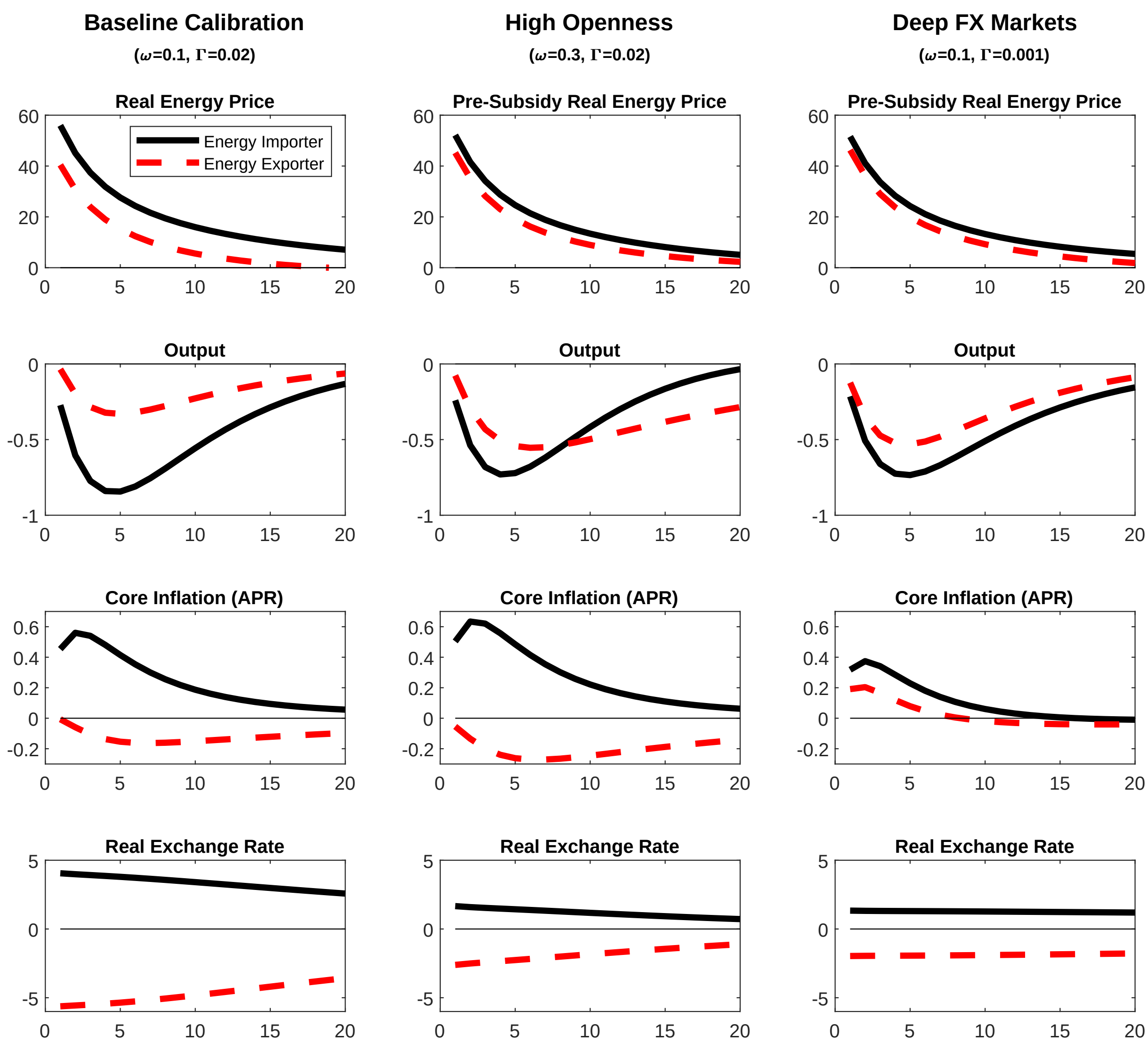
Parameter	Value
Relative country size; ζ	0.001
Share of energy production (energy importers vs exporters); Y_O/Y	0.05, 0.15
Share of imports in non-energy consumption; ω	0.1
Elasticity of substitution btw. non-energy inputs to consumption; η	0.8
Calvo probability in non-energy price setting for exports; ξ_m	0.9, 0.9
Indexation for non-energy prices for exports; ι_m, ι_m^*	0.5, 0.5
FX market shallowness; Γ	0.02

In most of our simulations we will focus on the case of a small open economy, which we obtain by setting the relative country size ζ to a very small number. To explore the difference between net energy exporters and importers, we consider two alternative steady state values for energy endowment, implying either an energy trade surplus or deficit worth about 5% of output. The calibrated value of the FX market depth parameter Γ corresponds to its median estimate for advanced economies reported by Chen et al. (2023). The import content of non-energy consumption reflects typical values observed in small open economies. To account for the observed low sensitivity of international trade volumes to the exchange rate, we opt for a fairly low elasticity of substitution between domestic and imported non-energy components of consumption. Finally, while calibrating the rigidity in price setting of non-energy goods sold to foreign markets, we draw on the open economy DSGE literature, which typically documents high Calvo probabilities and a substantial degree of dynamic price indexation. This helps us account for the empirically observed slow and delayed exchange rate pass-through to consumer prices.

7.4 Energy Importers vs Exporters

As different countries may have very different endowments of energy relative to what they use, we start by comparing the implications of an energy supply shock for net energy importers and net energy exporters. The first column of Figure 11 plots the small open economy's responses to a cut in foreign energy supply of the same magnitude and persistence that we considered in Section 5. Even a quick glance at the figure confirms that net energy importers and exporters respond markedly different to the same energy supply shock. Qualitatively, importers absorb the shock similarly to what we discussed before using the closed economy model: economic activity contracts and core inflation persistently increases. However, the reactions are stronger this time as the increase in relative energy prices sharply deteriorates the economy's terms of trade. As households try to smooth this negative wealth effect by borrowing from abroad, their net foreign assets fall, weakening the exchange rate. As the exchange rate pass-through to energy prices is complete, their relative price and hence inflation go up more than in the closed economy case. The picture is quite different for a net energy exporter, which faces a positive wealth shock if global energy prices go up. Non-energy output declines much less, propped up by stronger consumption. An improvement in the terms of trade translates into accumulation of foreign assets and the exchange rate appreciates. If the surplus in energy trade is large enough and the economy sufficiently open, as it is the case in our baseline calibration, core inflation may even decline.

Figure 11: Energy Price Shock in a Small Open Economy



Notes: All variables are expressed as percent deviations from the steady state. The responses of inflation is in annualized percentage points. The steady state energy trade balance relative to non-energy output is 0.05 for net energy exporters and −0.05 for energy importers.

The second column in Figure 11 shows that the economy's openness to trade in non-energy goods is an important factor shaping the responses. If the economy is more open than we assume in our baseline calibration, adjustments in non-energy trade balance can better absorb energy trade imbalances, bringing the responses of net energy exporters and importers closer to each other. In particular, output of the former may even fall below that of the latter in the medium run, reflecting the Dutch disease effect. On the other hand, more openness to non-energy trade implies stronger pass-through of exchange rate movements to core inflation, so the responses of this variable diverge more between energy importers and exporters.

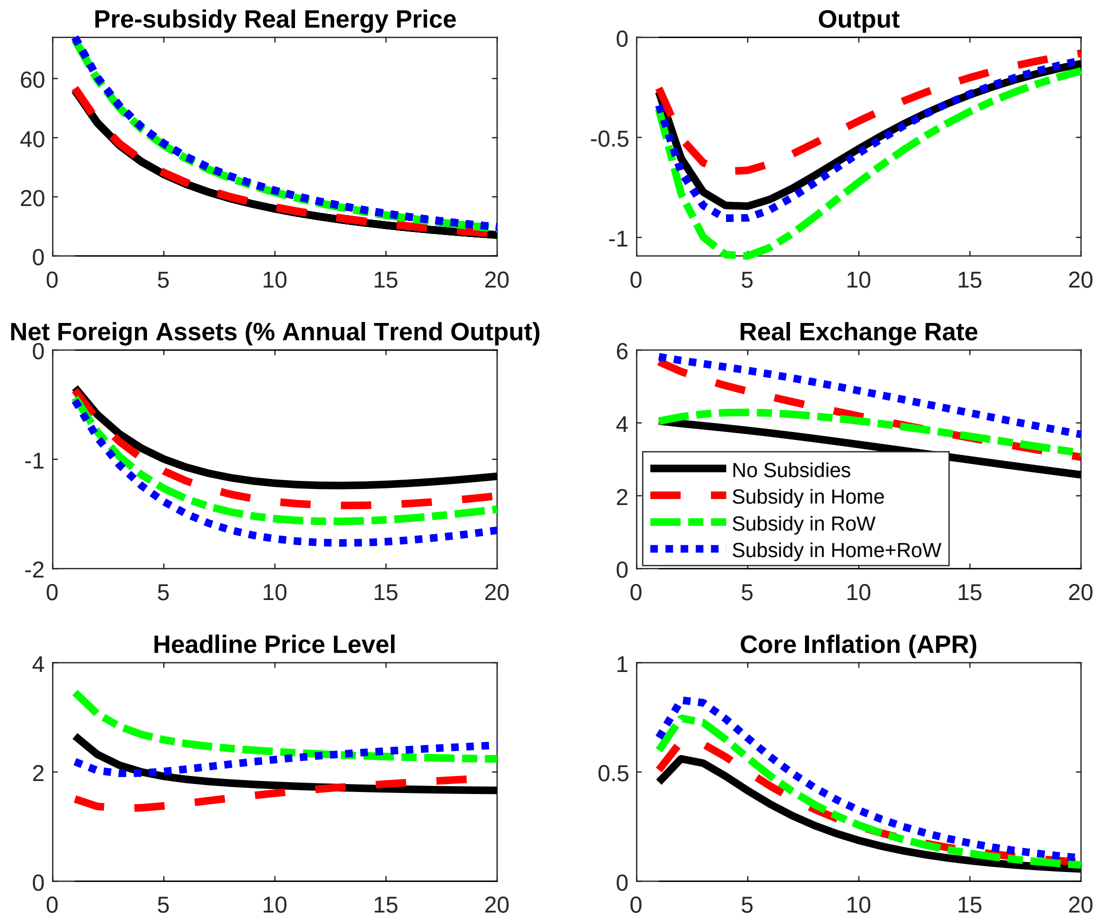
It is clear from the discussion above that the exchange rate and net foreign assets are key drivers of economic adjustment to energy shocks. In our model, where international borrowing is not frictionless, the relationship between these two variables is even stronger when FX markets are not perfectly deep, so that changes in net foreign assets directly affect the UIP risk premium. To highlight the importance of this channel, the third column in Figure 11 compares our baseline calibration to the case of much higher FX market depth, which we obtain by setting Γ to a very small number.[18] Deep markets allow for easier cross-border flow of funds, so the net foreign assets positions of energy exporters and importers diverge more under this parametrization. However, as net foreign assets no longer affect significantly the UIP risk premium, the exchange rate adjustment is much smaller, making core inflation dynamics in energy exporters and importers more similar.

7.5 Domestic and Multilateral Effects of Energy Subsidies

We now move to the transmission of energy subsidies, focusing on the case of a small open economy that is a net energy importer. Figure 12 shows the effects of subsidies to households, implemented as in Section 5. Consider first the case when only the Home economy uses the subsidy. As the country is small, subsidies are quite effective at limiting the fall in consumption, and hence in economic activity. Recall that, in a closed economy setting, the main reason why subsidies to households were backfiring was that they stimulated energy demand by consumers, leading to an increase in energy prices, which particularly hurt producers. Here, despite world energy prices being unaffected by subsidies introduced by the small Home economy, core inflation still goes up. As discussed before, the exchange rate depreciation plays the key role here, driven by further deterioration in the economy's net foreign assets position. Additionally, as stronger economic activity translates into an increase in labor demand, subsidies to consumers lead to a smaller fall in real producer wage than we have seen in the closed economy case. Nevertheless, the increase in core inflation is now much smaller and hence the overall macroeconomic effect of consumer energy subsidies is more favorable.

[18] A strictly positive value of this parameter is needed to ensure stationarity of the linearized model, see Schmitt-Grohe and Uribe (2003).

Figure 12: Energy Subsidies to Households in SOE Energy Importer

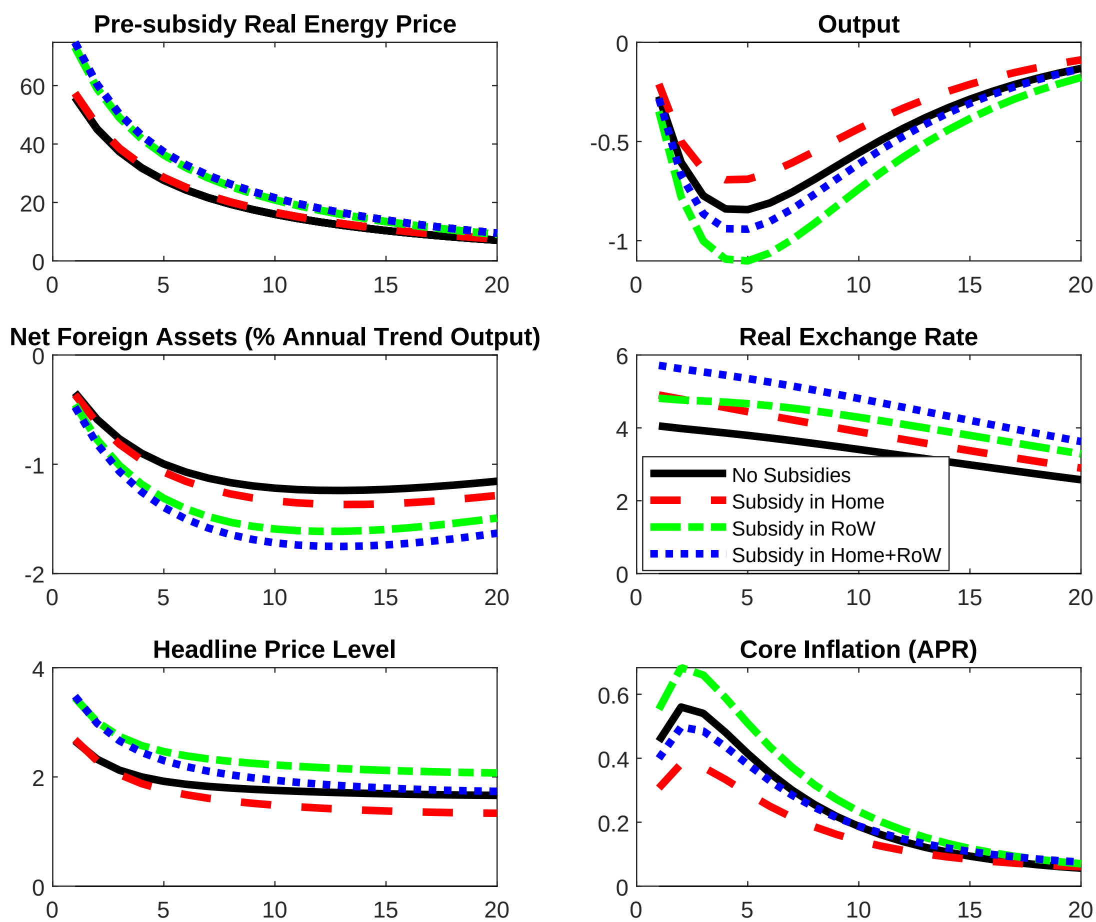


Notes: All variables are expressed as percent deviations from the steady state. The responses of inflation are in annualized percentage points.

The figure also shows the effect of energy subsidies to households deployed by the rest of the world. As such policies drive global energy prices up, they exacerbate the negative consequences of an energy price shock to an energy importer. By following other economies in implementing the subsidies, the Home country can limit the contraction in its economic activity, but this comes at a cost of even deeper deterioration of its net foreign assets, depreciation of the exchange rate, and further increase in core inflation. Recall from the closed economy version of the model that, if all countries introduce consumer energy subsidies, the outcome is very little improvement in economic activity and a significant and persistent increase in core inflation. As simulations presented in this section additionally show, the outcome of such globally implemented policy is even worse for countries that are net energy importers. This is because the subsidy-driven increase in global energy prices means a negative wealth transfer from energy importers to exporters, which also generates additional inflationary pressure via the exchange rate channel, especially if FX markets are shallow.

We now turn to the effect of energy subsidies to firms. Figure 13 confirms that, in contrast to the closed economy implications, the equivalence between subsidizing households and taxing firms (and vice versa) no longer holds, and that energy subsidies to firms and households now share some common features. In particular, both policies are expansionary when implemented by a small country acting in isolation. The key difference is that, in contrast to consumer energy subsidies, subsidies to firms help achieve lower core inflation. This happens because they mitigate the energy price-driven increase in marginal cost of production, which more than offsets the effect of increased import prices due to exchange rate depreciation.

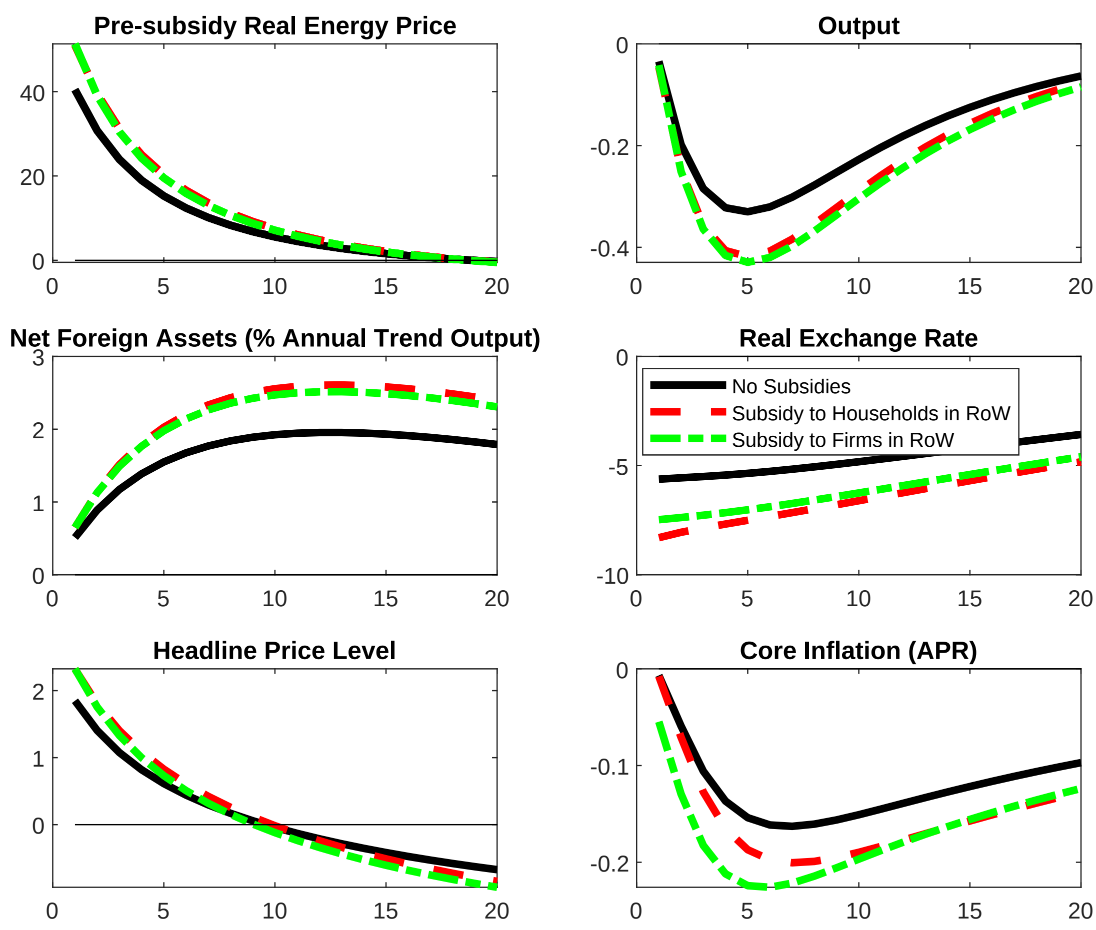
Figure 13: Energy Price Subsidies to Firms in SOE Energy Importer



Notes: All variables are expressed as percent deviations from the steady state. The responses of inflation are in annualized percentage points.

If the rest of the world subsidizes energy use by firms, spillovers to energy importers are similarly adverse as in the case of consumer subsidies. This is because both policies result in an increase in world energy prices, which hurts Home economic activity and push inflation up. Producer energy subsidies implemented globally also depress consumption (and hence non-energy output) in energy importing countries. However, unlike in the case of subsidies to households, they still help keep core inflation low compared to the no subsidy case, despite higher world energy prices and weaker exchange rate. In line with our previous discussion, this outcome may be less favorable in energy importing countries with shallow FX markets or greater openness to trade in non-energy goods.

Figure 14: Spillovers of Energy Price Subsidies to Energy Exporting Countries



Notes: All variables are expressed as percent deviations from the steady state. The responses of inflation are in annualized percentage points.

Finally, as we have explained above, external energy supply shocks transmit differently for energy importers and exporters. The latter actually benefit from improving terms of trade and, on account of stronger exchange rate, may even experience a fall in core inflation, hence facing little need to deploy energy subsidies. However, they can be still significantly affected by subsidies introduced by other countries. Figure 14 shows the effect of such policies, implemented in the rest of the word, on a small open economy that is a net energy exporter. The outcomes closely resemble those associated with a global energy supply shock on an exporter that we have already discussed using Figure 11. Moreover, there is no big difference whether other countries subsidize their producers or consumers. What is key for an energy exporter is that world energy prices go up, which improves its terms of trade, appreciates the exchange rate, and lowers core inflation. Higher energy prices and exchange rate appreciation hurt non-energy output, but the positive wealth transfer allows for an increase in consumption, so that the country clearly benefits.

8 Conclusions

Many countries responded to the recent global energy shock by using a range of unconventional fiscal measures, with a prominent role of consumer energy subsidies. Apart from shielding vulnerable households, these policies were sometimes advocated as a way to reduce upward pressure on wages and thus to prevent inflationary impulses from spreading throughout the economy. Our analysis show that these measures are more likely to prove counterproductive as an inflation-fighting tool when applied globally or in a segmented market and are also much less effective in preventing an increase in consumption inequality than simple targeted transfers. The key mechanism making the subsidies ineffective is their impact on the pre-subsidy energy price, so that they end up shifting the burden of adjustment from households to firms. While consumer energy subsidies are likely to work better in a small open economy that is well connected to world energy markets, the conditions under which they reduce inflation are still quite restrictive due to the endogenous adjustment of the exchange rate.

Cushioning the effects of high energy prices on vulnerable consumers is a valid policy objective, it is then important to design policies that can achieve it at the lowest possible efficiency cost. At the same time, they need to be feasible to implement. Screening out the most vulnerable households and helping them out in a way preserving the incentives to reduce energy consumption is a challenge and may call for unconventional measures. Tokarski et al. (2023) offer a high-level guidance on a possible design of a relief policy when transfers cannot be precisely targeted due to imperfect information on the side of the government, but more research is needed. As our study clearly highlights, such analyses should take into account the general equilibrium consequences of the proposed policies, especially when they are implemented by a large group of countries.

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Appendix

A.1 Proxy-SVAR

This section describes the proxy-SVAR used to trace the effects of oil price changes to wages and other variables of interest. In particular, we consider the following structural SVAR

$$A_0 Y_t = \sum_{j=1}^{p} A_j Y_{t-j} + B\varepsilon_t, \tag{A.1}$$

where Y_t is a vector containing n variables of interest, ε_t is a vector of unobservable zero mean white noise processes or structural shocks (with a diagonal variance and covariance matrix), A_j is the dynamic matrix, and B contains the coefficients with the impact effects of the structural shocks to the variables of interest. The structural SVAR above admits the following reduced form representation

$$Y_t = \sum_{j=1}^{p} D_j Y_{t-} + \mu_t, \tag{A.2}$$

where μ_t is a vector with the reduced-form residuals or innovations of the system $\mu_t = A_0^{-1} B\varepsilon_t$ and $D_j = A_0^{-1} A_j$. We focus on the identification of an oil supply shock and, following a vast part of the literature, we use an external instrument to identify a particular structural shock: the oil price changes around OPEC's announcements. A key element for this strategy is that the instrument has to be correlated with the shock of interest and uncorrelated with other structural shocks, i.e.

$$\begin{aligned} E[\epsilon_t^{oil}, z_t^{'}] &\neq 0 \\ E[\epsilon_t^{others}, z_t^{'}] &= 0. \end{aligned}$$

In addition to the instrument, our baseline specification considers eight macroeconomic variables: US (EA) core CPI, the fed funds rate (EONIA) as proxy for the monetary policy rate, US (EA) gross domestic product, US (EA) nominal wage growth, global oil production, global industrial production, and the WTI (Brent) oil price. The real wage is calculated post-estimation, so no stationarity is imposed, deflated with core CPI index. As robustness we also replace the core CPI index with headline CPI in the specification.

In the first stage, we regress the reduced-form VAR innovation for the WTI (Brent) oil prices on the oil price surprise (our instrument). This step allows us to identify the impact effect of the OPEC's announcements on oil prices. The second stage regresses the predicted value from the first stage regression on the remaining VAR innovations. The coefficients from these regressions identify, up to a scaling factor, the impact coefficients of the matrix B, that shapes the effects of a structural oil supply shock. Once we have identified the impact effects of the oil supply shock, we compute the impulse response functions in a traditional way, i.e., $IR_t = B_i$ for $t = 0$ and $IR_t = \boldsymbol{D} \cdot \boldsymbol{IR}_{t-1}$ for $t = 1, 2, \ldots, H$, where B_i is the i-th column of the impact matrix B.

A.2 Data Used in VAR

Table A.1 describes quarterly data in VAR in detail, including series description, data sources and transformations. The sample covers 1983Q1 - 2019Q4.

Table A.1: Data Description, Sources, and Sample Period.

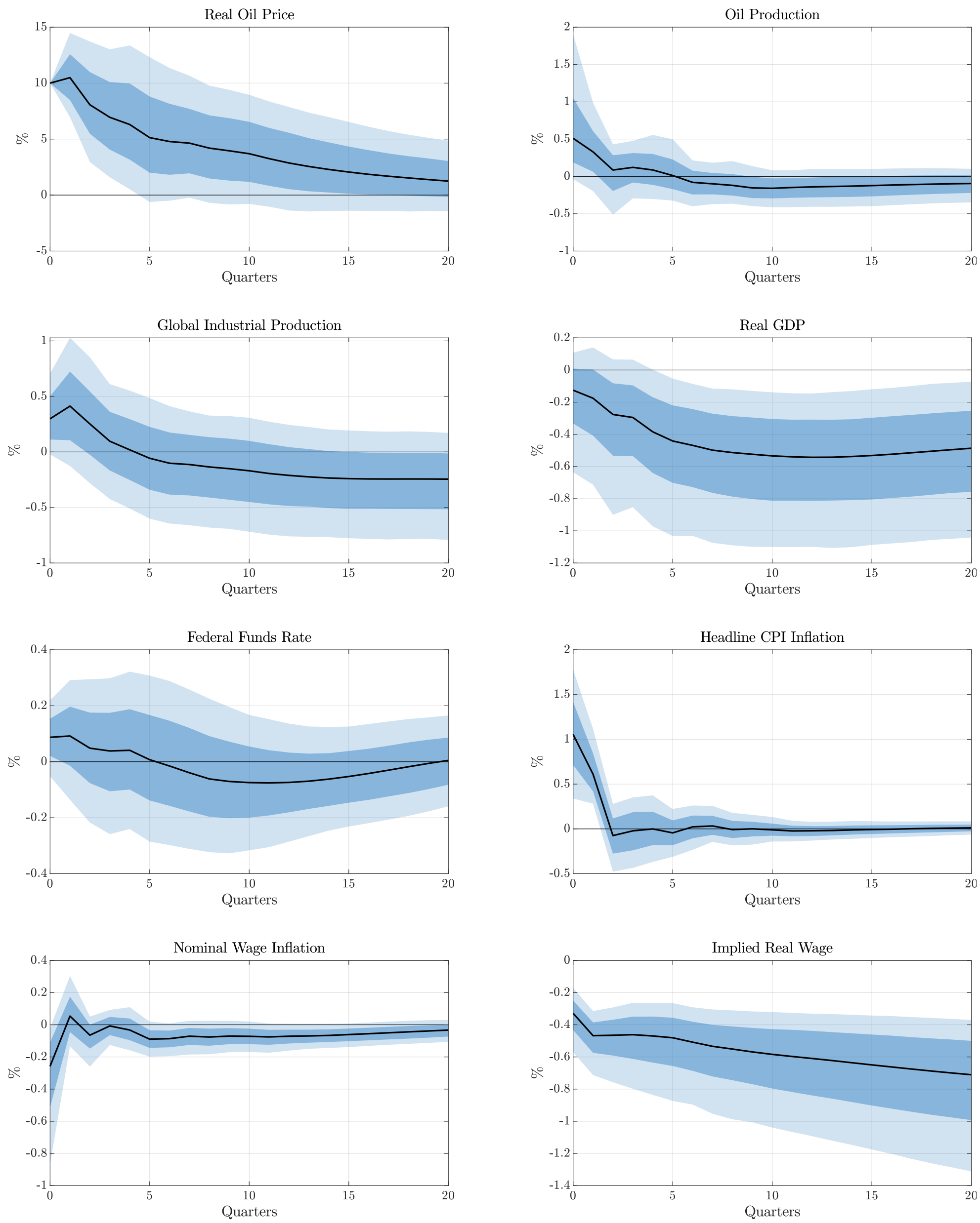
Variable	Description	Source	Trans.
Instrument			
Oil supply news	OPEC oil supply news shock from Känzig (2021)	Känzig's webpage	NA
VAR variables			
PROD	World crude oil production (WDPCOBD.P)	Datastream	100*log
GIP	Industrial production of OECD + 6 (Brazil, China, India, Indonesia, Russia and South Africa) from Baumeister and Hamilton (2019)	Baumeister's webpage	100*log
POIL_US	Spot Crude Oil Price: West Texas Intermediate (WTISPLC) deflated by US core or headline CPI according to VAR specifications	FRED	100*log
POIL_EA	Brent Forties Oseberg month 1 Europe, deflated by EA core or headline CPI according to VAR specifications	PCPS, IMF	100*log
WAGE_US	Employment Cost Index: Wages and Salaries: Private Industry Workers (ECIWAG), spliced by Average Hourly Earnings of Production and Nonsupervisory Employees, Total Private (AHETPI) before 2001	FRED	400*Δlog
WAGE_EA	EU27: Wages & Salaries: Business Economy spliced by Average compensation per head before 2001	Haver, AWM and IMF staff calculation	400*Δlog
GDP_US	Real Gross Domestic Product	FRED	100*log
GDP_EA	Real GDP	Haver, AWM and IMF staff calculation	100*log
FFR	Federal Funds Effective Rate	FRED	NA
US1Y	Market Yield on US Treasury Securities at 1-Year Constant Maturity	FRED	NA
EONIA	Euro Interbank Offered Rate, spliced by short-term (3-month) interest rate (STN) before 1999	FRED, AWM and IMF staff calculation	NA
G1Y	Germany: Estimated 1-Year Government Debt Yield	Haver	NA
CPI_US	Consumer Price Index for All Urban Consumers: All Items in US City Average	FRED	400*Δlog
CPI_EA	HICP: European Index of Consumer Prices spliced by AWM data before 2000	Haver, AWM and IMF staff calculation	400*Δlog
Core_US	Consumer Price Index for All Urban Consumers: All Items Less Food and Energy in US City Average	FRED	400*Δlog
Core_EA	HICP: Total excl Energy spliced by AWM data before 2001	Haver, AWM and IMF staff calculation	400*Δlog

A.3 Empirical Results: Robustness

A.3.1 Headline Inflation in SVAR

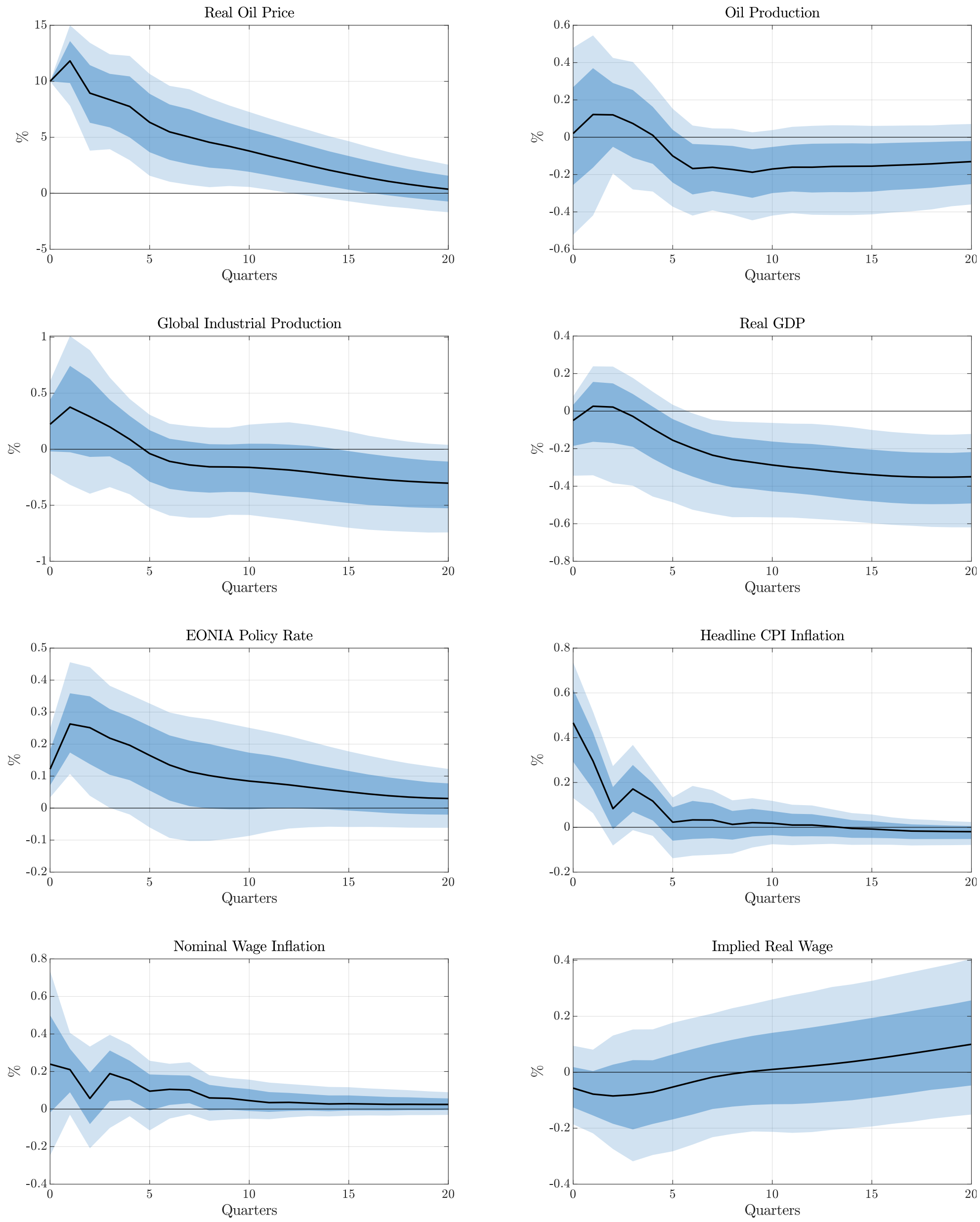
This appendix report the results for the SVAR models that include headline instead of core inflation. Figure A.1 report the impulse responses for the United States, whereas Figure A.2 reports the results for the euro area.

Figure A.1: US Proxy-VAR Evidence with Headline Inflation



Notes: All variables are expressed in percent deviations. Real oil prices deflated with headline CPI, implied real wage defined as accumulated nominal wage inflation minus headline inflation. Confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

Figure A.2: EA Proxy-VAR Evidence with Headline Inflation

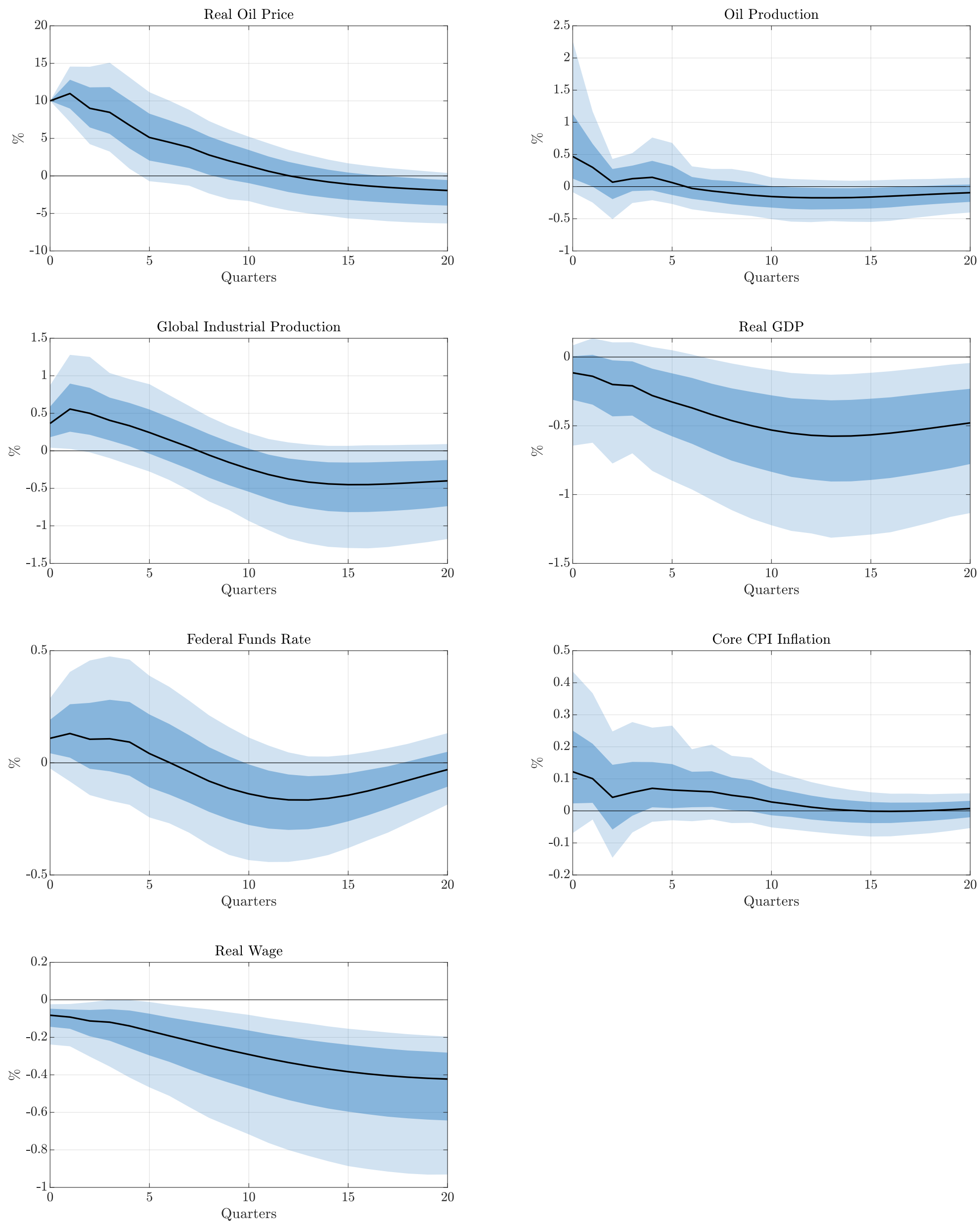


Notes: All variables are expressed in percent deviations. Real oil prices and wages deflated with core CPI, real wages are in log-levels. Confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

A.3.2 Imposing Stationary Real Wage

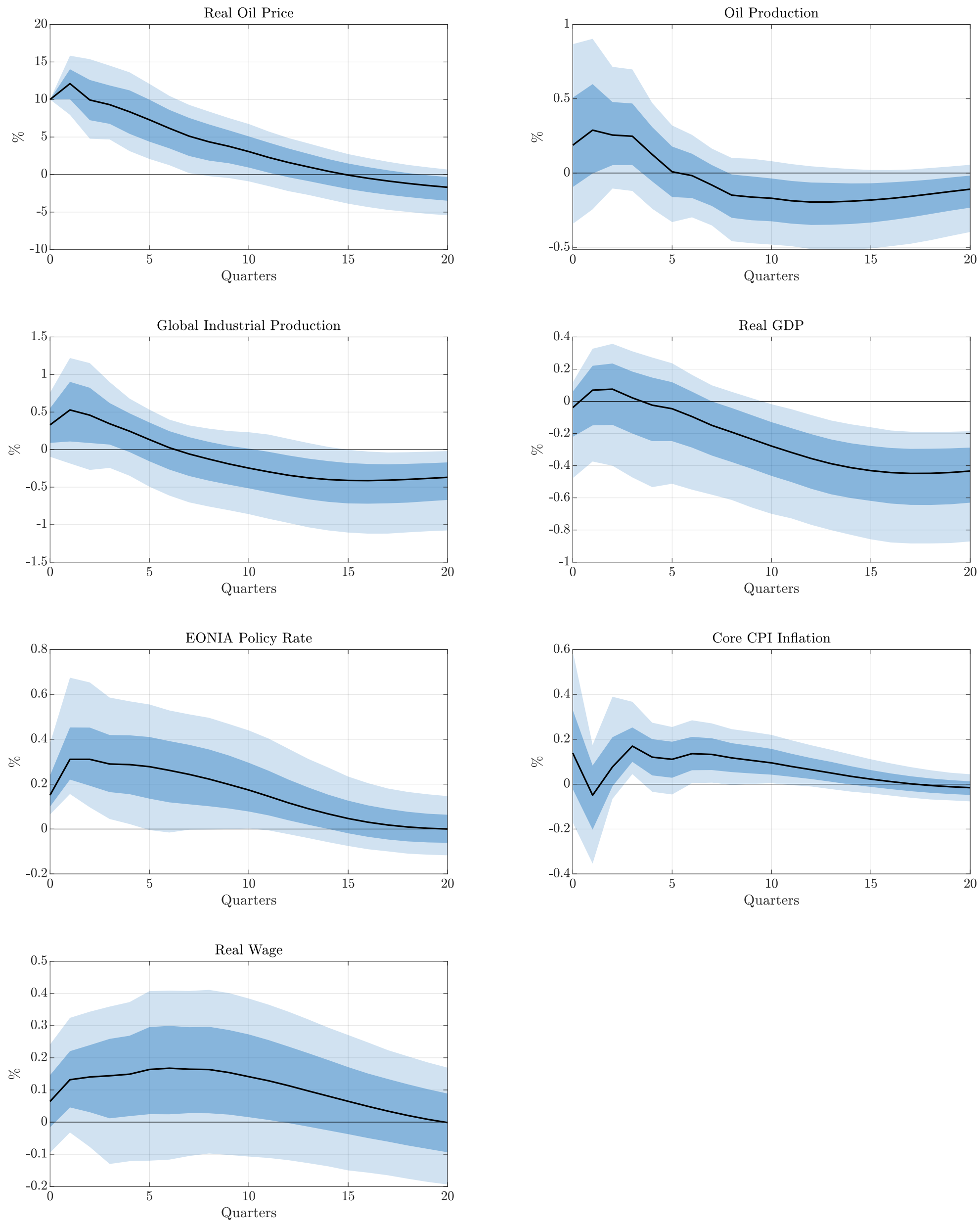
In Figures A.3 and A.4, additional robustness is performed by replacing in the SVAR the log-difference in nominal wages with the level of real wages, i.e., the nominal wage rate deflated by the core CPI index. In both cases, relative to the baseline specification, real wages in the US drop almost immediately, driven by an increase in headline inflation. In Europe, the impact on headline is smaller, however, after an initial fall in the point estimate that is not significant, real wages do not decline.

Figure A.3: US Proxy-VAR Evidence: Imposing Stationary Real Wage



Notes: All variables are expressed in percent deviations. Real oil prices and wages deflated with core CPI, real wages are in log-levels. Confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

Figure A.4: EA Proxy-VAR Evidence: Imposing Stationary Real Wage

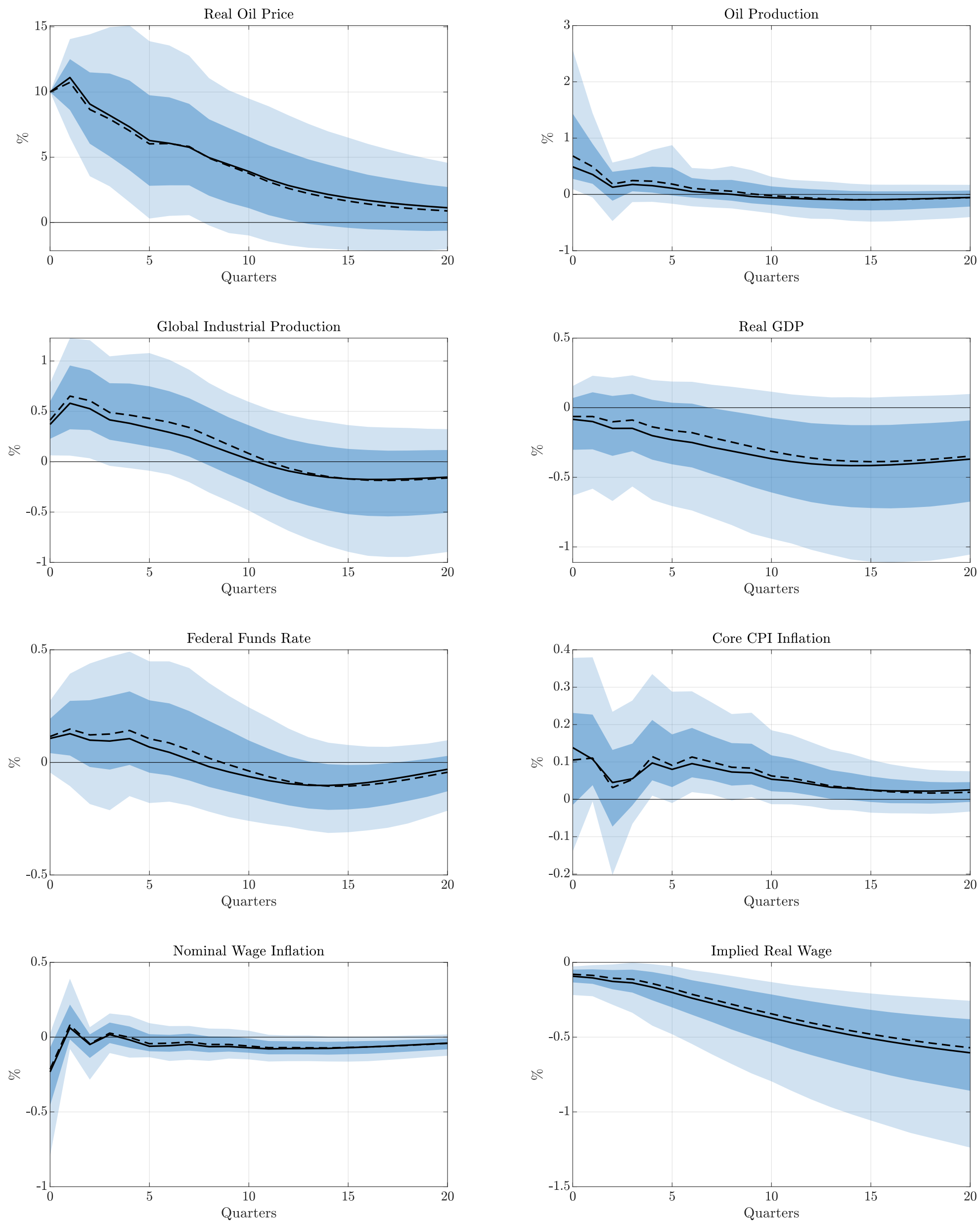


Notes: All variables are expressed in percent deviations. Real oil prices and wages deflated with core CPI, real wages are in log-levels. Confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

A.3.3 Testing for Non-Linearities

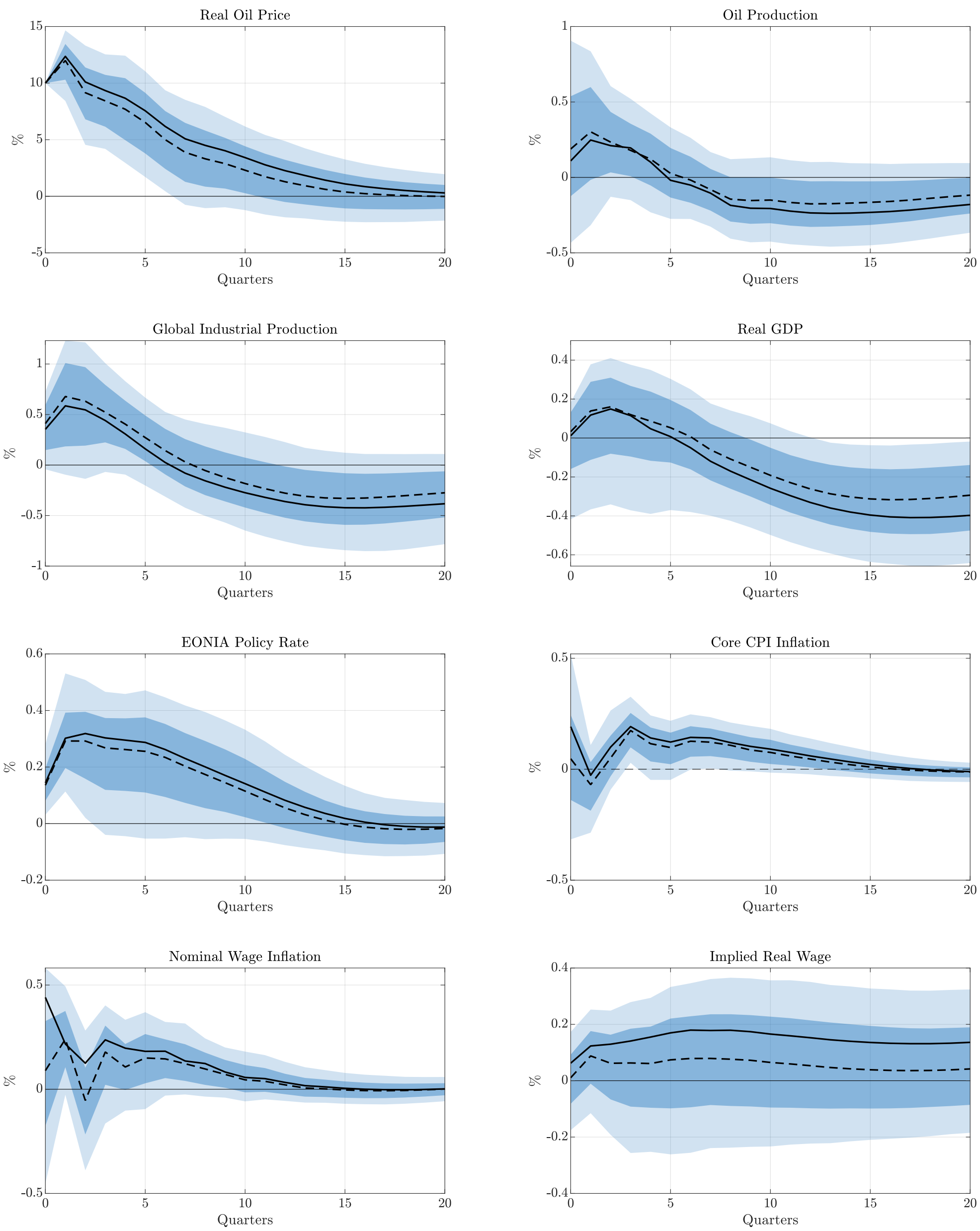
In this appendix we test whether big shocks lead to proportionally bigger or different responses from our baseline. We focus on announcements that only lead to an oil price response bigger than one standard deviation (calculated using the whole sample of oil price surprises). The results are presented in Figures A.5 and A.6, and are qualitatively the same as in our baseline specification. Quantitatively, the point estimates between the baseline VAR and the big-shock VAR differ visibly only for the EA real wage response, but the difference is not statistically significant. This means that the results under our baseline specification are driven mostly by announcements that had large price impacts (i.e., big shocks), which clearly generates more variation.

Figure A.5: US Proxy-VAR Evidence: Big Shocks



Notes: All variables are expressed in percent deviations. Solid black lines are the baseline results from Figure 1, confidence bands and dashed lines are from the proxy-VAR with big shocks (defined as absolute oil price surprises greater than one standard deviation. Confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

Figure A.6: EA Proxy-VAR Evidence: Big Shocks



Notes: All variables are expressed in percent deviations. Solid black lines are the baseline results from Figure 1, confidence bands and dashed lines are from the proxy-VAR with big shocks (defined as absolute oil price surprises greater than one standard deviation. Confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

As additional robustness, we have also used local projections methods, á la Jordà (2005). The local projection approach is more flexbile to test other type of non-linearities. We have tested if the initial inflation level may change the way the oil shock is transmitted to the rest of the economy. It might be possible that when inflation is high, the monetary policy response might differ (possibly being stronger, to avoid unanchoring of inflation expectations) than in normal times when inflation is close to target. We have, thus, interacted the oil price with 4-quarter core inflation moving average, lagged by one quarter. The interaction term has been instrumented with the Känzig oil shock series interacted with the 4-quarter core inflation moving average, lagged by one quarter. The results (available upon request) show that the interaction term has no statistical significance, suggesting that the initial level of inflation has not played a role during our sample period neither for the US nor for the euro area.

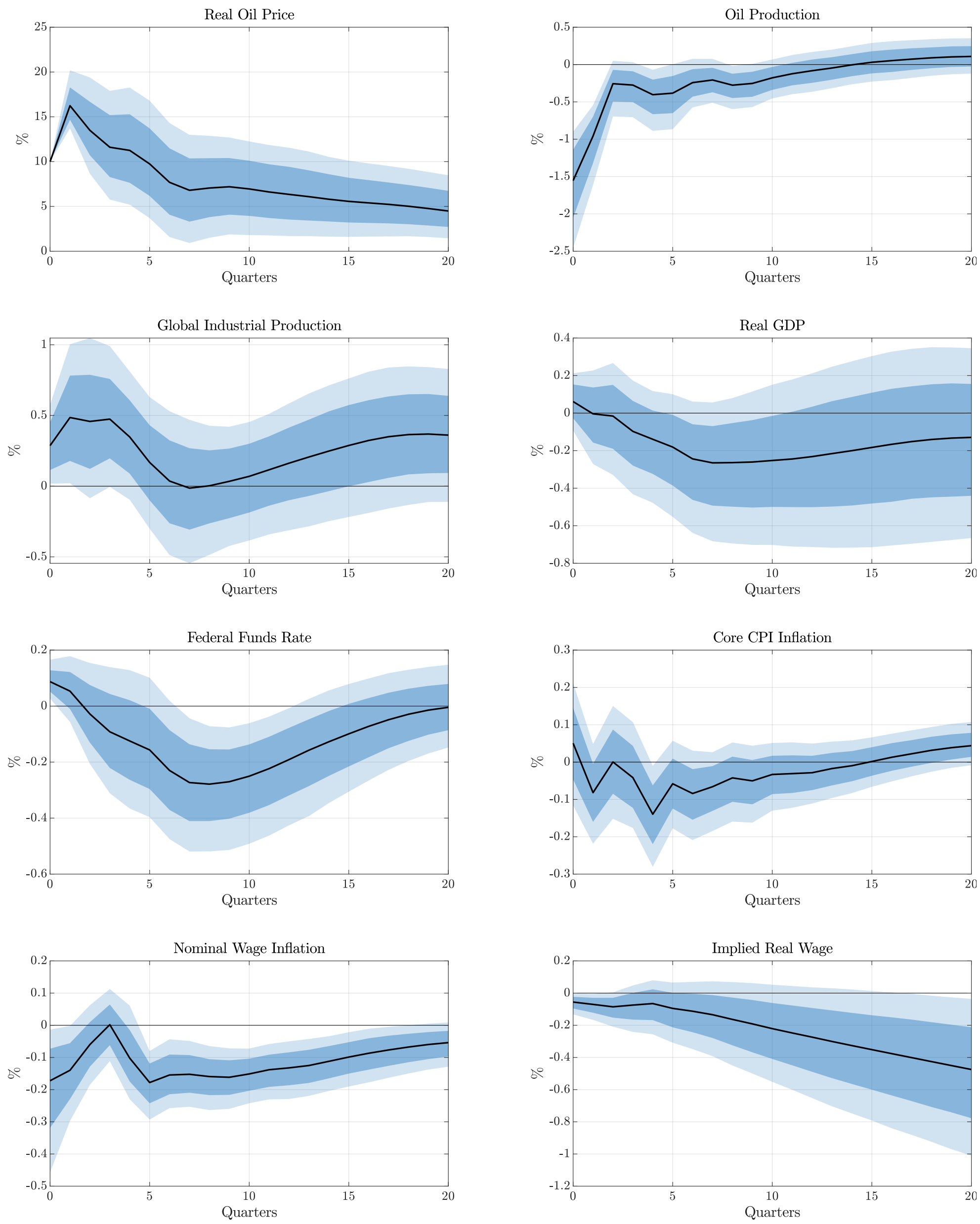
A.3.4 Alternative Identification Scheme

In this appendix we explore robustness to the choice of instrument for oil price changes. We, thus, use the approach of Baumeister and Hamilton (2019) to identify oil supply shocks, which are then used as instrument is our baseline proxy-SVAR.[19] Baumeister and Hamilton (2019) use a Bayesian approach that imposes (non-dogmatic) priors on the price elasticities of oil supply and demand and on the responses of variables to key shocks consistent with traditional sign restrictions (e.g., an oil supply shock must lead to oil production and prices moving in opposite direction).

The results presented in Figures A.7 and A.8 show that an oil price response is very similar to the baseline proxy-VAR, however, oil production declines strongly. Real GDP eventually declines in both US and EA, with the decline being stronger and more precisely estimated for Europe. The impact on core inflation is relatively muted in the US while stronger in Europe, suggesting relatively more indexation to headline in the European economy. Indeed, real (producer) wages rise in Europe, contrary to the US where they decline, consistently with the baseline results in the text.

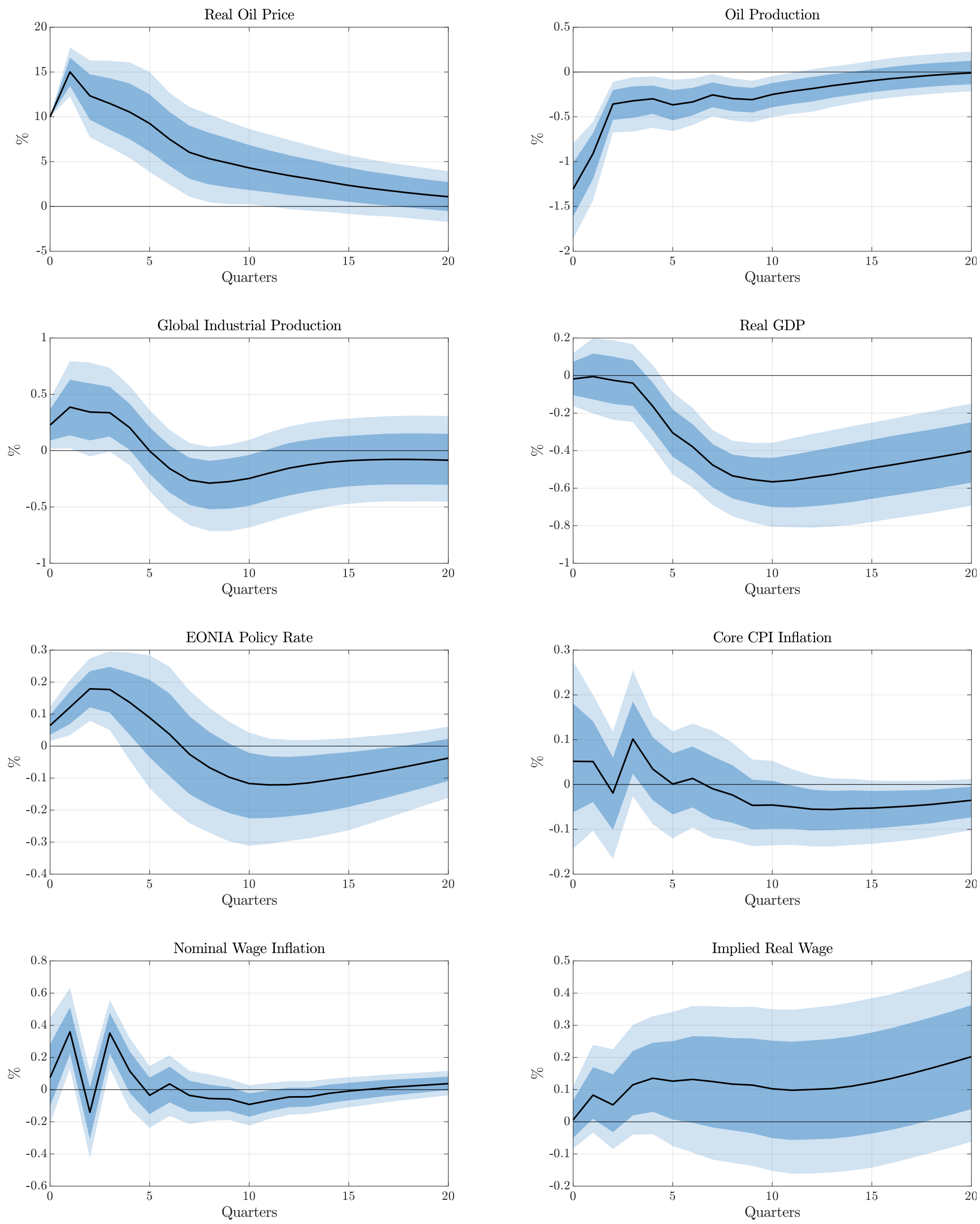
[19]The shocks can be found at https://sites.google.com/site/cjsbaumeister/research.

Figure A.7: US Proxy-VAR Evidence: Alternative Identification Scheme



Notes: Baseline proxy-VAR where supply shocks from Baumeister and Hamilton (2019) are used as instrument for oil price shocks. All variables are expressed in percent deviations. Real oil prices and wages deflated with core CPI, real wages are in log-levels. Confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

Figure A.8: EA Proxy-VAR Evidence: Alternative Identification Scheme



Notes: Baseline proxy-VAR where supply shocks from Baumeister and Hamilton (2019) are used as instrument for oil price shocks. All variables are expressed in percent deviations. Real oil prices and wages deflated with core CPI, real wages are in log-levels. Confidence bands are the 68 and 90 percent level bands based on 10,000 bootstrap replications.

A.4 Equilibrium Conditions

This appendix presents the full set of aggregate equilibrium conditions that jointly determine the evolution of real per capita allocations and real prices in the model described in Section 3, for given initial conditions and for given realizations and expected future paths of exogenous variables $Y_{O,t}$, $\tau_{C,t}$, and $\tau_{Y,t}$. With some abuse of notation, in the equations below all prices are defined in real terms, i.e., they are implicitly divided by the producer price index $P_{Y,t}$.

Aggregate production

$$Y_t P^{\#}_{Y,t} = \left((1-\omega_y)^{\frac{1}{\eta_y}} V_t^{\frac{\eta_y - 1}{\eta_y}} + \omega_y^{\frac{1}{\eta_y}} O_{Y,t}^{\frac{\eta_y - 1}{\eta_y}} \right)^{\frac{\eta_y}{\eta_y - 1}} \tag{A.3}$$

$$V_t = K^{\alpha} N_t^{1-\alpha} \tag{A.4}$$

Factor demand

$$\frac{O_{Y,t}}{V_t} = \frac{\omega_y}{1-\omega_y} \left((1-\tau_{Y,t}) \frac{P_{O,t}}{P_{V,t}} \right)^{-\eta_y} \tag{A.5}$$

$$\frac{K}{N_t} = \frac{\alpha}{1-\alpha} \frac{W_t}{R_{K,t}} \tag{A.6}$$

Price dynamics

$$1 = \left((1-\xi) \tilde{P}_{Y,t}^{-\frac{1}{\theta}} + \xi \left(\frac{\tilde{\Pi}_{Y,t}}{\Pi_{Y,t}} \right)^{-\frac{1}{\theta}} \right)^{-\theta} \tag{A.7}$$

$$\tilde{P}_{Y,t} = \frac{\mathbb{E}_t \sum_{j=0}^{\infty} (\xi\beta)^j \frac{\Lambda_{t+j}}{P_{C,t+j}} MC_{t+j} \left(\frac{\Pi_{Y,t}}{\tilde{\Pi}_{Y,t}} \frac{\tilde{\Pi}_{Y,t} \dots \tilde{\Pi}_{Y,t+j}}{\Pi_{Y,t} \dots \Pi_{Y,t+j}} \right)^{-\frac{1+\theta}{\theta}} Y_{t+j}}{\mathbb{E}_t \sum_{j=0}^{\infty} (\xi\beta)^j \frac{\Lambda_{t+j}}{P_{C,t+j}} \left(\frac{\Pi_{Y,t}}{\tilde{\Pi}_{Y,t}} \frac{\tilde{\Pi}_{Y,t} \dots \tilde{\Pi}_{Y,t+j}}{\Pi_{Y,t} \dots \Pi_{Y,t+j}} \right)^{-\frac{1}{\theta}} Y_{t+j}} \tag{A.8}$$

$$\tilde{\Pi}_{Y,t} = \Pi_{Y,t-1}^{\iota} \Pi^{1-\iota} \tag{A.9}$$

Price dispersion index

$$P^{\#}_{Y,t} = (1-\xi) \tilde{P}_{Y,t}^{-\frac{1+\theta}{\theta}} + \xi \left(\frac{\tilde{\Pi}_{Y,t}}{\Pi_{Y,t}} \right)^{-\frac{1+\theta}{\theta}} P^{\#}_{Y,t-1} \tag{A.10}$$

Headline price level and inflation

$$P_{C,t} = \left((1-\omega_c) + \omega_c \left((1-\tau_{C,t}) P_{O,t} \right)^{1-\eta_c} \right)^{\frac{1}{1-\eta_c}} \tag{A.11}$$

$$\Pi_{C,t} = \frac{P_{C,t}}{P_{C,t-1}} \Pi_{Y,t} \tag{A.12}$$

Marginal cost

$$MC_t = \left((1-\omega_y)P_{V,t}^{1-\eta_y} + \omega_y\left((1-\tau_{Y,t})P_{O,t}\right)^{1-\eta_y}\right)^{\frac{1}{1-\eta_y}} \tag{A.13}$$

$$P_{V,t} = \frac{1}{1-\alpha}W_t\left(\frac{N_t}{K}\right)^{\alpha} \tag{A.14}$$

Wage dynamics

$$W_{C,t} = \left((1-\xi_w)\tilde{W}_{C,t}^{-\frac{1}{\theta_w}} + \xi_w\left(\frac{\tilde{\Pi}_{W,t}}{\Pi_{C,t}}W_{C,t-1}\right)^{-\frac{1}{\theta_w}}\right)^{-\theta_w} \tag{A.15}$$

$$\tilde{W}_{C,t}^{1+\chi\frac{1+\theta_w}{\theta_w}} = \frac{\chi_0\mathbb{E}_t\sum_{j=0}^{\infty}(\xi_w\beta)^j\left(\frac{\Pi_{C,t}}{\tilde{\Pi}_{W,t}}\frac{\tilde{\Pi}_{W,t}\ldots\tilde{\Pi}_{W,t+j}}{\Pi_{C,t}\ldots\Pi_{C,t+j}}\right)^{-\frac{1+\theta_w}{\theta_w}(1+\chi)}W_{C,t+j}^{\frac{1+\theta_w}{\theta_w}(1+\chi)}N_{t+j}^{1+\chi}}{\mathbb{E}_t\sum_{j=0}^{\infty}(\xi_w\beta)^j\Lambda_{t+j}\left(\frac{\Pi_{C,t}}{\tilde{\Pi}_{W,t}}\frac{\tilde{\Pi}_{W,t}\ldots\tilde{\Pi}_{W,t+j}}{\Pi_{C,t}\ldots\Pi_{C,t+j}}\right)^{-\frac{1}{\theta_w}}W_{C,t+j}^{\frac{1+\theta_w}{\theta_w}}N_{t+j}} \tag{A.16}$$

$$\tilde{\Pi}_{W,t} = \Pi_{Y,t}^{\iota_y}\Pi_{C,t}^{\iota_c}\Pi^{1-\iota_y-\iota_c} \tag{A.17}$$

$$W_{C,t} = \frac{W_t}{P_{C,t}} \tag{A.18}$$

$$\Pi_{W,t} = \frac{W_{C,t}}{W_{C,t-1}}\Pi_{C,t} \tag{A.19}$$

Consumption

$$C_t = \left((1-\omega_c)^{\frac{1}{\eta_c}}Y_t^{\frac{\eta_c-1}{\eta_c}} + \omega_c^{\frac{1}{\eta_c}}O_{C,t}^{\frac{\eta_c-1}{\eta_c}}\right)^{\frac{\eta_c}{\eta_c-1}} \tag{A.20}$$

Optimal composition of consumption

$$\frac{O_{C,t}}{Y_t} = \frac{\omega_c}{1-\omega_c}\left((1-\tau_{C,t})P_{O,t}\right)^{-\eta_c} \tag{A.21}$$

Marginal utility

$$\Lambda_t = (C_t - \varkappa C_{t-1})^{-\frac{1}{\sigma}} - \varkappa\beta\mathbb{E}_t\left(C_{t+1} - \varkappa C_t\right)^{-\frac{1}{\sigma}} \tag{A.22}$$

Euler equation

$$\Lambda_t = \mathbb{E}_t\Lambda_{t+1}\frac{I_t}{\Pi_{C,t+1}} \tag{A.23}$$

Energy market clearing

$$Y_{O,t} = O_{C,t} + O_{Y,t} \tag{A.24}$$

Monetary policy rule

$$I_t = I + \psi_\pi\left(\Pi_{Y,t} - \Pi_Y\right) + \psi_y\left(\frac{Y_t}{Y_t^f} - 1\right) \tag{A.25}$$

Complementing these equations with a 'potential' block, defined by the same set of equations under full wage and price flexibility ($\xi, \xi_w \to 0$), gives us in total forty-six equilibrium conditions that jointly determine the evolution of twenty-three endogenous variables Y_t, C_t, Λ_t, V_t, $O_{Y,t}$, $O_{C,t}$, N_t, W_t, $R_{K,t}$, MC_t, $P_{C,t}$, $P_{V,t}$,$P_{O,t}$, $\Pi_{Y,t}$, $\tilde{\Pi}_{Y,t}$, $\tilde{P}_{Y,t}$, $P^{\#}_{Y,t}$, $\Pi_{C,t}$, $\tilde{W}_{C,t}$, $W_{C,t}$, $\Pi_{W,t}$, $\tilde{\Pi}_{W,t}$, I_t, and their twenty-three potential equivalents indicated with superscript f.

A.5 Equivalence Result (Proof of Proposition 1)

As alluded to in Section 4.1, the key step to prove Proposition 1 is to verify that pre-subsidy energy price $P_{O,t}$ and its potential level $P^f_{O,t}$ never show up in the model equilibrium conditions independently, but always net of subsidies. We can then define energy prices net of subsidies $P_{OC,t} \equiv (1-\tau_{C,t})P_{O,t}$, $P_{OY,t} \equiv (1-\tau_{Y,t})P_{O,t}$, and similarly in the potential block $P^f_{OC,t} \equiv (1-\tau_{C,t})P^f_{O,t}$, $P^f_{OY,t} \equiv (1-\tau_{Y,t})P^f_{O,t}$, and use these newly defined variables to eliminate pre-subsidy energy prices $P_{O,t}$ and $P^f_{O,t}$ from the equilibrium conditions listed in Appendix A.4. This modified set of equations will be isomorphic to the original one if we add the following two restrictions on net energy prices that follow directly from their definitions

$$\frac{P_{OC,t}}{P_{OY,t}} = \frac{P^f_{OC,t}}{P^f_{OY,t}} = \frac{1-\tau_{C,t}}{1-\tau_{Y,t}}. \tag{A.26}$$

Note that these two restrictions are now the only equations of the modified system in which energy subsidies $\tau_{C,t}$ and $\tau_{Y,t}$ show up. Hence, what matters for allocations in the model economy is the ratio of energy price wedges created by the subsidies $\frac{1-\tau_{C,t}}{1-\tau_{Y,t}}$. A given path of this ratio is consistent with infinitely many alternative paths of the two individual types of subsidies, but which one of them is chosen by the policy is irrelevant for allocations. It is also irrelevant for real prices other than the pre-subsidy real energy price $P_{O,t}$ (and its potential value $P^f_{O,t}$). This proves Proposition 1.

A.6 Linearized Model Equations

Linearizing around the non-stochastic steady state allows us to approximate the equilibrium dynamics in the model with the following seventeen equations

$$y_t = (1-\omega_y)v_t + \omega_y o_{Y,t} \tag{A.27}$$

$$v_t = (1-\alpha)n_t \tag{A.28}$$

$$o_{Y,t} - v_t = -\eta_y\left(p_{O,t} - \tau_{Y,t} - \alpha r_{k,t} - (1-\alpha)w_t\right) \tag{A.29}$$

$$r_{K,t} = w_t + n_t \tag{A.30}$$

$$\pi_{Y,t} - \iota\pi_{Y,t-1} = \beta\mathbb{E}_t\left\{\pi_{Y,t+1} - \iota\pi_{Y,t}\right\} + \frac{(1-\xi)(1-\beta\xi)}{\xi}mc_t \tag{A.31}$$

$$mc_t = \omega_y\left(p_{O,t} - \tau_{Y,t}\right) + (1-\omega_y)\left(\alpha r_{k,t} + (1-\alpha)w_t\right) \tag{A.32}$$

$$\pi_{W,t} - \tilde{\pi}_{W,t} = \beta \mathbb{E}_t \left\{ \pi_{W,t+1} - \tilde{\pi}_{W,t+1} \right\} + \frac{(1-\xi_w)(1-\beta\xi_w)}{\left(1 + \frac{1+\theta_w}{\theta_w}\chi\right)\xi_w} \left(mrs_t - w_t \right) \tag{A.33}$$

$$mrs_t = \chi n_t + \frac{1}{\sigma} c_t + \omega_c \left(p_{O,t} - \tau_{C,t} \right) \tag{A.34}$$

$$\tilde{\pi}_{W,t} = \iota_y \pi_{Y,t} + \iota_c \pi_{C,t} \tag{A.35}$$

$$\pi_{W,t} = w_t - w_{t-1} + \pi_{Y,t} \tag{A.36}$$

$$c_t = (1-\omega_c) y_t + \omega_c o_{C,t} \tag{A.37}$$

$$o_{C,t} - y_t = -\eta_c \left(p_{O,t} - \tau_{C,t} \right) \tag{A.38}$$

$$\begin{aligned}(1 + \varkappa^2 \beta + \varkappa) c_t = \varkappa c_{t-1} + (1 + \varkappa^2 \beta + \varkappa\beta) \mathbb{E}_t c_{t+1} - \varkappa\beta \mathbb{E}_t c_{t+2} \\ - (1-\varkappa)(1-\varkappa\beta)\sigma (i_t - \mathbb{E}_t \pi_{C,t+1})\end{aligned} \tag{A.39}$$

$$\pi_{O,t} = p_{O,t} - p_{O,t-1} + \pi_{Y,t} \tag{A.40}$$

$$\pi_{C,t} = (1-\omega_c)\pi_{Y,t} + \omega_c \left(\pi_{O,t} - \Delta\tau_{C,t} \right) \tag{A.41}$$

$$y_{O,t} = \frac{O_Y}{Y_O} o_{Y,t} + \frac{O_C}{Y_O} o_{C,t} \tag{A.42}$$

$$i_t = \psi_\pi \pi_{Y,t} + \psi_y \left(y_t - y_t^f \right) \tag{A.43}$$

They describe the evolution of seventeen endogenous variables, all expressed in log-deviations from the steady state: y_t, c_t, v_t, $o_{Y,t}$, $o_{C,t}$, n_t, w_t, $r_{K,t}$, mc_t, mrs_t, $\pi_{Y,t}$, $\pi_{O,t}$, $p_{O,t}$, $\pi_{C,t}$, $\pi_{W,t}$, $\tilde{\pi}_{W,t}$, i_t. Assuming no rigidities in price and wage setting ($\xi, \xi_w \to 0$), the same system of equations describes the 'potential' equilibrium, including the evolution of potential output y_t^f that enters the monetary policy rule given by equation (A.43).

A.7 Equilibrium with full price and wage flexibility

When prices and wages are fully flexible ($\xi, \xi_w \to 0$), the linearized price and wage Phillips curves (A.31) and (A.33) imply that the real marginal cost of production is constant ($mc_t^f = 0$) and the real wage rate is equal to the marginal rate of substitution between consumption and leisure ($w_t^f = mrs_t^f$). This leads to the following relationships

$$\omega_y \left(p_{O,t}^f - \tau_{Y,t} \right) + (1-\omega_y) \left(w_t^f + \alpha n_t^f \right) = 0, \tag{A.44}$$

$$w_t^f = \chi n_t^f + \frac{1}{\sigma} c_t^f + \omega_c \left(p_{O,t}^f - \tau_{C,t} \right), \tag{A.45}$$

where we used the equilibrium condition (A.30) to substitute for the rental rate on capital. The two equations above can be interpreted as the labor demand and labor supply schedules, respectively, and correspond to equations (19) and (20) in the main text.

Using the remaining linearized equations derived in Appendix A.6 (all of which must also hold when prices and wages are fully flexible), equation (A.45) can be further transformed into one that features only three endogenous variables: labor, real wage and real energy price. More specifically, we can use equation (A.37) to substitute for consumption, equation (A.38) to eliminate energy use by households, equation (A.27) to eliminate output, equation (A.29) to substitute for energy use by firms, and finally equations (A.30) and (A.28) to eliminate the capital rental rate and non-energy input to production. After rearrangement of terms, this leads to

$$\left(1-\frac{1}{\sigma}\eta_y\omega_y\right)w_t^f=\left(\chi+\frac{1-\alpha}{\sigma}+\frac{\alpha}{\sigma}\eta_y\omega_y\right)n_t^f \\ -\frac{1}{\sigma}\eta_y\omega_y\left(p_{O,t}^f-\tau_{Y,t}\right)+\omega_c\left(1-\frac{1}{\sigma}\eta_c\right)\left(p_{O,t}^f-\tau_{C,t}\right), \tag{A.46}$$

which is the equation we use to plot the labor supply schedule and its shift in Figure 4.

To derive the flexible price version of the energy market clearing condition, start with equation (A.42) and proceed similarly as above by using equation (A.38) to substitute for energy consumption by households, equation (A.27) to eliminate output, then equation (A.29) to eliminate energy use by firms, thus arriving at

$$y_{O,t}=v_t-\eta_y\left(\frac{O_Y}{Y_O}+\omega_y\frac{O_C}{Y_O}\right)(p_{O,t}-\tau_{Y,t}-\alpha r_{k,t}-(1-\alpha)w_t)-\eta_c\frac{O_C}{Y_O}(p_{O,t}-\tau_{C,t}), \tag{A.47}$$

which is equation (25) in the main text and it holds independently on the degree of nominal rigidities. We can further proceed as above to eliminate the capital rental rate and non-energy input to production to obtain the following formula, written below for the case of fully flexible prices and wages

$$y_{O,t}=(1-\alpha)n_t^f-\eta_y\left(\frac{O_Y}{Y_O}+\omega_y\frac{O_C}{Y_O}\right)\left(p_{O,t}^f-\tau_{Y,t}-\alpha n_t^f-w_t^f\right)-\eta_c\frac{O_C}{Y_O}\left(p_{O,t}^f-\tau_{C,t}\right). \tag{A.48}$$

Equations (A.44), (A.46) and (A.48) fully describe the evolution of the following three potential equilibrium variables, namely labor n_t^f, real producer wage w_t^f, and real pre-subsidy energy price $p_{O,t}^f$, for given realizations of energy supply shocks $y_{O,t}$ and subsidies $\tau_{C,t}$ and $\tau_{Y,t}$. Since this system of equations is static, it can be solved analytically. After some tedious algebra we arrive at the following solution for the pre-subsidy price of energy

$$-y_{O,t} = \left(\omega_c \frac{(1-\alpha)\left(1-\frac{1}{\sigma}\eta_c\right)}{\chi + \frac{1-\alpha}{\sigma} + \alpha} + \eta_c \frac{O_C}{Y_O}\right)\left(p^f_{O,t} - \tau_{OC,t}\right) + \left(\frac{\omega_y}{1-\omega_y}\frac{(1-\alpha)(1+\eta_y\chi)+\eta_y\alpha}{\chi + \frac{1-\alpha}{\sigma} + \alpha} + \frac{O_Y}{Y_O}\eta_y\right)\left(p^f_{O,t} - \tau_{OY,t}\right), \tag{A.49}$$

which is equation (18) in the main text if we define

$$\Psi_{oc} = \omega_c \frac{(1-\alpha)\left(1-\frac{1}{\sigma}\eta_c\right)}{\chi + \frac{1-\alpha}{\sigma} + \alpha} + \eta_c \frac{O_C}{Y_O}, \tag{A.50}$$

$$\Psi_{oy} = \frac{\omega_y}{1-\omega_y}\frac{(1-\alpha)(1+\eta_y\chi)+\eta_y\alpha}{\chi + \frac{1-\alpha}{\sigma} + \alpha} + \frac{O_Y}{Y_O}\eta_y. \tag{A.51}$$

It is straightforward to see that $\Psi_{oy} > 0$. Regarding Ψ_{oc}, we have

$$\begin{aligned}\Psi_{oc} &= \frac{O_C}{Y_O}\eta_c + \omega_c \frac{(1-\alpha)\left(1-\frac{1}{\sigma}\eta_c\right)}{\chi + \frac{1-\alpha}{\sigma} + \alpha} > \frac{O_C}{Y_O}\eta_c - \omega_c \frac{(1-\alpha)\frac{1}{\sigma}\eta_c}{\chi + \frac{1-\alpha}{\sigma} + \alpha} \\ &= \eta_c\left(\frac{O_C}{Y_O} - \frac{O_C}{C}\frac{(1-\alpha)\frac{1}{\sigma}}{\chi + \frac{1-\alpha}{\sigma} + \alpha}\right) > \eta_c\left(\frac{O_C}{Y_O} - \frac{O_C}{C}\right) = \eta_c\left(\frac{O_C}{Y_O} - \frac{O_C}{Y_O + V}\right) > 0.\end{aligned} \tag{A.52}$$

From $\Psi_{oc}, \Psi_{oy} > 0$ it then follows that a fall in energy endowment or an increase in any type of energy subsidies must lead to an increase in the potential pre-subsidy real energy price.

Deriving the closed-form solution for real producer wage is more algebraically involved and reads

$$w^f_t\left(\alpha + \chi + \frac{1-\alpha}{\sigma}\right) = -\frac{\Psi_{\tau c}\Psi_{oy} + \Psi_{\tau y}\Psi_{oc}}{\Psi_{oc} + \Psi_{oy}}\left(\tau_{C,t} - \tau_{Y,t}\right) + \frac{\Psi_{\tau y} - \Psi_{\tau c}}{\Psi_{oc} + \Psi_{oy}} y_{O,t} \tag{A.53}$$

where

$$\Psi_{\tau c} = \omega_c \alpha\left(1 - \frac{1}{\sigma}\eta_c\right), \tag{A.54}$$

$$\Psi_{\tau y} = \frac{\omega_y}{1-\omega_y}\left[(1-\alpha)\left(\chi + \frac{1}{\sigma}\right) + \alpha\frac{1}{\sigma}\eta_y\right]. \tag{A.55}$$

Given that $\Psi_{oc}, \Psi_{oy} > 0$, consumer energy subsidies have a negative effect on potential real producer wages if and only if

$$\omega_c \alpha\left(1 - \frac{1}{\sigma}\eta_c\right)\Psi_{oy} + \frac{\omega_y}{1-\omega_y}\left[(1-\alpha)\left(\chi + \frac{1}{\sigma}\right) + \alpha\frac{1}{\sigma}\eta_y\right]\Psi_{oc} > 0, \tag{A.56}$$

which, after dividing by α, gives the parameter restriction (21) in the main text.

A.8 Aggregate Demand Implications of Energy Shocks

While for most part of the paper we focus on the supply side, our analysis has also some interesting implications for aggregate demand. If we combine equations (A.37)-(A.39) and abstract away from habits, the aggregate IS curve can be written as

$$y_t = \mathbb{E}_t y_{t+1} - \sigma(i_t - \mathbb{E}_t \pi_{C,t+1}) - \omega_c \eta_c \mathbb{E}_t \left\{ \Delta p_{O,t+1} - \Delta \tau_{C,t+1} \right\}. \tag{A.57}$$

Note that this formula implies a positive relationship between energy prices relevant to consumers and economic activity if the central bank stabilizes the real interest rate.[20] This point is also made by Auclert et al. (2023), who exploit it to contrast representative agent models with a HANK framework.

However, efficiency considerations require output to contract in response to a negative energy supply shock, at least for realistic model parametrization. Stabilization of the real interest rate is then far from approximating optimal policy. It is also very different from what central banks usually do facing this type of shocks. Consider a temporary but persistent energy supply shock. As energy enters the consumption basket directly, headline inflation shoots up, but then turns negative. The interest rate path consistent with stabilization of the real interest rate hence implies a fall in the policy rate in response to the shock, which is exactly what generates economic expansion. By contrast, a typical reaction of central banks to energy price shocks is to increase the policy rate in line with growing core inflation.

It is then instructive to use equations (A.40) and (A.41) to rewrite the IS curve (A.57) such that it features core inflation-based real interest rate

$$y_t = \mathbb{E}_t y_{t+1} - \sigma(i_t - \mathbb{E}_t \pi_{Y,t+1}) + \omega_c(\sigma - \eta_c) \mathbb{E}_t \left\{ \Delta p_{O,t+1} - \Delta \tau_{C,t+1} \right\}. \tag{A.58}$$

The above variant of the IS curve implies that, if the policy rate perfectly tracks expected core inflation, the relationship between energy prices and output is negative, at least for reasonable calibration which assumes energy and non-energy goods being complements in household preferences ($\sigma > \eta_c$). Another important observation is that, in this case, subsidies to energy consumption by households stimulate economic activity.

[20] To see it, iterate forward to obtain

$$y_t = -\sigma \mathbb{E}_t \sum_{s=0}^{\infty} (i_{t+s} - \pi_{C,t+1}) + \omega_c \eta_c (p_{O,t} - \tau_{C,t}).$$

The same remark applies to equation (A.58).

A.9 Gap Representation of the Sticky Price and Wage Equilibrium

A.9.1 Energy Market Clearing

To derive equation (26), we start from equation (25), and then use equations (A.30) and (A.28) to eliminate the rental rate on capital and non-energy input to production. After rearrangement of terms we arrive at

$$\begin{aligned} y_{O,t} = & \left[(1-\alpha) + \alpha\eta_y \left(\frac{O_Y}{Y_O} + \omega_y \frac{O_C}{Y_O}\right)\right] n_t + \eta_y \left(\frac{O_Y}{Y_O} + \omega_y \frac{O_C}{Y_O}\right) w_t \\ & - \eta_y \left(\frac{O_Y}{Y_O} + \omega_y \frac{O_C}{Y_O}\right)(p_{O,t} - \tau_{Y,t}) - \eta_c \frac{O_C}{Y_O}(p_{O,t} - \tau_{C,t}). \end{aligned} \quad (A.59)$$

Note that the same equation must hold in the flexible price equilibrium, which implies

$$\begin{aligned} \left(\eta_y \frac{O_Y}{Y_O} + \omega_y \eta_y \frac{O_C}{Y_O} + \eta_c \frac{O_C}{Y_O}\right)\left(p_{O,t} - p^f_{O,t}\right) = & \left[(1-\alpha) + \alpha\eta_y \left(\frac{O_Y}{Y_O} + \omega_y \frac{O_C}{Y_O}\right)\right]\left(n_t - n^f_t\right) \\ & + \eta_y \left(\frac{O_Y}{Y_O} + \omega_y \frac{O_C}{Y_O}\right)\left(w_t - w^f_t\right). \end{aligned} \quad (A.60)$$

or in short as in equation (26) in the main text

$$\hat{p}_{O,t} = \Psi_{on}\hat{n}_t + \Psi_{ow}\hat{w}_t, \quad (A.61)$$

where we used hats to indicate the deviations from the potential equilibrium and where

$$\Psi_{on} = \frac{(1-\alpha) + \alpha\eta_{oy}\left(\frac{O_Y}{Y_O} + \omega_{oy}\frac{O_C}{Y_O}\right)}{\eta_{oy}\frac{O_Y}{Y_O} + (\omega_{oy}\eta_{oy} + \eta_{oc})\frac{O_C}{Y_O}}, \quad (A.62)$$

$$\Psi_{ow} = \frac{\eta_{oy}\left(\frac{O_Y}{Y_O} + \omega_{oy}\frac{O_C}{Y_O}\right)}{\eta_{oy}\frac{O_Y}{Y_O} + (\omega_{oy}\eta_{oy} + \eta_{oc})\frac{O_C}{Y_O}}. \quad (A.63)$$

A.9.2 Price Phillips Curve

From the definition of real marginal cost (A.32) and $mc^f_t = 0$ if follows immediately

$$mc_t = \omega_y \hat{p}_{O,t} + (1-\omega_y)\hat{w}_t + \alpha(1-\omega_y)\hat{n}_t. \quad (A.64)$$

Combining this equation with the energy market clearing condition (A.61)

$$mc_t = \Psi^{mpl}_n \hat{n}_t + \Psi^{mpl}_w \hat{w}_t, \quad (A.65)$$

where

$$\Psi_n^{mpl} = \alpha(1-\omega_{oy}) + \omega_{oy}\Psi_{on}, \tag{A.66}$$
$$\Psi_w^{mpl} = (1-\omega_{oy}) + \omega_{oy}\Psi_{ow}. \tag{A.67}$$

This allows us to rewrite the Phillips curve (A.31) as follows

$$\pi_{Y,t} - = \beta\mathbb{E}_t\left\{\pi_{Y,t+1}\right\} + \kappa_p\left(\Psi_n^{mpl}\hat{n}_t + \Psi_w^{mpl}\hat{w}_t\right), \tag{A.68}$$

where $\kappa_p \equiv \frac{(1-\xi)(1-\beta\xi)}{\xi}$ and where we additionally imposed no indexation in price setting ($\iota = 0$). This gives equation (27) in the main text.

A.9.3 Wage Phillips Curve

Starting from the definition of the marginal rate of substitution (A.34), substitute for consumption using equation (A.37), for energy use by households using equation (A.38), for output using equation (A.27), and for energy demand by firms using equation (A.29). After using equations (A.28) and (A.30) and rearranging we obtain

$$mrs_t = \left(\chi + \frac{1-\alpha(1-\eta_y\omega_y)}{\sigma}\right)n_t - \frac{\eta_y}{\sigma}\omega_y\left(p_{O,t} - \tau_{Y,t} - w_t\right) + \left(\omega_c - \frac{\eta_c}{\sigma}\omega_c\right)\left(p_{O,t} - \tau_{C,t}\right). \tag{A.69}$$

If prices and wages are fully flexible, this equation needs to hold as well. We hence have

$$mrs_t - w_t^f = \left(\chi + \frac{1-\alpha(1-\eta_y\omega_y)}{\sigma}\right)\hat{n}_t - \left(\frac{\eta_y}{\sigma}\omega_y + \frac{\eta_c}{\sigma}\omega_c - \omega_c\right)\hat{p}_{O,t} + \frac{1}{\sigma}\eta_y\omega_y\hat{w}_t. \tag{A.70}$$

Now use the energy market clearing condition (A.61) to eliminate energy prices, after which we obtain

$$mrs_t - w_t^f = \Psi_n^{mrs}\hat{n}_t + \Psi_w^{mrs}\hat{w}_t, \tag{A.71}$$

where

$$\Psi_n^{mrs} = \chi + \frac{1-\alpha(1-\eta_y\omega_y)}{\sigma} - \Psi_{on}\left[\frac{1}{\sigma}\eta_y\omega_y + \frac{1}{\sigma}\eta_c\omega_c - \omega_c\right], \tag{A.72}$$
$$\Psi_w^{mrs} = \frac{1}{\sigma}\eta_y\omega_y - \Psi_{ow}\left[\frac{1}{\sigma}\eta_y\omega_y + \frac{1}{\sigma}\eta_c\omega_c - \omega_c\right]. \tag{A.73}$$

We also have $mrs_t^f = w_t^f = -\hat{w}_t + w_t$. As a result, the wage Phillips curve (A.33) can be rewritten as follows

$$\pi_{W,t} - \tilde{\pi}_{W,t} = \beta\mathbb{E}_t\left\{\pi_{W,t+1} - \tilde{\pi}_{W,t+1}\right\} + \kappa_w\left(\Psi_n^{mrs}\hat{n}_t + (\Psi_w^{mrs} - 1)\hat{w}_t\right), \tag{A.74}$$

where $\kappa_w \equiv \frac{(1-\xi_w)(1-\beta\xi_w)}{\left(1+\frac{1+\theta_w}{\theta_w}\chi\right)\xi_w}$, which is equation (28) in the main text.

A.9.4 Real Wage Dynamics

Since the nominal wage inflation rate is $\pi_{W,t} = w_t - w_{t-1} + \pi_{Y,t}$, the wage Phillips curve (A.74) can be written as

$$w_t - w_{t-1} + \pi_{Y,t} - \tilde{\pi}_{W,t} = \beta \mathbb{E}_t \left\{ w_{t+1} - w_t + \pi_{Y,t+1} - \tilde{\pi}_{W,t+1} \right\} + \kappa_w \left(\Psi_n^{mrs} \hat{n}_t + (\Psi_w^{mrs} - 1)\hat{w}_t \right). \tag{A.75}$$

Subtracting from it the Phillips curve (A.68) and rearranging yields

$$w_t - w_{t-1} - \tilde{\pi}_{W,t} = \beta \mathbb{E}_t \left\{ w_{t+1} - w_t - \tilde{\pi}_{W,t+1} \right\} + \left(\kappa_w \Psi_n^{mrs} - \kappa_p \Psi_n^{mpl} \right) \hat{n}_t - \left(\kappa_w (1 - \Psi_w^{mrs}) + \kappa_p \Psi_w^{mpl} \right) \hat{w}_t. \tag{A.76}$$

If we further assume that wages are indexed to core inflation, i.e., $\tilde{\pi}_{W,t} = \iota_y \pi_{Y,t}$, we can multiply the Phillips curve A.68 by ι_y and add to the equation above to obtain

$$w_t - w_{t-1} = \beta \mathbb{E}_t \left\{ w_{t+1} - w_t \right\} + \left(\kappa_w \Psi_n^{mrs} - \kappa_p (1-\iota_y) \Psi_n^{mpl} \right) \hat{n}_t - \left(\kappa_w (1 - \Psi_w^{mrs}) + \kappa_p (1-\iota_y) \Psi_w^{mpl} \right) \hat{w}_t. \tag{A.77}$$

A.10 Proof of Proposition 2

Assume now that the central bank closes the employment gap so that we can write equation (A.77) as follows

$$w_t - w_{t-1} = \beta \mathbb{E}_t \left\{ w_{t+1} - w_t \right\} - \kappa \left(w_t - w_t^f \right), \tag{A.78}$$

where

$$\kappa = \kappa_w \left[1 - \Psi_w^{mrs} \right] + \kappa_p (1 - \iota_y) \Psi_w^{mpl} \tag{A.79}$$

We hence have a second-order difference equation in real producer wage.

To solve it, it is convenient to write it using a lag operator

$$\mathbb{E}_t \left\{ (1 - r_1 L)(1 - r_2 L) w_{t+1} \right\} = -\frac{\kappa}{\beta} w_t^f, \tag{A.80}$$

where

$$r_1, r_2 = \frac{\left(1 + \frac{1}{\beta} + \frac{\kappa}{\beta}\right) \pm \sqrt{\left(1 + \frac{1}{\beta} + \frac{\kappa}{\beta}\right)^2 - \frac{4}{\beta}}}{2}. \tag{A.81}$$

It is easy to verify that both roots r_1 and r_2 are real. Now define $b_t = (1 - r_2 L) w_t$ so that we can write

$$\mathbb{E}_t\left\{b_{t+1}\right\} - r_1 b_t = -\frac{\kappa}{\beta} w_t^f. \tag{A.82}$$

We know from Vieta's formulas that at least one root is larger than unity. Letting r_1 be the bigger root, we can write

$$b_t = \frac{1}{r_1}\mathbb{E}_t\left\{b_{t+1}\right\} + \frac{\kappa}{r_1\beta} w_t^f \tag{A.83}$$

and hence solve

$$b_t = \frac{\kappa}{r_1\beta}\mathbb{E}_t \sum_{j=0}^{\infty} r_1^{-j} w_{t+j}^f. \tag{A.84}$$

We are interested in the economy's responses to a particular shock (e.g. energy supply or subsidy). Assuming that this shock is AR(1) with autoregressive coefficient $-1 < \rho < 1$, so is the potential wage w_t^f. This is because the equilibrium in our model under full price and wage flexibility is given by a static set of equation. We can hence write

$$b_t = \frac{\kappa}{r_1\beta}\mathbb{E}_t \sum_{j=0}^{\infty} \left(\frac{\rho}{r_1}\right)^j w_t^f = \frac{\kappa}{\beta}\frac{r_1}{r_1-\rho} w_t^f. \tag{A.85}$$

Going back to real producer wage we have

$$w_t = r_2 w_{t-1} + \frac{\kappa}{\beta}\frac{r_1}{r_1-\rho} w_t^f. \tag{A.86}$$

We now use $r_1 r_2 = \frac{1}{\beta}$ and $r_1 + r_2 = 1 + \frac{1}{\beta} + \frac{\kappa}{\beta} = 1 + r_1 r_2 + \frac{\kappa}{\beta}$ that are implied by Vieta's formulas to rewrite the equation above as follows

$$w_t = r_2 w_{t-1} + (1-r_2)\frac{1-\beta r_2}{1-\rho\beta r_2} w_t^f \tag{A.87}$$

Note that $0 < r_2 < 1$, where the first inequality follows from Vieta's formulas and the second one from stability.

Having solved for the real wage, we are ready to work out the implications of energy subsidies for core inflation. If we assume as in Proposition 2 that the central bank fully closes the employment gap, the Phillips curve (A.68) implies

$$\pi_{Y,t} = \beta\mathbb{E}_t\pi_{Y,t+1} + \kappa_p \Psi_w^{mpl}\hat{w}_t = \kappa_p \Psi_w^{mpl}\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \hat{w}_{t+j}. \tag{A.88}$$

Since $\kappa_p, \Psi_w^{mpl} > 0$, the response of core inflation has the same sign as the discounted sum of the wage gaps. To determine this sign, let us define $A \equiv (1-r_2)\frac{1-\beta r_2}{1-\rho\beta r_2} < 1$ to ease notation and write equation (A.87) as follows

$$w_t = r_2 w_{t-1} + A w_t^f. \tag{A.89}$$

Assuming that the economy is initially in the steady state and is hit by a shock at time t, the sequence of expected future wage gaps is

$$\begin{aligned}
\hat{w}_t &= (A-1)\, w_t^f \\
\mathbb{E}_t \hat{w}_{t+1} &= (A\,[r_2+\rho] - \rho)\, w_t^f \\
\mathbb{E}_t \hat{w}_{t+2} &= \left(A\left[r_2^2 + r_2\rho + \rho^2\right] - \rho^2\right) w_t^f \\
&\vdots \\
\mathbb{E}_t \hat{w}_{t+j} &= \left(A\left[r_2^j + r_2^{j-1}\rho + r_2^{j-2}\rho^2 + ... + r_2^2\rho^{j-2} + r_2\rho^{j-1} + \rho^j\right] - \rho^j\right) w_t^f
\end{aligned}$$

and hence their expected discounted sum is

$$\begin{aligned}
\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \hat{w}_{t+j} &= w_t^f \left\{(A-1) + \beta A(r_2+\rho) - \beta\rho + \beta^2 A\left[r_2^2 + r_2\rho + \rho^2\right] - \beta^2\rho^2 + ...\right\} \\
&= w_t^f \left\{A\left(1 + \beta r_2\left[1 + \frac{\rho}{r_2}\right] + \beta^2 r_2^2\left[1 + \frac{\rho}{r_2} + \left(\frac{\rho}{r_2}\right)^2\right] + ...\right) - \frac{1}{1-\beta\rho}\right\} \\
&= w_t^f \left\{A\left(1 + \beta r_2 + ... + \frac{\rho}{r_2}\left[\beta r_2 + \beta^2 r_2^2 + ...\right] + ...\right) - \frac{1}{1-\beta\rho}\right\} \\
&= w_t^f \left\{\frac{A}{1-\beta r_2}\left(1 + \rho\beta + \rho^2\beta^2 + ...\right) - \frac{1}{1-\beta\rho}\right\} \\
&= w_t^f \left\{\frac{1}{1-\rho\beta}\left(\frac{A}{1-\beta r_2} - 1\right)\right\}.
\end{aligned}$$

Since $\frac{A}{1-\beta r_2} = \frac{1-r_2}{1-\rho\beta r_2} < 1$, the term in curly brackets is negative. Note further that assumption (i) in Proposition 2 ensures that potential real producer wages fall in response to an increase in consumer energy subsidies. We have hence proved that such a policy increases core inflation.

A.11 Adding Hand-to-Mouth Households (TANK Extension)

As explained in Section 6, hand-to-mouth (Keynesian) agents work the same number of hours as Ricardian agents and simply consume their disposable income. Their consumption and labor is then described by the following equations

$$C_{K,t} = W_{C,t} N_{K,t} - T_{K,t}, \tag{A.90}$$

$$N_{K,t} = N_{R,t}. \tag{A.91}$$

Taxes paid by Keynesian households evolve according to

$$\frac{T_{K,t} - T_K}{Y} = t_{K,t}, \tag{A.92}$$

where t_t^K is determined by fiscal policy. We also have the following definitions of aggregate consumption and labor

$$C_t = \lambda C_{K,t} + (1-\lambda) C_{R,t}, \tag{A.93}$$

$$N_t = \lambda N_{K,t} + (1-\lambda) N_{R,t}. \tag{A.94}$$

The five equations listed above correspond to five new variables, namely $C_{R,t}$, $N_{R,t}$, $C_{K,t}$, $N_{K,t}$, and $T_{K,t}$.

Other equations listed in Appendix A.4 still hold, except that the optimal reset wage given by equation (A.16) must now reflect decisions of Ricardian agents only. It hence becomes

$$\tilde{W}_{C,t}^{1+\chi\frac{1+\theta_w}{\theta_w}} = \frac{\chi_0 \mathbb{E}_t \sum_{j=0}^{\infty} (\xi_w \beta)^j \left(\frac{\Pi_{C,t}}{\tilde{\Pi}_{W,t}} \frac{\tilde{\Pi}_{W,t} \ldots \tilde{\Pi}_{W,t+j}}{\Pi_{C,t} \ldots \Pi_{C,t+j}} \right)^{-\frac{1+\theta_w}{\theta_w}(1+\chi)} W_{C,t+j}^{\frac{1+\theta_w}{\theta_w}(1+\chi)} N_{R,t+j}^{1+\chi}}{\mathbb{E}_t \sum_{j=0}^{\infty} (\xi_w \beta)^j \Lambda_{t+j} \left(\frac{\Pi_{C,t}}{\tilde{\Pi}_{W,t}} \frac{\tilde{\Pi}_{W,t} \ldots \tilde{\Pi}_{W,t+j}}{\Pi_{C,t} \ldots \Pi_{C,t+j}} \right)^{-\frac{1}{\theta_w}} W_{C,t+j}^{\frac{1+\theta_w}{\theta_w}} N_{R,t+j}}, \tag{A.95}$$

where marginal utility given by equation (A.22) is now

$$\Lambda_t = \left(C_{R,t} - \varkappa C_{R,t-1} \right)^{-\frac{1}{\sigma}} - \varkappa \beta \mathbb{E}_t \left(C_{R,t+1} - \varkappa C_{R,t} \right)^{-\frac{1}{\sigma}}. \tag{A.96}$$

This redefinition of Λ_t also ensures that all assets in the model are priced by Ricardian households. This is consistent with the assumption that only these agents can trade bonds and receive dividends from firms.

The same modifications need to be introduced in the potential block of the model that describes the equilibrium under full wage and price flexibility ($\xi, \xi_w \rightarrow 0$). As a result, the TANK extension can be characterized by fifty-six equations in the same number of endogenous variables, driven by four exogenous variables, namely $Y_{O,t}$, $\tau_{C,t}$, $\tau_{Y,t}$, and $t_{K,t}$.

When defining optimal policy in this version of the model, we assume that Keynesian households' utility has the same functional form as that of Ricardian agents, and so it aggregates to

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left(\frac{\left(C_{K,t+s} - \varkappa C_{K,t+s-1} \right)^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} - \chi_0 \frac{N_{K,t+s}^{1+\chi}}{1+\chi} \right). \tag{A.97}$$

This is the same formula as equation (33) in the main text, which still applies to Ricardian households, except that it does not feature the wage dispersion term as Keynesian households all earn the same aggregate wage. Social welfare is defined as the population weighted average of Keynesian and Ricardian households' utility.

A.12 Open Economy Extension

We cast the open economy extension of the model in a two-country setting. In this version of the model, most of the equations listed in Appendix A.4 still hold for the Home economy, so we only discuss those that are modified or newly introduced. All prices showing up in the equations below are expressed in real terms by dividing them by the producer price index $P_{Y,t}$ for the Home economy and $P^*_{Y,t}$ for the foreign economy, and the real exchange rate is defined as $Q_t \equiv \varepsilon_t P^*_{Y,t}/P_{Y,t}$.

In the open economy extension, equation (A.20) defining total consumption is replaced with

$$C_t = \left((1-\omega_c)^{\frac{1}{\eta_c}} C_{N,t}^{\frac{\eta_c-1}{\eta_c}} + \omega_c^{\frac{1}{\eta_c}} O_{C,t}^{\frac{\eta_c-1}{\eta_c}}\right)^{\frac{\eta_c}{\eta_c-1}}, \tag{A.98}$$

where the non-energy consumption bundle now includes both domestic production and imports

$$C_{N,t} = \left((1-\omega)^{\frac{1}{\eta}} Y_t^{\frac{\eta-1}{\eta}} + \omega^{\frac{1}{\eta}} M_t^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}. \tag{A.99}$$

Consequently, the following two equations replace formulas (A.11) and (A.21), describing the consumer price level and the optimal composition of the consumption basket

$$P_{C,t} = \left((1-\omega_c)P_{N,t} + \omega_c\left((1-\tau_{C,t})P_{O,t}\right)^{1-\eta_c}\right)^{\frac{1}{1-\eta_c}}, \tag{A.100}$$

$$\frac{O_{C,t}}{C_{N,t}} = \frac{\omega_c}{1-\omega_c}\left((1-\tau_{C,t})\frac{P_{O,t}}{P_{N,t}}\right)^{-\eta_c}, \tag{A.101}$$

where the optimal composition of the core consumption bundle is

$$\frac{M_t}{Y_t} = \frac{\omega}{1-\omega} P_{M,t}^{-\eta}, \tag{A.102}$$

the core price level is given by

$$P_{N,t} = \left((1-\omega) + \omega P_{M,t}^{1-\eta_c}\right)^{\frac{1}{1-\eta_c}}, \tag{A.103}$$

and core inflation is

$$\Pi_{N,t} = \frac{P_{N,t}}{P_{N,t-1}} \Pi_{Y,t}. \tag{A.104}$$

We keep assuming that wages are indexed to core (and possibly also to headline) inflation, so equation (A.17) becomes

$$\tilde{\Pi}_{W,t} = \Pi_{N,t}^{\iota_y} \Pi_{C,t}^{\iota_c} \Pi^{1-\iota_y-\iota_c}. \tag{A.105}$$

Firms now sell both to domestic and foreign markets, and hence aggregate production function (A.3) is now

$$Y_t P^{\#}_{Y,t} + M^*_t P^{\#}_{M,t} = \left((1-\omega_y)^{\frac{1}{\eta_y}} V_t^{\frac{\eta_y - 1}{\eta_y}} + \omega_y^{\frac{1}{\eta_y}} O_{Y,t}^{\frac{\eta_y - 1}{\eta_y}} \right)^{\frac{\eta_y}{\eta_y - 1}}. \tag{A.106}$$

Assuming local currency pricing, the export price setting decisions and export price dispersion are described by the following block of equilibrium conditions

$$1 = \left((1-\xi) \left(\frac{\tilde{P}^*_{M,t}}{P^*_{M,t}} \right)^{-\frac{1}{\theta}} + \xi \left(\frac{\tilde{\Pi}^*_{M,t}}{\Pi^*_{M,t-1}} \right)^{-\frac{1}{\theta}} \right)^{-\theta}, \tag{A.107}$$

$$\frac{\tilde{P}^*_{M,t}}{P^*_{M,t}} = \frac{\mathbb{E}_t \sum_{j=0}^{\infty} (\xi_m \beta)^j \frac{\Lambda_{t+j}}{P_{C,t+j}} MC_{t+j} \left(\frac{\Pi^*_{M,t}}{\tilde{\Pi}^*_{M,t}} \frac{\tilde{\Pi}^*_{M,t} \dots \tilde{\Pi}^*_{M,t+j}}{\Pi^*_{M,t} \dots \Pi^*_{M,t+j}} \right)^{-\frac{1+\theta}{\theta}} M^*_{t+j}}{\mathbb{E}_t \sum_{j=0}^{\infty} (\xi_m \beta)^j \frac{\Lambda_{t+j} P^*_{M,t+j}}{P^*_{C,t+j}} Q_{t+j} \left(\frac{\Pi^*_{M,t}}{\tilde{\Pi}^*_{M,t}} \frac{\tilde{\Pi}^*_{M,t} \dots \tilde{\Pi}^*_{M,t+j}}{\Pi^*_{M,t} \dots \Pi^*_{M,t+j}} \right)^{-\frac{1}{\theta}} M^*_{t+j}}, \tag{A.108}$$

$$\tilde{\Pi}^*_{M,t} = \Pi^{*\iota}_{M,t-1} \Pi^{1-\iota}, \tag{A.109}$$

$$\Pi^*_{M,t} = \frac{P^*_{M,t}}{P^*_{M,t-1}} \Pi^*_{Y,t}, \tag{A.110}$$

$$P^{\#}_{M,t} = (1-\xi) \tilde{P}_{M,t}^{-\frac{1+\theta}{\theta}} + \xi \left(\frac{\tilde{\Pi}_{M,t}}{\Pi_{M,t}} \right)^{-\frac{1+\theta}{\theta}} P^{\#}_{M,t-1}. \tag{A.111}$$

The central bank still targets core inflation and responds to the deviation of total output – which now includes both domestic sales and exports – from its potential. This means that the monetary policy rule (A.25) becomes

$$I_t = I + \psi_\pi \left(\Pi_{N,t} - \Pi_Y \right) + \psi_y \left(\frac{\zeta Y_t + (1-\zeta) M^*_t}{\zeta Y^f_t + (1-\zeta) M^{*f}_t} - 1 \right). \tag{A.112}$$

The energy market now clears on the world-wide level, meaning that equation A.24 and its Foreign economy equivalent are replaced with

$$\zeta Y_{O,t} + (1-\zeta) Y^*_{O,t} = \zeta (O_{C,t} + O_{Y,t}) + (1-\zeta)(O^*_{C,t} + O^*_{Y,t}) \tag{A.113}$$

and the law of one price for energy implies

$$P_{O,t} = Q_t P^*_{O,t}. \tag{A.114}$$

Finally, international borrowing is described by the UIP condition and Home economy's net foreign assets accumulation

$$1 = \mathbb{E}_t \left\{ \frac{I_t^*}{I_t} \frac{\Pi_{Y,t+1}}{\Pi_{Y,t+1}^*} \frac{Q_{t+1}}{Q_t} \right\} - \Gamma \frac{B_t}{P_{Y,t}}, \tag{A.115}$$

$$B_t = \left((1-\zeta) I_{t-1} + \zeta \frac{Q_t}{Q_{t-1}} I_{t-1}^* \right) B_{t-1} + Q_t P_{M,t}^* M_t^* - P_{M,t} M_t + P_{O,t} (Y_{O,t} - O_{Y,t} - O_{C,t}). \tag{A.116}$$

Summing up, the open economy extension of the model: (i) assigns the equilibrium conditions listed in Appendix (A.4) to the Home economy; (ii) creates their duplicates and assigns them to the Foreign economy; (iii) introduces sixty-eight new equilibrium conditions – fifteen equations (A.98)-(A.112) for the Home country, their fifteen Foreign counterparts, four equations (A.113)-(A.116), and the corresponding thirty-four equations describing the potential equilibrium; (iii) drops twenty-eight conditions – seven equations (A.20), (A.11), (A.21), (A.17), (A.3), (A.25), (A.24) for the Home economy, their seven Foreign counterparts, and the corresponding fourteen formulas in the potential equilibrium block. The net increase of forty equations corresponds to the following twenty new endogenous variables: $C_{N,t}$, $C_{N,t}^*$, M_t, M_t^*, $P_{N,t}$, $P_{N,t}^*$, $\Pi_{N,t}$, $\Pi_{N,t}^*$, $P_{M,t}$, $P_{M,t}^*$, $\tilde{P}_{M,t}$, $\tilde{P}_{M,t}^*$, $P_{M,t}^{\#}$, $P_{M,t}^{\#,*}$, $\Pi_{M,t}$, $\Pi_{M,t}^*$, $\tilde{\Pi}_{M,t}$, $\tilde{\Pi}_{M,t}^*$, Q_t, B_t and their twenty counterparts making up the potential block.