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Abstract

A common assumption in macroeconomics is that energy prices are determined in a world-wide, rather frictionless market. This no longer seems an adequate description for the situation that much of Europe currently faces. Rather, one reading is that shortages exist in the quantity of energy available. Such limits to the supply of energy mean that the local price of energy is affected by domestic economic activity. In a simple open-economy New Keynesian setting, the paper shows conditions under which energy shortages can raise the risk of self-fulfilling fluctuations. A firmer focus of the central bank on input prices (or on headline consumer prices) removes such risks.

JEL Classification: E31, E32, E52, F41, Q43

Keywords: Energy crisis, macroeconomic instability, sunspots, monetary policy, heterogeneous households.

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1 Introduction

A common assumption in macroeconomics is that energy prices are determined in a worldwide, rather frictionless market. From the perspective of a small open economy, then, the supply of energy is abundant. This means that domestic economic activity does not affect the domestic-currency price of energy other than through the exchange rate. Abundance, though, does not appear to adequately describe the situation in Europe today. Instead, a shortage of energy may render the domestic price of energy endogenous to domestic economic activity, with potentially profound implications for stabilization policy.

This paper studies the risks to macroeconomic stability that might emerge. We look at an entirely standard New Keynesian model of a small open economy (think Blanchard and Gali, 2009). The economy imports energy from the rest of the world. Goods are produced using labor and energy. And both goods and energy feature in households' consumption baskets. Trade is balanced. There is one change relative to Blanchard and Gali (2009): energy is not abundantly available at an exogenous *price*. Rather, we treat the *quantity* of energy available to households and firms as fixed and the price as endogenous. Energy is scarce, in line with the current situation facing Europe.

We ask under which considerations the scarcity of energy exposes the economy to the risk of self-fulfilling fluctuations. Such a situation could arise from a feedback loop between energy prices and economic activity. Namely, suppose that households and firms hold the non-fundamental belief that energy prices will be high. Under these beliefs, firms face high marginal costs. Inflation rises. But since goods prices are rigid, firms cannot pass all the costs on to households. Therefore, the fall in domestic demand does not fully reflect the rise in energy prices. What is more, higher energy prices mean higher external demand. Aggregate demand (domestic plus external) can, therefore, rise. The ensuing rise in labor demand in turn induces higher real wages, further amplifying the rise in marginal costs and validating the initial beliefs. To rule out such a feedback loop, the central bank would need to reduce domestic demand sufficiently much to reduce total aggregate demand. We find that this may require a notably stronger response to inflation than the Taylor principle commands, or a response to input prices.

At the core of our findings lies that, in order to interrupt the energy-price-activity feedback loop, monetary policy has to lean sufficiently strongly against rising input costs. It can do so directly (*raising* rates when energy prices *rise* or when *nominal wages* rise). Or it can do so indirectly through its response to inflation and economic activity. A focus on headline inflation is more conducive to cutting the feedback loop than a monetary response focused on core inflation. The reason is that core inflation does reflect the rise in energy prices to a lesser extent. The feedback loop comes with rising production and employment, but a fall in value added (GDP). A monetary response that focuses on stabilizing GDP would, thus, further fuel the feedback loop, whereas a monetary response to the level of production works against the loop.

The reaminder of the paper is structured as follows. We review the literature next. Section 2 presents the model. Section 3 provides pencil-and-paper results for a special case, so as to provide intuition for the possibility that the feedback loop arises. Section 4 calibrates the model economy to a stylized euro area and provides quantitative results. The same section also provides sensitivity analysis, including an extension to a model environment with household heterogeneity. A final section concludes.

Related literature

Our paper emphasizes that an environment of scarce energy may make it notably harder for the central bank to anchor inflation expectations and economic activity. The key finding is that, in such an environment, there is a case for focusing on headline inflation instead of core inflation or, more generally, to engineer tighter monetary policy in the face of what looks like a cost-push shock.

There is, of course, a vast literature on energy and the macro-economy, a literature to which we cannot do full justice here. Closest in terms of modeling are Blanchard and Gali (2009). They and a related paper, Blanchard and Riggi (2013), point to the structural features that shape the response to fundamental energy-supply shocks; namely, the share of energy in production and consumption, the monetary response, and the extent of real wage rigidities. Nakov and Pescatori (2009) focus on the energy elasticity of output.

Sterk, Olivi and Xhani (2022) and Känzig (2022) have analyzed the distributional effects of changes in energy prices. All these papers consider an environment of abundant energy supply, which rules out the energy-price-activity feedback loop that we study. Other papers, like us, work with exogenous energy supply, for example, Datta et al. (2021). Differences in the calibration explain why a feedback does not emerge in their work. Our calibration in large measure relies on Bachmann et al. (2022) who are motivated by the current situation and estimate the effect that an exogenous cut to natural-gas supply from Russia has for the German economy, abstracting from nominal rigidities. Pieroni (forthcoming) provides an assessment of a European scenario in a heterogeneous-household New Keynesian model. What sets us apart from all these papers is that we study how limits to energy supply may translate into self-fulfilling energy-price-activity loops.

In our calibrated model, an increase of energy prices by 20 percent is related to a fall in GDP of 1 percent. This is broadly in line with empirical estimates in the literature; for example, the effect of inventory-demand shocks on global activity in Baumeister and Hamilton (2019), the SVAR-based findings in Blanchard and Gali (2009) and Blanchard and Riggi (2013), and the oil-supply news shocks identified by Känzig (2021). Needless to say, though, that these authors understand fluctuations as originating from exogenous fundamental shocks rather than the sunspots that drive prices in our environment.

We propose a novel mechanism that can generate an energy-price-activity feedback loop. This loop opens the economy to sunspot equilibria even if monetary policy follows a standard Taylor (1993) rule. This novel mechanism differentiates the current paper from other work that also questions the Taylor principle. Bilbiie (2008) and Galí, López-Salido and Vallés (2004) derive the failure of the Taylor principle in a closed economy with limited asset-market participation. Bilbiie (2021) adds to this precautionary savings. Our paper shares with the aforementioned what technically lies at the heart of the indeterminacy: an inversion of the IS curve, that is, the relationship between aggregate output and the *ex-ante* real interest rate.[1] As a result, our pencil and paper solutions for the determinacy

[1] Branch and McGough (2009) and Ilabaca and Milani (2021) derive a break-down of the Taylor principle from adaptive expectations, Ascari and Ropele (2009) from trend inflation. Llosa and Tuesta

regions are almost nested by those in the aforementioned papers. Almost, because in our framework also the Phillips curve relationship is affected by the energy shortage (owing to the fact that higher prices for imported energy make households poorer and there is a wealth effect on labor supply). So whether or not the Taylor principle fails does not depend on the IS curve alone.

Our results appear to run counter to the conventional wisdom about the best monetary response to energy-price shocks. In positive contributions, Carlstrom, Fuerst and Ghironi (2006) show that, in their setting, a central bank that reacts more than one-to-one to contemporaneous inflation of *any* arbitrary subset of goods in the economy (e.g., to core inflation only) ensures determinacy; compare also Airaudo and Zanna (2012). In our setting, instead, it matters which price index the central bank targets. The reason is that different price indexes reflect energy-price changes differently, and that these price changes shape external demand. A monetary response to energy-price changes, as would help ensure determinacy in our setting, appears to run counter to the normative implications of a long stream of literature that finds that central banks should best focus on the inflation rate of those goods and services that have rigid prices rather than of those goods or services that have flexible prices. Aoki (2001) formalizes the notion that policy should react to inflation in goods with rigid prices for the closed economy, Bodenstein, Erceg and Guerrieri (2008) for the open economy with an energy-supply shock. Contributions for multi-sector models, such as Eusepi, Hobijn and Tambalotti (2011) and Rubbo (2022) come to similar conclusions. Whereas this literature focuses on welfare-maximizing monetary policy, we focus on belief formation. We find that unless the targeting policies mentioned above are implemented in a sufficiently strict manner, a further response to energy prices may help prevent non-fundamental fluctuations.

(2009) focus on a cost channel of monetary policy and Kurozumi (2006) focuses on non-separability of consumption and real money balances.

2 Model

There are two countries. The Home economy imports energy from a generic energy-exporting country in exchange for goods that are produced domestically. This is the only link between the two economies. In particular, they do not trade in financial markets. Hence, by construction, trade is balanced period by period: the value of exports in goods equals the value of imports of energy. Energy is used in two ways: it is consumed by households directly and it serves as an input factor for the production of consumption goods. Time t is discrete and marked by $t = 0, 1, ...$

2.1 Households

There is a representative, infinitely-lived household. The household consumes goods produced in Home and energy imported from Foreign. The household works and saves in domestic-currency bonds. The household maximizes expected life-time utility

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{N_t^{1+\varphi}}{1+\varphi} \right] \right\}.$$

$\mathbb{E}_t$ marks expectations conditional on period-t information. C_t is a basket of consumption goods, defined below. N_t marks hours worked in Home's competitive labor market. Throughout, we shall assume that $\beta \in (0, 1)$, $\sigma > 0$, $\chi > 0$ and $\varphi \geq 0$. The household owns the domestic firms and pays lump-sum taxes to the government.

The household's consumption basket is composed of the consumption of energy, $C_{E,t}$, and goods, $C_{G,t}$. Consumption preferences are described by the CES aggregator

$$C_t = \left[\gamma^{\frac{1}{\eta}} \left(C_{E,t} - \bar{e} \right)^{\frac{\eta-1}{\eta}} + (1-\gamma)^{\frac{1}{\eta}} C_{G,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}.$$

Above, $\bar{e} \geq 0$ marks the subsistence level for the consumption of energy. $\gamma \in (0, 1)$ measures the weight on energy in the consumption basket and $\eta > 0$ measures the elasticity of substitution between energy and goods in the eyes of consumers. Hence, the larger η is the more substitutable are the consumption of energy and of goods. The household's flow budget constraint is given by

$$P_{E,t}C_{E,t} + P_{G,t}C_{G,t} + B_t = W_tN_t + B_{t-1}R_{t-1} + P_tD_t - P_tT_t. \tag{1}$$

Here, the first term marks nominal expenditures for energy consumption ($P_{E,t}$ being the energy price), the second term the expenditures for non-energy consumption goods ($P_{G,t}$ being their price). The third term on the left-hand side (B_t) marks the nominal expenditures for the purchase of nominal, risk-free one-period bonds. On the right, income side, the first term corresponds to nominal earnings (W_t being the nominal wage rate). The second terms marks the nominal proceeds from bonds purchased the previous periods (R_{t-1} marking the gross nominal interest rate on these bonds). The third term corresponds to the nominal dividends that that the domestic firms pay to households. The fourth and final term marks nominal lump-sum taxes to the government.

With this, the household's optimal demand schedules are

$$C_{E,t} - \bar{e} = \gamma \left(\frac{P_{E,t}}{P_t}\right)^{-\eta} C_t, \text{ and } \quad C_{G,t} = (1-\gamma) \left(\frac{P_{G,t}}{P_t}\right)^{-\eta} C_t,$$

where the consumer price index for non-subsistence (that is, marginal) consumption is defined as

$$P_t = \left[\gamma P_{E,t}^{1-\eta} + (1-\gamma)P_{G,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}, \tag{2}$$

Hence, P_t reflects both energy prices and producer prices. Household expenditures, then, can be written as

$$P_{E,t}C_{E,t} + P_{G,t}C_{G,t} = P_{E,t}\bar{e} + P_tC_t.$$

With this, the household's budget constraint (1) can be rewritten in real terms as

$$C_t + \frac{P_{E,t}}{P_t}\bar{e} + b_t = \frac{W_t}{P_t}N_t + \frac{R_{t-1}}{\Pi_t}b_{t-1} + D_t - T_t. \tag{3}$$

Here, b_t is the real value of bonds, and $\Pi_t := P_t/P_{t-1}$ is the gross inflation rate for marginal consumption. D_t and T_t denote real profits and taxes, in terms of the price for the marginal consumption aggregate.

The usual Euler equation and labor supply schedule hold

$$1 = \mathbb{E}_t \left[\beta \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{R_t}{\Pi_{t+1}} \right],$$
$$\frac{W_t}{P_t} = \chi C_t^{\sigma} N_t^{\varphi}.$$

Consumer price inflation (accounting for both, marginal and inframarginal consumption) based on a Laspeyres-type notion of inflation is given by

$$\Pi_{CPI,t} = \frac{P_{E,t}C_{E,t-1} + P_{G,t}C_{G,t-1}}{P_{E,t-1}C_{E,t-1} + P_{G,t-1}C_{G,t-1}}. \tag{4}$$

2.2 Firms

There is a unit mass of producers of differentiated goods, indexed by $j \in [0,1]$. Differentiated goods in turn are purchased by retailers. Retailers assemble the differentiated goods into tradable consumption goods which they sell in competitive markets at price $P_{G,t}$. Let retailers have the production function

$$Y_{G,t} = \left[\int_0^1 y_{G,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}}.$$

Here $\varepsilon > 0$ is the elasticity of substitution between the different differentiated inputs. The retailer's optimization leads to the conventional demand function

$$y_{G,t}(j) = \left(\frac{P_{G,t}(j)}{P_{G,t}} \right)^{-\varepsilon} Y_{G,t},$$

with $P_{G,t}(j)$ being the price of intermediate good j and $P_{G,t} = \left[\int_0^1 P_{G,t}(j)^{1-\varepsilon} dj \right]^{1/(1-\varepsilon)}$. The producer of a differentiated good j in turn produces its good using labor $N_t(j)$ and energy $E_t(j)$ as inputs. The production function is given by

$$y_{G,t}(j) = \left[\alpha E_t(j)^{\frac{\theta-1}{\theta}} + (1-\alpha) N_t(j)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}.$$

Here, $\alpha \in (0,1)$ marks the input share of energy in production and $\theta > 0$ marks the elasticity of substitution of energy and hours worked in the production of intermediate goods.

Firms face Rotemberg-style price adjustment costs. Let $\psi > 0$ index the extent of the price-adjustment costs and let $\tau \geq 0$ mark a constant subsidy on production. The differentiated goods producer's problem—once imposing symmetry—yields a standard Rotemberg-style New Keynesian Phillips curve

$$\begin{aligned} \psi \Pi_{G,t}(\Pi_{G,t} - 1) = (1+\tau)(1-\varepsilon) + \varepsilon \Lambda_t \left(\frac{P_{G,t}}{P_t}\right)^{-1} \\ + \psi \mathbb{E}_t \left[\beta \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \Pi_{G,t+1}(\Pi_{G,t+1} - 1) \frac{Y_{G,t+1}}{Y_{G,t}} \frac{P_{G,t+1}/P_{t+1}}{P_{G,t}/P_t}\right]. \end{aligned} \quad (5)$$

Above, $\Pi_{G,t} = P_{G,t}/P_{G,t-1}$ is producer-price inflation (here commensurate with core inflation), and Λ_t marks real marginal costs, real in terms of the consumption aggregate, and defined by the following first-order conditions for factor demand

$$\frac{W_t}{P_t} = \Lambda_t (1-\alpha) \left(\frac{Y_{G,t}}{N_t}\right)^{\frac{1}{\theta}},$$

$$\frac{P_{E,t}}{P_t} = \Lambda_t \alpha \left(\frac{Y_{G,t}}{E_t}\right)^{\frac{1}{\theta}}.$$

Alternatively, and equivalently, factor shares are given by

$$\frac{W_t}{P_{E,t}} = \frac{1-\alpha}{\alpha} \left(\frac{E_t}{N_t}\right)^{1/\theta}.$$

And real marginal costs are given by

$$\Lambda_t = \left[\alpha^\theta \left(\frac{P_{E,t}}{P_t}\right)^{1-\theta} + (1-\alpha)^\theta \left(\frac{W_t}{P_t}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}. \quad (6)$$

From this define an index of inflation of nominal marginal costs (an input-price index) as

$$\Pi_{\mathrm{nmc,t}} = \Pi_t \Lambda_t / \Lambda_{t-1}. \tag{7}$$

The firm sector's real profits are given by

$$D_t = (1+\tau)\frac{P_{G,t}}{P_t} Y_t - \frac{W_t}{P_t} N_t - \frac{P_{E,t}}{P_t} E_t.$$

2.3 Fiscal and monetary policy

We assume that fiscal policy is Ricardian. Without loss of generality we, thus, abstract from government debt. This means that all debt is issued and held within the domestic household sector. The government budget is balanced period by period, so that

$$T_t = \tau \frac{P_{G,t}}{P_t} Y_{G,t}.$$

That is, taxes on households finance the production subsidy.

We assume that the central bank sets the gross interest rate R_t on nominal debt according to a Taylor rule. In the baseline, the Taylor rule responds to core inflation

$$R_t = \bar{R} \left(\Pi_{G,t}\right)^{\phi_\Pi} \text{ with } \phi_\Pi > 0, \bar{R} = 1/\beta.$$

However, we consider other target indices below as well. Recall that the so-called "Taylor-principle" asserts that $\phi_\Pi > 1$ would ensure a unique bounded equilibrium irrespective of what rate of inflation the central bank responds to.

2.4 Energy supply and international trade

In keeping with the change in the energy-supply paradigm that we mentioned as a motivation of the paper, we assume that the amount of energy that is supplied by Foreign is entirely exogenous. That is, let the *quantity* of energy supplied be given and denoted by $\xi_{E,t} > 0$. Unless noted otherwise later one, we shall assume that energy supply is constant, $\xi_{E,t} = \xi_E$. This amount of energy is sold in the Home market for the prevailing price of energy, $P_{E,t}$. Instant settlement means that trade is balanced period by period, namely

$$P_{E,t}\xi_{E,t} = P_{G,t}X_{G,t},$$

where $X_{G,t}$ are the exports that pay for the energy imports.

2.5 Market clearing

In equilibrium, all markets need to clear. Financial markets clear if bonds are in zero net supply, $B_t = 0$. The notation above already anticipated labor market clearing, such that labor demanded by producers of differentiated goods is met by the supply of labor from households. Using the symmetry of producers, goods markets clear if

$$Y_{G,t} = C_{G,t} + X_{G,t} + \frac{\psi}{2}\left(\Pi_{G,t} - 1\right)^2 Y_{G,t}.$$

The first term is domestic demand for consumption, the second term are exports and the final term are price adjustment costs. The energy market clears if

$$\xi_{E,t} = C_{E,t} + E_t,$$

that is, if all energy supplied by Foreign is consumed by households in Home or used in Home's production of goods. Finally, real gross domestic product GDP_t is defined as consumption plus net exports, that is, $\text{GDP}_t = \frac{P_{G,t}}{P_t}C_{G,t} + \frac{P_{E,t}}{P_t}C_{E,t} + \frac{P_{G,t}}{P_t}X_{G,t} - \frac{P_{E,t}}{P_t}\xi_{E,t}$, which boils down to

$$\text{GDP}_t = \frac{P_{G,t}}{P_t}C_{G,t} + \frac{P_{E,t}}{P_t}C_{E,t}. \tag{8}$$

3 Pencil-and-paper intuition

This section provides approximate closed-form pencil-and-paper solutions for a special case of the model. The derivations provide the source of the indeterminacy and the factors that drive the indeterminacy. Indeterminacy arises from a source of demand for goods that is not as interest-sensitive as domestic absorption. For the latter source to matter, the share of energy in production needs to be large enough, the prices of non-energy goods have to be sufficiently rigid, and households need to be sufficiently unwilling to substitute consumption over time.

Parametric assumptions for the pencil-and-paper case. For this section, we suppose that energy is used in production only. That is, we look at the case $\gamma \to 0$ and $\bar{e} \to 0$. This also means that core and headline inflation are identical. We make a few more assumptions so as to simplify the exposition still further. Namely, production subsidies are used to render the steady state efficient and energy supply is fixed at $\xi_E = 1$. Next, we assume that the scaling parameter of the disutility of work, χ, is such that in the steady state the labor supply equals unity. Last, we look at the limit $\beta \to 1$.

Steady state for the pencil-and-paper case. We focus on a zero-inflation steady state. Let a bar mark steady-state values. Steady-state inflation is given by $\overline{\Pi} = 1$, the steady-state gross nominal interest by $\overline{R} = 1/\beta$, and steady-state hours worked by $\overline{N} = 1$. Steady-state production is given by $\bar{Y}_G = 1$, steady-state marginal costs by $\overline{\Lambda} = 1$, and steady-state consumption in Home is $\overline{C} = (1-\alpha)$. Let $q_t := P_{E,t}/P_t$ be the real price of energy and let $w_t := W_t/P_t$ be the real wage. In the steady state, $\overline{q} = \alpha$, and $\overline{w} = (1-\alpha)$. Parameter α, thus, marks the equilibrium share of energy in production.

Linearized equilibrium dynamics. Let a hat mark percentage deviations of a variable from the steady state outlined above. The following system of seven equations in seven unknowns describes the evolution of the economy up to a first-order approximation around the steady state. The consumption Euler equation (after substituting the central bank's Taylor rule) gives $-\sigma\widehat{C}_t = -\sigma\mathbb{E}_t\widehat{C}_{t+1} + \left[\phi_\Pi\widehat{\Pi}_t - \mathbb{E}_t\widehat{\Pi}_{t+1}\right]$. The household's labor supply first-order condition gives $\widehat{w}_t = \varphi\widehat{N}_t + \sigma\widehat{C}_t$. The Phillips curve gives $\psi\widehat{\Pi}_t = \psi\beta\mathbb{E}_t\widehat{\Pi}_{t+1} + \epsilon\widehat{\Lambda}_t$. The firms' first-order conditions for factor inputs give $\widehat{w}_t = \widehat{\Lambda}_t + \frac{1}{\theta}[\widehat{Y}_{G,t} - \widehat{N}_t]$, and $\widehat{q}_t =$

$\widehat{\Lambda}_t + \frac{1}{\theta}\widehat{Y}_{G,t}$, where we have already used that energy is in fixed supply.

Goods-market clearing and energy-market clearing imply $\widehat{Y}_{G,t} = (1-\alpha)\widehat{C}_t + \alpha\widehat{q}_t$. Last, the production function implies $\widehat{Y}_{G,t} = (1-\alpha)\widehat{N}_t$.

Simplifying. Consolidating the IS equation and the goods-market clearing condition, we have

$$\widehat{Y}_{G,t} - \alpha\widehat{q}_t = \mathbb{E}_t\widehat{Y}_{G,t+1} - \alpha\mathbb{E}_t\widehat{q}_{t+1} - \frac{(1-\alpha)}{\sigma}\left[\phi_\Pi\widehat{\Pi}_t - \mathbb{E}_t\widehat{\Pi}_{t+1}\right]$$

Combining labor demand and supply as well as the goods-market clearing condition, one can further show that marginal costs are given by

$$\widehat{\Lambda}_t = \left[\frac{1}{1-\alpha}\left[\varphi + \sigma + 1/\theta\right] - \frac{1}{\theta}\right]\widehat{Y}_{G,t} - \frac{\sigma\alpha}{1-\alpha}\widehat{q}_t.$$

Since at the same time, the energy-demand equation of firms gives

$$\widehat{\Lambda}_t = -\frac{1}{\theta}\widehat{Y}_{G,t} + \widehat{q}_t,$$

we have that the equilibrium price of energy is given by

$$\widehat{q}_t = \frac{\varphi + \sigma + \frac{1}{\theta}}{(1-\alpha) + \sigma\alpha}\widehat{Y}_{G,t}.$$

That is, the energy price is the more elastic to output, the less substitutable energy is as an input (the smaller θ) and the less elastic labor supply is (the larger φ). With this, marginal costs are given by

$$\widehat{\Lambda}_t = \frac{\varphi + \frac{\alpha}{\theta} + \sigma\left[1 - \frac{\alpha}{\theta}\right]}{(1-\alpha) + \sigma\alpha}\widehat{Y}_{G,t}.$$

Combining all this, we have the following **IS-equation and Phillips curve**:

$$\widehat{Y}_{G,t} = \mathbb{E}_t \widehat{Y}_{G,t+1} - \frac{1}{\widetilde{\sigma}} \left[\phi_\Pi \widehat{\Pi}_t - \mathbb{E}_t \widehat{\Pi}_{t+1} \right], \qquad \text{with } \frac{1}{\widetilde{\sigma}} := \frac{1-\alpha}{\sigma} \frac{(1-\alpha)+\sigma\alpha}{(1-\alpha) - \alpha\left[\varphi + \frac{1}{\theta}\right]}, \tag{9}$$

$$\widehat{\Pi}_t = \beta \mathbb{E}_t \widehat{\Pi}_{t+1} + \widetilde{\kappa} \widehat{Y}_{G,t}, \qquad \text{with } \widetilde{\kappa} := \frac{\epsilon}{\psi} \frac{\varphi + \frac{\alpha}{\theta} + \sigma\left[1 - \frac{\alpha}{\theta}\right]}{(1-\alpha)+\sigma\alpha}. \tag{10}$$

The two equations (9) and (10) summarize the evolution of output and inflation. This means that the analysis of (in)determinacy can conceptually follow standard lines. This gives us the following proposition.

Proposition 1. ***Determinacy with energy use in production only.***

Consider the model of Section 2 with the parametric assumptions laid out earlier in the current section. The following two cases summarize the conditions for determinacy.

1) If $\widetilde{\sigma}$ and $\widetilde{\kappa}$ have the same sign, there is local determinacy if and only if $\phi_\Pi > 1$.

2) if $\widetilde{\sigma} < 0$ and $\widetilde{\kappa} > 0$, there is local determinacy if and only if

$$\phi_\Pi > \max\left(1, -4\frac{\widetilde{\sigma}}{\widetilde{\kappa}} - 1\right).$$

Proof. The proof is provided in Appendix A and is entirely standard. It follows the well-known lines of proof of (in)determinacy for the three-equation New Keynesian model, such as the one in Woodford (2003, p. 670 ff). There are cases 1) and 2) only since $\widetilde{\kappa}$ can be negative only if $\widetilde{\sigma}$ is negative as well. □

The proposition shows that obeying the standard Taylor principle ($\phi_\Pi > 1$) may not be sufficient to ensure determinacy. This is the case if $\widetilde{\sigma} < 0$, $\widetilde{\kappa} > 0$ and $|\widetilde{\sigma}/\widetilde{\kappa}|$ is large. The following corollary clarifies the conditions under which this can be the case.

Corollary 1. *Consider the same conditions as in Proposition 1. Suppose further that $\alpha = \theta$, that is that the weight of energy in production equals the elasticity of substitution between energy and labor. Then the lower bound on ϕ_Π that ensures indeterminacy will* *be higher than suggested by the Taylor principle if*

$$1 > \frac{1}{2}\frac{\epsilon/\psi}{\sigma}\frac{1-\alpha}{\alpha},$$

that is, if the Phillips curve absent energy-price feedback is sufficiently flat, if households are sufficiently unwilling to substitute intertemporally, and if energy inputs are a sufficiently important cost factor in production [and, since $\alpha = \theta$, if energy is sufficiently hard to substitute].

Proof. Follows directly from the inspection of case 2) of the earlier proposition. □

In sum, in an environment with limits to energy supply, a central bank that seeks to uniquely anchor expectations may need to react more strongly to inflation than is envisaged by the Taylor principle. The extent to which these concerns might matter in practice is a quantitative question. We turn to this next.

4 Implications for monetary policy

This section first calibrates the model to a stylized euro area. The calibrated baseline shows indeterminacy although the monetary response satisfies the Taylor principle. That is, the energy-price-activity feedback loop emerges. With the calibrated model baseline at hand, we explore how different policy choices by the central bank policy shape the (in)determinacy.

4.1 Calibration

The model is calibrated to a stylized euro area. One period is taken to be a quarter. We jointly calibrate several parameters to meet energy-related ratios in the national accounts. The calibration focuses only on the portion of energy that is imported. All the remaining parameters are taken from the literature.

4.1.1 Calibrated parameters

Table 1 gives the calibrated parameters for the model's baseline. We set time preferences

Table 1 Parameters of the baseline calibration

Parameter	Value	Description
Preferences		
β	0.99	Discount factor.
σ	2	Inverse of intertemporal elasticity of substitution.
χ	0.94	Disutility of labour supply.
φ	2	Inverse of Frisch elasticity of labor supply.
$\bar{e}$	0.05	Subsistence level of energy consumption.
γ	0.1	Share of energy expenditures in consumption expenditures.
η	0.1	Elasticity of substitution energy/goods in consumption.
Firms		
ε	11	Elasticity of substitution different varieties of differentiated good.
ψ	188	Price adjustment costs.
α	0.05	Production cost share of energy.
θ	0.04	Elasticity of substitution between energy and labour in production.
Energy supply		
ξ_E	1.19	Steady-state energy supply.
Government		
τ	0.1	Production subsidy.
ϕ_Π	1.25	Response to inflation.

Notes: Parameters of the baseline calibration. See the text for details.

to $\beta = 0.99$, in line with a four-percent real rate of interest in the steady state. The parameter of constant relative risk aversion is set to $\sigma = 2$. This implies a realistic intertemporal elasticity of substitution of consumption of 0.5. We set the scaling parameter in the disutility of work to $\chi = 0.94$ such that steady-state labor supply is normalized to unity. We calibrate $\varphi = 2$ so as to have a Frisch elasticity of labor supply of 0.5, which is within the range of values regularly used in the literature (Chetty et al., 2011).

Turning to the energy-related part of preferences, we set the subsistence level of energy consumption to $\bar{e} = 0.05$, following Fried, Novan and Peterman (2022), and we calibrate $\gamma = 0.1$. We do so with a view towards capturing the share of expenditures for raw energy imports in households' consumption expenditures; this share is roughly one percent, see Bachmann et al. (2022) for Germany or compare Känzig (2022) for the UK. The elasticity of substitution between energy and goods in consumption is $\eta = 0.1$, a value that we take from the literature as well (Bachmann et al., 2022).

Turning to the production sector next, we set the own-price elasticity of demand to $\varepsilon = 11$, a conventional value that implies a ten-percent price markup. The Rotemberg costs of price adjustment, $\psi = 188$ are calibrated to match the slope of the Phillips curve that would arise in a Calvo setting and with an average duration of prices of three quarters, a realistic degree of nominal rigidity in light of Dhyne et al. (2006).

Parameter α, that governs the energy intensity of production, is set to $\alpha = 0.05$. Here we follow Bachmann et al. (2022) and Fried, Novan and Peterman (2022) with an eye toward matching the share of energy expenses in production costs. We set the elasticity of substitution between energy and labor input in production to $\theta = 0.04$, a value that is in line with the estimates reported in Bachmann et al. (2022), but at the lower end of the values entertained in the literature. The elasticity of substitution within production is a crucial parameter, of course. The parameter here is to be understood as a short-run elasticity.

We target a steady state in which we normalize the supply of energy, ξ_E, so that firms' energy usage takes on a value of unity. This is just a normalization. It makes sure that output is unity in steady state and that we can directly interpret α as the energy share of production.

Last, it remains to specify the parameters that relate to the government's policies. We set $\tau = 0.1$ so that—in the steady state—the production subsidy undoes the distortion of production associated with firms' market power. Next, unless specified otherwise, we look at a monetary response of to inflation of $\phi_\Pi = 1.25$. This value is in the range of parameter values that the literature tends to use, for example Blanchard and Riggi (2013).

4.1.2 Implied steady state

Table 2 reports on the steady state associated with this parametrization. In the steady state, households spend one percent of their expenditures for consumption on raw energy, as targeted. Similarly, the cost-share of energy in output is five percent, again as targeted.

Table 2 Steady state under baseline parametrization

Variable	Value	Description	Variable	Value	Description
Households			Prices		
C	1.06	Consumption	Π	1	CPI inflation
C_E	0.19	Energy consumption	Π_G	1	Producer-price inflation
C_G	0.94	Goods consumption	P_E/P	0.06	Energy price to CPI
N	1	Labour supply	P_G/P	1.11	Goods price to CPI
Production			W/P	1.06	Real wage
Y_G	1	Output	R	1.01	Gross nom. interest
E	1	Energy in production			
D	0.11	Profits			
Λ	1.11	Real marginal costs			
		Implied ratios			
$\frac{P_E C_E}{P_E C_E + P_G C_G}$	0.01	Expenditure share of raw energy in consumption expenditures			
$\frac{P_E E}{P_G Y_G}$	0.05	Energy input in production bill over value of output			
$\frac{P_E \xi_E}{P_G Y_G}$	0.0595	Economy-wide expenditure on energy over value of output			

Notes: steady state that corresponds to the baseline parameters.

These two targets taken together mean that energy imports account for roughly six percent of the value of economy-wide production.

4.2 Results with representative households

With the calibrated model baseline at hand, this section analyzes how central bank policy affects (in)determinacy in an environment with limits to energy supply. Throughout, we focus on the first-order dynamics of the model, after linearizing around a zero-inflation steady state. We first document that the Taylor principle fails in the calibrated model and zoom in on the energy-price-activity feedback loop. Thereafter, we discuss which modifications to the monetary policy reaction function may ensure determinacy. We look at a stronger response to core inflation, a focus on *headline* instead of core consumer prices, a response to the level of output, or an explicit focus on stabilizing marginal costs. The end of this section provides extensive sensitivity analysis, including a discussion of how household heterogeneity would shape the findings.

4.2.1 The Taylor principle does not hold with a response to core inflation

A common prescription for the optimal response of monetary policy to relative price changes is that the central bank should focus on the inflation rates of those goods or services that have sticky prices; see, for example, Aoki (2001). In the current context, this would mean to focus on the inflation rate associated with tradable goods or, "core inflation." This is why we first discuss the scope for indeterminacy when the central bank responds to core inflation $\Pi_{G,t}$.

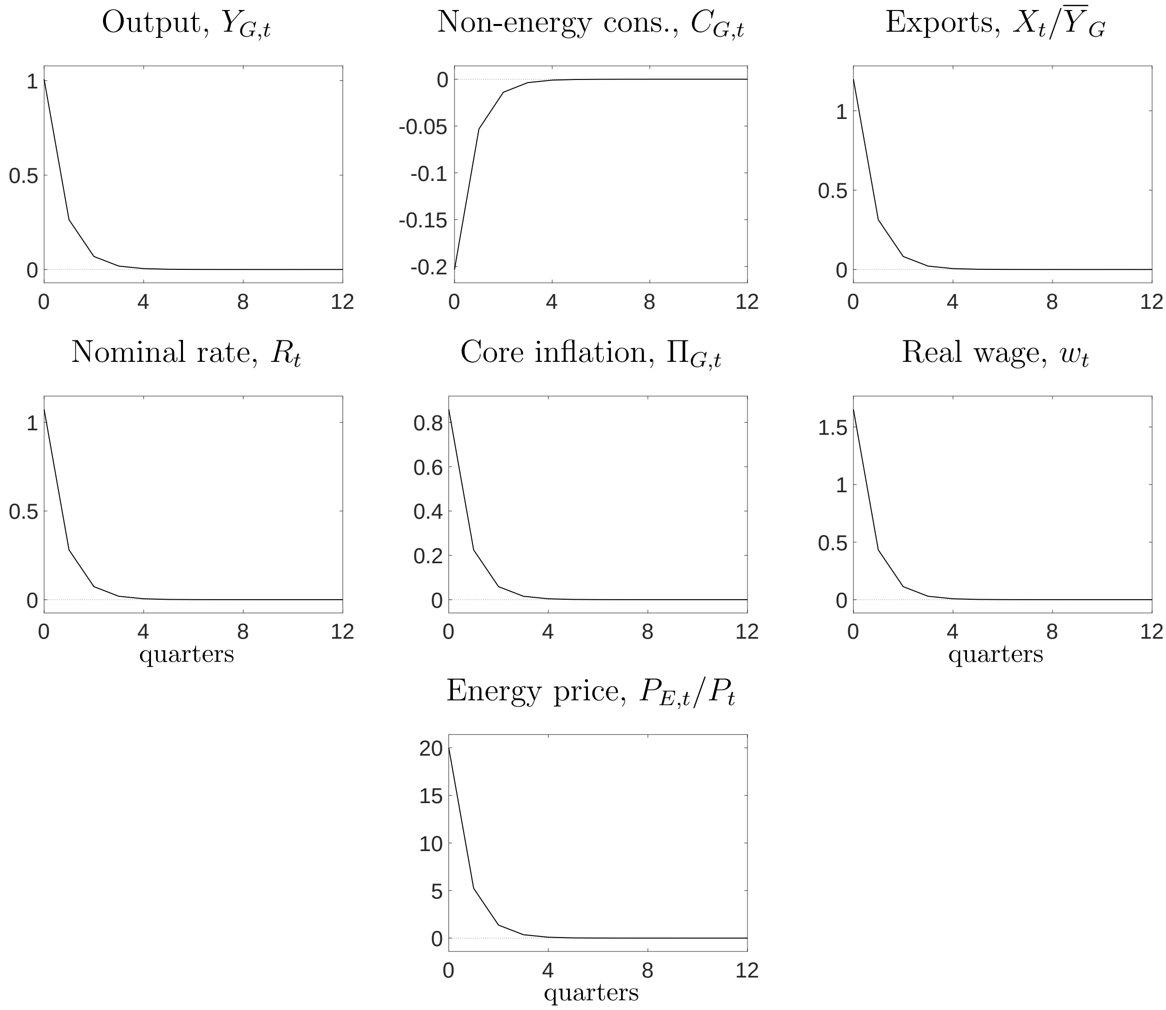
It turns out that for core inflation the Taylor principle is violated resoundingly. Whereas one might think that a more-than-one-to-one response ($\phi_\Pi > 1$) to core inflation suffices to anchor expectations, this is not the case in the scarce-energy environment that we map out here. Instead, there would be determinacy only for a much stronger response to inflation; namely, whenever $\phi_\Pi > 6.18$. This cutoff for determinacy is more than six times as large as prescribed by the Taylor principle. In order to anchor expectations about inflation and economy activity, the central bank would need to lean aggressively against core inflation.[2]

In the baseline model, exactly one explosive root is missing to satisfy the Blanchard-Kahn conditions. In other words, there is exactly one degree of indeterminacy and one possible sunspot shock. So as to see the mechanism at work more clearly, Figure 1 plots impulse responses to this "energy-price sunspot" shock. Theory uniquely pins down the shock's persistence. We anchor the shock's size such that the shock raises energy prices by 20 percent on impact (bottom row, center panel). The impulse responses are computed following the methodology of Bianchi and Nicolò (2021).

Under the sunspot beliefs of higher energy prices, firms face higher marginal costs. Inflation rises (second row, center panel). The central bank raises the interest rate in response (second row, left panel). The real interest rate rises. Consumption of both energy and non-energy goods falls by 0.2 percent (first row, center panel for non-energy goods). Domestic absorption, thus, falls. Nevertheless, output *rises* by 1 percent (first row, left

[2] There also is another small segment that implies determinacy, namely, $\phi_\Pi \in [0, 0.01]$. The pencil-and-paper results did not have this segment by virtue of the assumption in Section 3 that $\beta \to 1$, that is, the assumption that the Phillips curve is vertical in the long run.

Figure 1 Sunspot shock amid targeting core inflation



Notes: Impulse response to a sunspot shock that raises energy prices by 20 percent on impact. The central bank responds to core inflation, with response parameter $\phi_\Pi = 1.25$. Scaling: all response are scaled to give percentage deviations from steady state. The exception is the response of exports (percent of steady-state output). Also, interest rates and inflation rates are in annualized percentage points.

panel). The key to this is that the higher cost of energy goes in hand with rising external demand. External demand rises by a little over one percent of steady-state output (first row, right panel).[3] Since aggregate demand (domestic plus external) rises, labor demand rises, in turn inducing higher real wages (second row, right panel). This makes firms rely on energy even though the energy price increases.

Note that all of this happens even though the central bank raises the real interest rate. Usually, for the closed economy or if energy supply is elastic, the Taylor principle makes sure to invalidate such sunspot beliefs. If energy is in ample supply, the fall in domestic

[3]The panels do not explicitly show the response of GDP (as measured by (8)). GDP falls by about as much as consumption of non-energy goods.

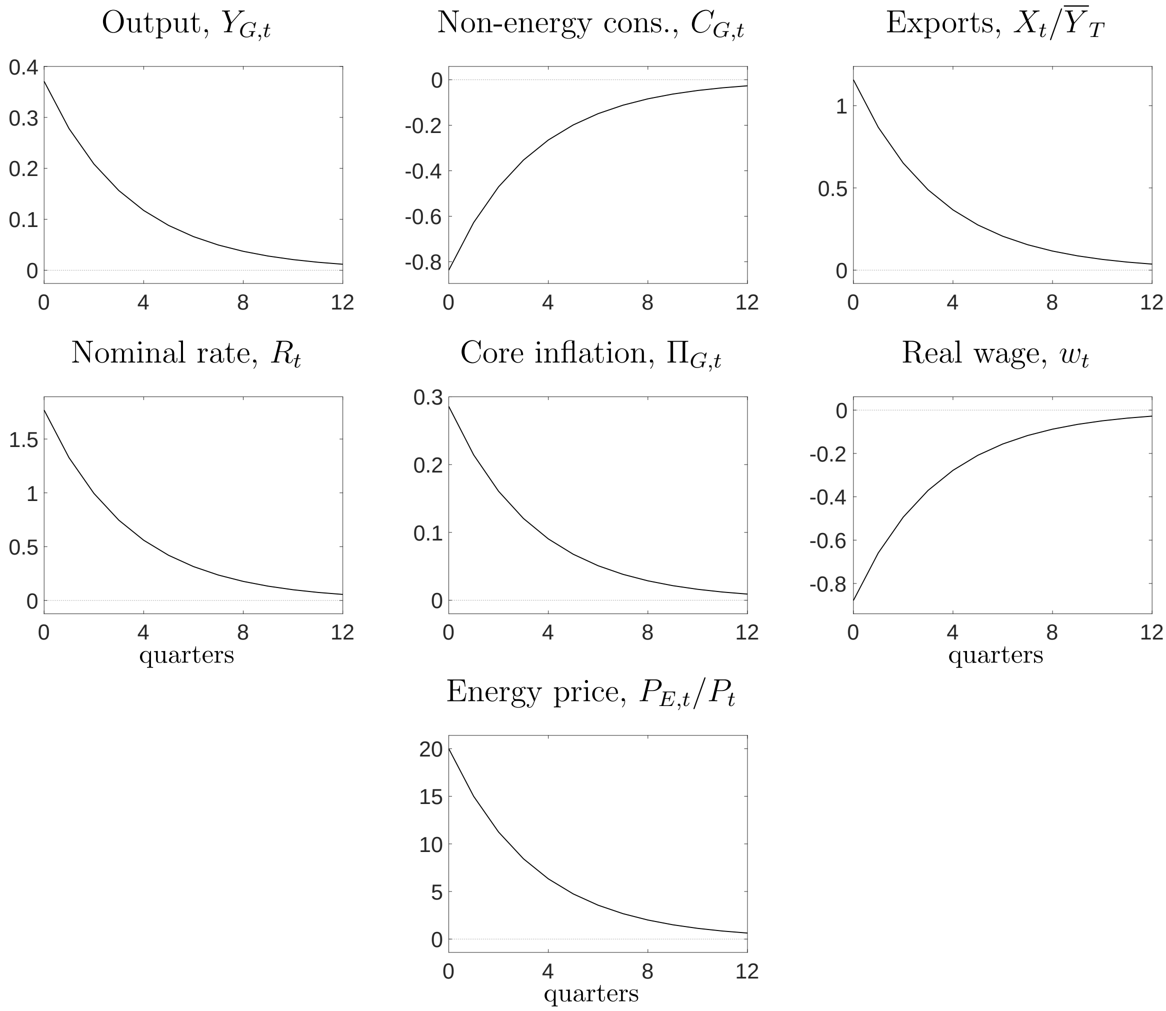
demand is sufficient to dampen total demand. In a scarce-energy scenario, instead, external demand is positively related to energy prices and, thus, to production itself. Thus, while domestic demand falls, external demand (real exports X_t) may still rise, even if monetary policy obeys the Taylor principle.

So as to further highlight the mechanism, Figure 2 plots the economy's response to a persistent negative fundamental energy-supply shock (a different shock than above), when the central bank reacts strongly enough to core inflation to ensure determinacy ($\phi_\Pi = 6.19$, a different policy than above). The figure shows the responses to an autocorrelated fall in energy supply that leads to a 20 percent increase in energy prices. We choose this size of shock to ensure that the price response of energy in the two figures is comparable in size (bottom rows, center panels). The cut in energy supply raises the price of energy. As a result, even though the quantity of energy supplied falls, energy expenditures as a whole rise, and export demand rises (first row, right panel). But now the interest rate (second row, left panel) rises by much more than inflation (second row, center panel), meaning that the real interest rate rises notably more strongly than in Figure 1. What this means is that non-energy consumption falls sharply (and at 0.8 percentage point notably more than in the earlier figure, first row, center panel). The home economy still has to produce more to meet the energy bills, but not nearly as much more as in Figure 1 (compare top rows, left panel). Indeed, in line with the fact that here Home households have notably lower levels of consumption, the real wage falls (second row, right panel; instead of rising).

4.2.2 Responding to alternative measures of inflation

Comparing the scenarios in Figures 1 and 2 suggests that a stronger focus of the central bank on inflation may help anchor expectations and ensure macroeconomic stability. This section looks into the implications for policy in somewhat more detail. First, it discusses targeting headline instead of core inflation. Second, it discusses targeting input prices rather than core or headline consumer prices. Last, it discusses targeting measures of economic activity alongside measures of inflation.

Figure 2 Energy-supply shock under hawkish policy



Notes: Same as Figure 1 but now the source of shock is a persistent cut in energy supply. Responses are calibrated to match a 20 percent increase in the relative energy price. The central bank responds to core inflation, with response parameter $\phi_\Pi = 6.19$. The scaling of the responses is as in Figure 1.

Targeting headline inflation helps ensure determinacy. Common wisdom suggests that central banks best "see through" fluctuations of energy prices and rather focus on stabilizing core inflation. As we showed above, however, this may invite self-fulfilling cyclical fluctuations. The energy-price-activity feedback loop entails a rise in energy prices. Determinacy can be restored by leaning precisely against this rise. If the central bank were to continue to react to core inflation with a weight of $\phi_\Pi = 1.25$ but were also to have an additional weight in the Taylor rule of 0.01 on energy-price inflation $P_{E,t}/P_{E,t-1}$, directly, determinacy would be ensured.

Similarly, headline consumer price inflation includes an additional weight on energy prices, compare (4). Therefore, if the central bank responds to headline inflation, $\Pi_{CPI,t}$, (instead of core inflation) determinacy would prevail already when $\phi_\Pi > 1.02$.[4] In this sense, *not* seeing through fluctuations in energy prices helps avoid the energy-price-activity feedback loop.

Targeting input prices rather than consumer prices helps ensure determinacy. At the core of the energy-price-activity feedback loop lies that economic activity can rise because firms do not fully pass rising costs on to consumers. This suggests that the central bank might as well try to respond to those rising nominal marginal costs directly; namely to input price inflation, (7). Indeed, with such a focus, the determinacy regions are entirely conventional: the Taylor principle is alive and well.

Any response to economic activity needs to be calibrated well. The energy-price-activity loop sees higher energy prices go in hand with higher output (and employment) but lower GDP (since a larger share of value added accrues to Foreign). Consider a central bank that responds to core inflation with the calibrated weight of $\phi_\Pi = 1.25$. Next to this, however, let the central bank respond to a measure of economic activity. The choice of what measure of activity to respond to matters.

A central bank that responds to the level of production (or employment) implicitly leans against the rise in energy prices. The central bank needs to be committed to *raising* the real rate sufficiently much so as to lean against the non-fundamental beliefs (engineering a recession when households anticipated a boom). In our setting, this requires a rather strong response to output; a coefficient on output of at least 0.39. Note that this is notably stronger than under both Taylor (1993) and Taylor (1999) (which have output coefficients of 0.125 and 0.25, respectively).[5]

Alternatively, the central bank may respond to GDP. Since the energy-price sunspot shock lets GDP fall, however, leaning against movements in GDP *stimulate* economic activity

[4] If monetary policy responds to the price change of marginal consumption expenditures, $\Pi_t := P_t/P_{t-1}$ the equilibrium is determinate for any $\phi_\Pi > 1.31$. Note the Π_t has a lower weight for energy prices than $\Pi_{CPI,t}$.

[5] Neither would a response to core inflation of $\phi_\Pi = 1.5$ and the weights on output as in Taylor (1993) or Taylor (1999) ensure determinacy.

(and the energy price) still further. A response to GDP, therefore, further exacerbates the risks to macroeconomic stability.[6]

4.2.3 Sensitivity analysis for the representative-agent baseline

Above, we have argued that an insufficient response of the central bank to fluctuations in the price of energy imports can expose the economy to the risk of sunspot-driven fluctuations. This section probes the results from several angles.

Domestic or foreign supply of energy. For the energy-price-activity feedback loop to arise, it is essential that the beneficiaries of energy price increases are located abroad. To corroborate this, we have looked at the feedback loop between energy prices and economic activity in a closed economy, where all energy is owned by domestic households. Otherwise the economy was identical to the baseline model sketched above. Even under the baseline calibration, the determinacy conditions were entirely conventional again: the Taylor principle held for core or headline inflation alike even though energy is in fixed supply.

The elasticity of energy supply. So far, we have focused on an environment in which energy is scarce and in fixed supply. Next, we relax this assumption. Suppose that energy supply is given by

$$\xi_{E,t} = \left(\frac{P_{E,t}/P_t}{\bar{P}_E/\bar{P}} \right)^{\delta} \xi_E,$$

so that total energy supply $\xi_{E,t}$ is increasing in the relative price of energy $\frac{P_{E,t}/P_t}{\bar{P}_E/\bar{P}}$. $\delta > 0$ marks the price-elasticity of energy supply. For $\delta = 0$, our previous results emerge. For δ sufficiently small, we still obtain that the Taylor principle is insufficient to rule out sunspot dynamics. As δ increases, the energy price responds less to an increase in energy

[6] It should be noted that a response coefficient to GDP above a value of 24 would again ensure determinacy. The mechanism by which the sunspot would be ruled out is entirely different, though. Namely, in this case any expectation of a non-fundamental rise in energy prices/boom in output/rise in inflation would be invalidated by the central bank as it engineers a larger boom/price drift still – up to the point where the path of output or inflation would be explosive.

demand, weakening the sunspot belief's effect on external demand. At some point, this breaks the feedback loop; when energy prices do not increase as much, foreign demand for goods also increases less, allowing for a weaker interest-rate response to engineer the same decline in *overall* demand. For $\delta > 0.005$, in the baseline, the Taylor principle is reestablished even with a response to core inflation.

Sensitivity with respect to parameter choices. Next, we discuss the the sensitivity of our representative-household results toward the specific parametrization. The respective tables are in Appendix B. The results are as follows. The larger the energy-dependence of production is (for a given weight of raw energy in consumption baskets), the larger the risk of indeterminacy; see Table B.1 in the appendix. In light of the fact that the energy-price output feedback loop runs through the firm sector, this may not be entirely surprising. At an energy share of 4.5 percent or below, the determinacy regions are entirely conventional. Above that value, the range of responses to inflation that are insufficient rises rapidly–implying that $\phi_\Pi > 6.18$ is needed for an energy share of five percent, say, and already a response of $\phi_\Pi > 21.94$ for an energy share of 6 percent. Turning this upside down, for a given size of energy imports, the more of these the households use directly in consumption, the less of a concern is indeterminacy; see Table B.2 in the appendix.

Next, the more elastically households or firms can respond to energy price fluctuations, the lower the risk of indeterminacy. Tables B.3 through B.5 illustrate this for $\overline{e}, \eta$, and ω. The larger $\overline{e}$, the larger the share of energy consumption that is entirely price inelastic. Similarly, the determinacy range for $\eta = 0.1$ is $\phi_\Pi > 6.18$. For $\eta = 0.05$, the cutoff more than doubles ($\phi_\Pi > 13.82$). On the firm's side, in turn, the more substitutable energy is, the more convential the determinacy regions. For $\theta > 0.05$, the determinacy regions are conventional. For $\theta = 0.04$, we have the values discussed in the calibrated baseline. For $\theta = 0.03$ determinacy would already require a response of $\phi_\Pi > 17.19$.

The other element that matters for determinacy is the extent to which households are willing to substitute over time. Starting from the baseline calibration, the less willing households are to substitute over time, the larger the range of policy responses for which there is indeterminacy. Going from $\sigma = 2$ to $\sigma = 3$, for example, nearly doubles the required policy responses for determinacy from $\phi_\Pi > 6.18$ to $\phi_\Pi > 11.99$, see Table B.6 in the appendix. *Vice versa* for $\sigma \leq 1$, the determinacy region is entirely conventional again. The Frisch elasticity of labor supply, $1/\varphi$ in turn proved to matter little for the range of policies that induce determinacy, see Table B.7 in the appendix.

Finally, the degree of nominal rigidities in the economy, that is, the size of price adjustment costs ψ, works as expected. First, for close-to-flexible prices, the energy price feedback loop disappears whereas for higher ψ, the Phillips curve flattens and the central bank needs to respond much more aggressively to core inflation to tame self-fulfilling expectations, see Table B.8 in the appendix.

4.3 Results with household heterogeneity

So far, we have worked under the fiction of a representative family that provides full insurance to its member households. Next, we extend the model to tractably allow for household heterogeneity, namely, a role for marginal propensities to consume and precautionary motives. It turns out that this notably strengthens the energy-price-activity feedback loop. The reason is that the feedback loop that we described above comes with higher wage income which will be stimulating domestic demand further when there is household heterogeneity.

More precisely, we embed the two-type-of-household structure of Bilbiie (2021) (a "THANK" model) into our scarce-energy supply environment. Appendix C provides a detailed summary of the resulting model. Here, we provide only a rough overview. The variant models two idiosyncratic states for the household. Households can be savers, S, or hand-to-mouth households, H. Exogenous shocks make households move between these states. Borrowing is ruled out and following Bilbiie (2020), we assume that the savers receive all the profits in the economy.

We refer the reader to Appendix C for a definition of parameters. We amend the calibration of Section 4.1 as follows. In line with the euro-area estimates in Slacalek, Tristani and Violante (2020), we consider a share of hand-to-mouth households of 15 percent

($\lambda = 0.15$) and set the same probability of becoming constrained as does Bilbiie (2020) ($1 - s = 0.04$). Profits are fully allocated to savers ($\tau^d = 0$). This parametrization implies reasonable values for the amplification of monetary policy and the size of indirect effects; see Bilbiie (2020) for details.

There are two reasons why household heterogeneity raises the scope for the energy-price-activity feedback loop. When savers and firms coordinate on non-fundamental beliefs of high energy prices, not only does this entail high output but also will wages rise at the expense of profits. Therefore, first, hand-to-mouth households' consumption increases. They will consume the increase in income, irrespective of the interest-rate increase that the central bank engineers. This accelerates the boom in aggregate demand, amplifying the self-fulfilling dynamics embedded in the model. Second, a household that is unconstrained today (a saver) faces the risk of becoming constrained (hand-to-mouth) tomorrow. The sunspot shock persistently raises wages and reduces profits. The same shock, thus, persistently reduces the gap between savers' income and the income that the hand-to-mouth households have. In other words, the sunspot shock also reduces consumption *risk* for savers. Lower risk means that the natural rate of interest rises, rendering any increase in real rates that the central bank engineers less effective in curbing demand.

The quantitative results are as follows. If the central bank responds to core inflation, only a response as aggressive $\phi_\Pi = 17.15$ or more will ensure determinacy, a cutoff that is three times as high as in the representative-household baseline. Importantly, now the risk of indeterminacy does not fall significantly even if the central bank targets CPI inflation. Here determinacy would require a weight of ϕ_Π above 2.83, a value considerably above "standard" estimates of the monetary response.

At the same time, the strategies that reliably ensured determinacy in the representative household benchmark continue to work well with heterogeneous households, too. For example, a central bank that puts additional weight on energy-price inflation (here a weight on core inflation of 1.25 and on energy price inflation of 0.03 suffices) ensures determinacy. Alternatively, if the central bank responds to input-price inflation, the Taylor principle continues to apply throughout. That is, any response to input-price inflation of $\phi_\Pi > 1$ will suffice. Appendix C provides the counterparts to Figures 1 and 2 for the THANK economy.

What is notable is that the sunspot shock shows much more persistence. Similarly, the rise in inflation is notably stronger with heterogeneous households. For the same rise in energy prices and a rise in output that is comparable to that in the representative-household baseline, inflation now rises by 2.5 percentage points rather than by 0.8 percent. And the effect of the sunspot shock dies out after 12 quarters instead of after three quarters; compare Figure 1 to Figure C.1 in the Appendix.

In this setting, we have also considered the effect of more elastic energy supply or of domestic ownership of the energy source for the heterogeneous-household model. The determinacy regions now normalize when $\delta > 0.02$, that is the energy-price-activity feedback loop would continue to prevail for a larger range of supply elasticities than for representative households. And, as before, with energy supply belonging to domestic households (here: the savers) the self-fulfilling dynamics of energy prices disappear.

5 Conclusions

Energy prices have risen steeply in Europe and, nevertheless, the risk of severe energy shortages remains. This suggests that–at least in the near term– supply is rather inelastic and, instead, the energy price will have to move to clear the energy market. The current paper has explored possible implications of this for the business cycle and monetary policy, in particular. We did so through the lens of a New Keynesian business-cycle model with energy imports.

In the paper's setting, an energy-price-activity feedback loop arises that can give rise to self-fulfilling beliefs about the movement of energy prices, inflation, and economic activity. The channel provides a rationale, why–in a scarce-energy situation such as witnessed today–the central bank may precisely *not* follow the common wisdom to "see through shocks" or to disregard movements in prices that are flexible. Instead, it may rather want to *raise* interest rates if energy prices rise–even if this is recessionary. In the same vein, the central bank may want to precisely focus on headline inflation instead of core, may precisely overweight the energy price in inflation considerations (even though energy prices are flexible), or may more actively seek to curb economic activity even if the gross domestic product has fallen already.

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A Proof of the proposition

This appendix provides the proof to the proposition in the main text. The proof is straightforward and the steps well-known in the New Keynesian literature.
The model is given by equations (9) and (10), repeated here for convenience.

$$\widehat{Y}_{G,t} = \mathbb{E}_t \widehat{Y}_{G,t+1} - \frac{1}{\widetilde{\sigma}} \left[\phi_\Pi \widehat{\Pi}_t - \mathbb{E}_t \widehat{\Pi}_{t+1} \right], \qquad \text{with } \frac{1}{\widetilde{\sigma}} := \frac{1-\alpha}{\sigma} \frac{(1-\alpha)+\sigma\alpha}{(1-\alpha)-\alpha\left[\varphi + \frac{1}{\theta}\right]}, \tag{11}$$

$$\widehat{\Pi}_t = \beta \mathbb{E}_t \widehat{\Pi}_{t+1} + \widetilde{\kappa} \widehat{Y}_{G,t}, \qquad \text{with } \widetilde{\kappa} := \frac{\epsilon}{\psi} \frac{\varphi + \frac{\alpha}{\theta} + \sigma\left[1 - \frac{\alpha}{\theta}\right]}{(1-\alpha)+\sigma\alpha}. \tag{12}$$

The proposition states the importance of the signs of $\widetilde{\sigma}$ and $\widetilde{\kappa}$ which are determined by

$$\operatorname{sgn} \widetilde{\sigma} = \operatorname{sgn} \frac{\sigma\left(1-\alpha-\alpha(\varphi+1/\theta)\right)}{(1-\alpha)(1-\alpha+\alpha\sigma)} = \operatorname{sgn}\left(1-\alpha-\alpha\varphi-\frac{\alpha}{\theta}\right),$$

$$\operatorname{sgn} \widetilde{\kappa} = \operatorname{sgn} \frac{\epsilon}{\psi} \frac{\varphi + \frac{\alpha}{\theta} + \sigma\left[1-\frac{\alpha}{\theta}\right]}{(1-\alpha)+\sigma\alpha} = \operatorname{sgn}\left(\varphi + \frac{\alpha}{\theta} + \sigma\left[1-\frac{\alpha}{\theta}\right]\right),$$

or

$$\widetilde{\sigma} > 0 \qquad \longleftrightarrow \qquad 1 - \frac{\alpha}{\theta} > \alpha(1+\varphi),$$

$$\widetilde{\kappa} > 0 \qquad \longleftrightarrow \qquad 1 - \frac{\alpha}{\theta} > -\frac{1}{\sigma}\left(\varphi + \frac{\alpha}{\theta}\right),$$

where $\alpha(1+\varphi) > 0$ and $-\frac{1}{\sigma}\left(\varphi + \frac{\alpha}{\theta}\right) < 0$. Hence, whenever $\widetilde{\sigma} > 0$, also $\widetilde{\kappa} > 0$. For $\widetilde{\sigma} < 0$, we can still have either $\widetilde{\kappa} > 0$ or $\widetilde{\kappa} < 0$.
Write the model in Blanchard and Kahn (1980) form:

$$\begin{bmatrix} 1 & 1/\widetilde{\sigma} \\ 0 & \beta \end{bmatrix} \mathbb{E}_t \begin{bmatrix} \widehat{Y}_{G,t+1} \\ \widehat{\Pi}_{t+1} \end{bmatrix} = \begin{bmatrix} 1 & \phi_\Pi/\widetilde{\sigma} \\ -\widetilde{\kappa} & 1 \end{bmatrix} \begin{bmatrix} \widehat{Y}_{G,t} \\ \widehat{\Pi}_t \end{bmatrix}$$

or, alternatively

$$\mathbb{E}_t \begin{bmatrix} \widehat{Y}_{G,t+1} \\ \widehat{\Pi}_{t+1} \end{bmatrix} = \underbrace{\frac{1}{\beta} \begin{bmatrix} \beta + \frac{\widetilde{\kappa}}{\widetilde{\sigma}} & \beta\phi_\Pi/\widetilde{\sigma} - \frac{1}{\widetilde{\sigma}} \\ -\widetilde{\kappa} & 1 \end{bmatrix}}_{:=A} \begin{bmatrix} \widehat{Y}_{G,t} \\ \widehat{\Pi}_t \end{bmatrix}$$

There are two nonpredetermined variables. So there will always be bounded equilibria. There is a locally unique bounded equilibrium iff either (cf. Woodford, 2003, p. 670):
Case a): $det(A) > 1$, $det(A) - tr(A) > -1$ and $det(A) + tr(A) > -1$, or
Case b): $det(A) < 1$, $det(A) - tr(A) < -1$ and $det(A) + tr(A) < -1$.
Here, $det(A) = \left[\frac{1}{\beta} + \frac{\phi_\Pi}{\beta}\frac{\widetilde{\kappa}}{\widetilde{\sigma}}\right]$ and $tr(A) = \left[1 + \frac{1}{\beta} + \frac{1}{\beta}\frac{\widetilde{\kappa}}{\widetilde{\sigma}}\right]$.

Proof of the proposition's item 1). Suppose that $\widetilde{\sigma} > 0$ and $\widetilde{\kappa} > 0$. Then the determinacy conditions are as in the standard closed-economy New Keynesian model. More in detail, $det(A) > 1$ and $tr(A) > 0$, so that Case a) applies. The condition that may bind is $det(A) - tr(A) > -1$, which leads to the conventional determinacy condition $\phi_\Pi > 1$.

Proof of the proposition's item 1) c'td. Suppose that $\widetilde{\sigma} < 0$ and $\widetilde{\kappa} < 0$. Again, in this case $det(A) > 1$ for any $\phi_\Pi > 0$. Thus, we need to check Case a) again. $tr(A) > 0$, so that $det(A) + tr(A) > -1$ always. So, what we need for determinacy is $det(A) - tr(A) > -1$. Or, equivalently $\left[\frac{1}{\beta} + \frac{\phi_\Pi}{\beta}\frac{\widetilde{\kappa}}{\widetilde{\sigma}}\right] - \left[1 + \frac{1}{\beta} + \frac{1}{\beta}\frac{\widetilde{\kappa}}{\widetilde{\sigma}}\right] = \frac{1}{\beta}\frac{\widetilde{\kappa}}{\widetilde{\sigma}}[\phi_\Pi - 1] - 1 > -1$, or, once more, $\phi_\Pi > 1$.

Proof of the proposition's item 2). By assumption for this case, $\tilde{\sigma} < 0, \tilde{\kappa} > 0$. In this case, *two* determinacy regions can arise.
Focus on the set of conditions for case a) first. $det(A) = \left[\frac{1}{\beta} + \frac{\phi_\Pi}{\beta}\frac{\widetilde{\kappa}}{\widetilde{\sigma}}\right] > 1$ can be achieved by setting $\phi_\Pi < \frac{\widetilde{\sigma}}{\widetilde{\kappa}}(\beta - 1)$, where $\frac{\widetilde{\sigma}}{\widetilde{\kappa}}(\beta - 1) > 0$ since $\frac{\widetilde{\sigma}}{\widetilde{\kappa}} < 0$. The second condition can be achieved by setting $\phi_\Pi < 1$. Finally, the third condition can be achieved by setting $\phi_\Pi < -2(1+\beta)\frac{\widetilde{\sigma}}{\widetilde{\kappa}} - 1$. Hence, in sum, this determinacy region exists if there is a $\phi_\Pi \geq 0$ such that

$$\phi_\Pi < \min\left(\frac{\widetilde{\sigma}}{\widetilde{\kappa}}(\beta - 1),\ 1,\ -2(1+\beta)\frac{\widetilde{\sigma}}{\widetilde{\kappa}} - 1\right)$$

Importantly, for $\beta \to 1$, this determinacy region disappears.
Focus on the set of conditions for case b) next. $det(A) < 1$ can be achieved for $\phi_\Pi \geq 0$ since $\frac{\widetilde{\sigma}}{\widetilde{\kappa}} < 0$. For $det(A) - tr(A) < -1$, we need $\frac{1}{\beta}\frac{\widetilde{\kappa}}{\widetilde{\sigma}}[\phi_\Pi - 1] - 1 < -1$, meaning $\phi_\Pi > 1$. For $det(A) + tr(A) < -1$, we need $1 + \frac{2}{\beta} + \frac{1}{\beta}\frac{\widetilde{\kappa}}{\widetilde{\sigma}}(\phi_\Pi + 1) < -1$, meaning $\phi_\Pi > -2(1+\beta)\frac{\widetilde{\sigma}}{\widetilde{\kappa}} - 1$. So that both $det(A) \pm tr(A) < -1$, therefore we need

$$\phi_\pi > \max\left(1, -2(1+\beta)\frac{\widetilde{\sigma}}{\widetilde{\kappa}} - 1\right),$$

or for $\beta \to 1$, $\phi_\pi > \max(1, -4\widetilde{\sigma}/\widetilde{\kappa} - 1)$.

□

B Representative-household model: Sensitivity with respect to parameter choices

This appendix collects results on the sensitivity of the determinacy cutoffs for different parameterizations of the baseline representative household model.

Table B.1 Sensitivity: targeted steady-state energy share of production, $\frac{P_E E}{P_G Y_G}$

	Steady State							Determinacy	
	ξ_E	$\frac{P_E}{P}$	$\frac{P_G}{P}$	C	C_E	C_G	W	$\phi_\Pi <$	$\phi_\Pi >$
0.001	.	.	.	.	.	.	.	.	.
0.005	2.99	0.01	2.33	2.31	1.99	0.99	2.32	.	1
0.01	1.99	0.02	1.67	1.66	0.99	0.98	1.66	.	1
0.015	1.66	0.02	1.45	1.43	0.66	0.98	1.43	.	1
0.02	1.49	0.03	1.33	1.3	0.49	0.97	1.31	.	1
0.025	1.39	0.03	1.26	1.23	0.39	0.97	1.23	.	1
0.03	1.32	0.04	1.21	1.18	0.32	0.96	1.18	.	1
0.035	1.28	0.04	1.18	1.14	0.28	0.96	1.14	.	1
0.04	1.24	0.05	1.15	1.1	0.24	0.95	1.11	.	1
0.045	1.21	0.05	1.13	1.08	0.21	0.95	1.08	.	1
0.05	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.18
0.055	1.17	0.06	1.1	1.04	0.17	0.94	1.04	0.03	13.59
0.06	1.16	0.07	1.09	1.02	0.16	0.93	1.02	0.05	21.94
0.065	1.14	0.07	1.08	1	0.14	0.93	1.01	0.08	.
0.07	1.13	0.07	1.07	0.99	0.13	0.92	0.99	0.1	.
0.075	1.12	0.08	1.06	0.98	0.12	0.92	0.98	0.13	.
0.08	1.12	0.08	1.06	0.97	0.12	0.91	0.97	0.17	.
0.085	1.11	0.09	1.05	0.96	0.11	0.91	0.96	0.21	.
0.09	1.1	0.09	1.04	0.95	0.1	0.9	0.95	0.26	.
0.095	1.1	0.1	1.04	0.94	0.1	0.9	0.94	0.32	.
0.1	1.09	0.1	1.03	0.93	0.09	0.89	0.93	0.39	.

Notes: each row represents one variation of the parameter mentioned in caption; first, the new steady state is computed; next, the determinacy regions for PPI targeting are computed: the column $\phi_\Pi <$ shows the upper bound of a potential determinacy region ϕ_Π below this value, the column $\phi_\Pi >$ shows the lower bound of a potential determinacy region ϕ_Π above this value.

Table B.2 Sensitivity: targeted steady-state energy share of consumption, $\frac{P_E C_E}{P_E C_E + P_G C_G}$

	Steady State							Determinacy	
	ξ_E	$\frac{P_E}{P}$	$\frac{P_G}{P}$	C	C_E	C_G	W	$\phi_\Pi <$	$\phi_\Pi >$
0.001	1.02	0.05	0.97	0.92	0.02	0.95	0.93	0.08	.
0.005	1.1	0.05	1.04	0.98	0.09	0.95	0.98	0.04	16.62
0.01	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.18
0.015	1.29	0.06	1.19	1.13	0.29	0.94	1.13	0	1
0.02	1.38	0.06	1.27	1.2	0.38	0.93	1.21	.	1
0.025	1.48	0.07	1.35	1.28	0.48	0.93	1.28	.	1
0.03	1.57	0.07	1.43	1.35	0.57	0.92	1.36	.	1
0.035	1.67	0.08	1.51	1.43	0.67	0.92	1.43	.	1
0.04	1.76	0.08	1.59	1.51	0.76	0.91	1.51	.	1
0.045	1.86	0.08	1.67	1.58	0.86	0.91	1.59	.	1
0.05	1.95	0.09	1.75	1.66	0.95	0.9	1.66	.	1
0.055	2.05	0.09	1.83	1.74	1.05	0.9	1.74	.	1
0.06	2.14	0.1	1.92	1.82	1.14	0.89	1.82	.	1
0.065	2.23	0.1	2	1.89	1.24	0.89	1.9	.	1
0.07	2.33	0.1	2.08	1.97	1.33	0.88	1.98	.	1
0.075	2.43	0.11	2.16	2.05	1.43	0.88	2.06	.	1
0.08	2.52	0.11	2.25	2.13	1.52	0.87	2.13	.	1
0.085	2.62	0.12	2.33	2.21	1.61	0.87	2.21	.	1
0.09	2.71	0.12	2.41	2.29	1.71	0.86	2.29	.	1
0.095	2.81	0.12	2.5	2.37	1.81	0.86	2.37	.	1
0.1	2.9	0.13	2.58	2.45	1.9	0.86	2.45	.	1

Notes: each row represents one variation of the parameter mentioned in caption; first, the new steady state is computed; next, the determinacy regions for PPI targeting are computed: the column $\phi_\Pi <$ shows the upper bound of a potential determinacy region ϕ_Π below this value, the column $\phi_\Pi >$ shows the lower bound of a potential determinacy region ϕ_Π above this value.

Table B.3 Sensitivity: subsistence level of energy consumption, $\bar{e}$

	Steady State							Determinacy	
	ξ_E	$\frac{P_E}{P}$	$\frac{P_G}{P}$	C	C_E	C_G	W	$\phi_\Pi <$	$\phi_\Pi >$
0	1.19	0.06	1.15	1.1	0.19	0.94	1.1	0	1
0.01	1.19	0.06	1.15	1.09	0.19	0.94	1.09	0	1.61
0.02	1.19	0.06	1.14	1.08	0.19	0.94	1.08	0	2.65
0.03	1.19	0.06	1.13	1.07	0.19	0.94	1.07	0.01	3.75
0.04	1.19	0.06	1.12	1.06	0.19	0.94	1.07	0.01	4.93
0.05	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.18
0.06	1.19	0.06	1.11	1.05	0.19	0.94	1.05	0.02	7.53
0.07	1.19	0.05	1.1	1.04	0.19	0.94	1.04	0.02	8.97
0.08	1.19	0.05	1.09	1.03	0.19	0.94	1.04	0.02	10.51
0.09	1.19	0.05	1.08	1.02	0.19	0.94	1.03	0.03	12.18
0.1	1.19	0.05	1.07	1.01	0.19	0.94	1.02	0.03	13.99

Notes: each row represents one variation of the parameter mentioned in caption; first, the new steady state is computed; next, the determinacy regions for PPI targeting are computed: the column $\phi_\Pi <$ shows the upper bound of a potential determinacy region ϕ_Π below this value, the column $\phi_\Pi >$ shows the lower bound of a potential determinacy region ϕ_Π above this value.

Table B.4 Sensitivity: households' elasticity of substitution between energy and goods, η

	Steady State							Determinacy	
	ξ_E	$\frac{P_E}{P}$	$\frac{P_G}{P}$	C	C_E	C_G	W	$\phi_\Pi <$	$\phi_\Pi >$
0.02	1.19	0.06	1.13	1.08	0.19	0.94	1.08	0.05	19.85
0.03	1.19	0.06	1.13	1.07	0.19	0.94	1.08	0.04	17.69
0.04	1.19	0.06	1.13	1.07	0.19	0.94	1.07	0.04	15.68
0.05	1.19	0.06	1.13	1.07	0.19	0.94	1.07	0.03	13.82
0.06	1.19	0.06	1.12	1.06	0.19	0.94	1.07	0.03	12.08
0.07	1.19	0.06	1.12	1.06	0.19	0.94	1.07	0.02	10.46
0.08	1.19	0.06	1.12	1.06	0.19	0.94	1.06	0.02	8.94
0.09	1.19	0.06	1.12	1.06	0.19	0.94	1.06	0.02	7.52
0.1	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.18
0.2	1.19	0.05	1.09	1.04	0.19	0.94	1.04	.	1
0.3	1.19	0.05	1.08	1.02	0.19	0.94	1.02	.	1
0.4	1.19	0.05	1.06	1.01	0.19	0.94	1.01	.	1
0.5	1.19	0.05	1.05	1	0.19	0.94	1	.	1
0.6	1.19	0.05	1.04	0.99	0.19	0.94	0.99	.	1
0.7	1.19	0.05	1.04	0.98	0.19	0.94	0.98	.	1

Notes: each row represents one variation of the parameter mentioned in caption; first, the new steady state is computed; next, the determinacy regions for PPI targeting are computed: the column $\phi_\Pi <$ shows the upper bound of a potential determinacy region ϕ_Π below this value, the column $\phi_\Pi >$ shows the lower bound of a potential determinacy region ϕ_Π above this value.

Table B.5 Sensitivity: firms' elasticity of substitution between energy and labor, θ

	Steady State							Determinacy	
	ξ_E	$\frac{P_E}{P}$	$\frac{P_G}{P}$	C	C_E	C_G	W	$\phi_\Pi <$	$\phi_\Pi >$
0.02	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.09	.
0.03	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.04	17.19
0.04	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.18
0.05	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.06	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.07	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.08	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.09	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.1	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.2	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.3	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.4	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.5	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.6	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
0.7	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1

Notes: each row represents one variation of the parameter mentioned in caption; first, the new steady state is computed; next, the determinacy regions for PPI targeting are computed: the column $\phi_\Pi <$ shows the upper bound of a potential determinacy region ϕ_Π below this value, the column $\phi_\Pi >$ shows the lower bound of a potential determinacy region ϕ_Π above this value.

Table B.6 Sensitivity: risk aversion/inverse IES, σ

	Steady State							Determinacy	
	ξ_E	$\frac{P_E}{P}$	$\frac{P_G}{P}$	C	C_E	C_G	W	$\phi_\Pi <$	$\phi_\Pi >$
0.8	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
1	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0	1
1.2	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0	1.83
1.4	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0	2.89
1.6	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	3.98
1.8	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.07
2	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.18
2.2	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.02	7.31
2.4	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.02	8.46
2.6	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.02	9.62
2.8	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.02	10.8
3	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.03	11.99

Notes: each row represents one variation of the parameter mentioned in caption; first, the new steady state is computed; next, the determinacy regions for PPI targeting are computed: the column $\phi_\Pi <$ shows the upper bound of a potential determinacy region ϕ_Π below this value, the column $\phi_\Pi >$ shows the lower bound of a potential determinacy region ϕ_Π above this value.

Table B.7 Sensitivity: inverse Frisch elasticitiy, φ

	Steady State							Determinacy	
	ξ_E	$\frac{P_E}{P}$	$\frac{P_G}{P}$	C	C_E	C_G	W	$\phi_\Pi <$	$\phi_\Pi >$
2	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.18
2.25	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.03
2.5	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.89
2.75	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.77
3	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.67
3.25	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.59
3.5	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.51
3.75	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.44
4	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.37
4.25	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.32
4.5	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.27
4.75	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.22
5	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	5.18

Notes: each row represents one variation of the parameter mentioned in caption; first, the new steady state is computed; next, the determinacy regions for PPI targeting are computed: the column $\phi_\Pi <$ shows the upper bound of a potential determinacy region ϕ_Π below this value, the column $\phi_\Pi >$ shows the lower bound of a potential determinacy region ϕ_Π above this value.

Table B.8 Sensitivity: price adjustment costs, ψ

	Steady State							Determinacy	
	ξ_E	$\frac{P_E}{P}$	$\frac{P_G}{P}$	C	C_E	C_G	W	$\phi_\Pi <$	$\phi_\Pi >$
1	1.19	0.06	1.11	1.06	0.19	0.94	1.06	.	1
50	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0	1
100	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0	2.82
150	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	4.73
188	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.18
200	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.01	6.64
250	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.02	8.55
300	1.19	0.06	1.11	1.06	0.19	0.94	1.06	0.02	10.47

Notes: each row represents one variation of the parameter mentioned in caption; first, the new steady state is computed; next, the determinacy regions for PPI targeting are computed: the column $\phi_\Pi <$ shows the upper bound of a potential determinacy region ϕ_Π below this value, the column $\phi_\Pi >$ shows the lower bound of a potential determinacy region ϕ_Π above this value.

C T(H)ANK model

This appendix presents the model with heterogeneous households that we used in Section 4.2.3 of the main text.

C.1 Model

In the following, we shortly describe the model with household heterogeneity, following Bilbiie (2021). Importantly, only the household block changes.
There are two types of households: savers, S, and hand-to-mouth households, H. The exogenous probability that a saver stays saver is s, that a hand-to-mouth household stays constrained is h. Hence, the mass of hand-to-mouth households, λ is given by

$$\lambda = \frac{1-s}{2-s-h}.$$

Savers have access to financial markets and can trade bonds, yet, only with each other since hand-to-mouth households cannot trade in financial markets. In equilibrium, there is no heterogeneity within groups, only across.
Savers' Euler equation, accounting for the risk of becoming constrained, is

$$C_{S,t}^{-\sigma} = \mathbb{E}_t \left[\beta \left(sC_{S,t+1}^{-\sigma} + (1-s)C_{H,t+1}^{-\sigma} \right) \frac{R_t}{\Pi_{t+1}} \right],$$

where a saver in period t becomes constrained in $t+1$ with probability $(1-s)$.
Labor supply schedules for $i \in \{S, H\}$ are

$$\frac{W_t}{P_t} = \chi C_{i,t}^{\sigma} N_{i,t}^{\varphi}.$$

Demand curves for $i \in \{S, H\}$ are

$$C_{i,E,t} - \bar{e} = \gamma \left(\frac{P_{E,t}}{P_t} \right)^{-\eta} C_{i,t}, \quad C_{i,G,t} = (1-\gamma) \left(\frac{P_{G,t}}{P_t} \right)^{-\eta} C_{i,t}.$$

In equilibrium, bonds are in zero net supply, hence, real budgets are

$$P_{E,t}\bar{e} + C_{H,t} = \frac{W_t}{P_t} N_{H,t} + \frac{\tau^d}{\lambda} \left(D_t - \tau^s \frac{P_{G,t}}{P_t} Y_{G,t} \right),$$
$$P_{E,t}\bar{e} + C_{S,t} = \frac{W_t}{P_t} N_{S,t} + \frac{(1-\tau^d)}{(1-\lambda)} \left(D_t - \tau^s \frac{P_{G,t}}{P_t} Y_{G,t} \right).$$

Finally, household-specific variables are aggregated via

$$X_t = (1-\lambda) X_{S,t} + \lambda X_{H,t},$$

for $X \in \{N, C, C_E, C_G\}$.
The supply side of the model is, apart from the stochastic discount factor of firms, unaffected. Yet, up to first order, firms' discount factor is simply β.

C.2 Paper-and-pencil solution

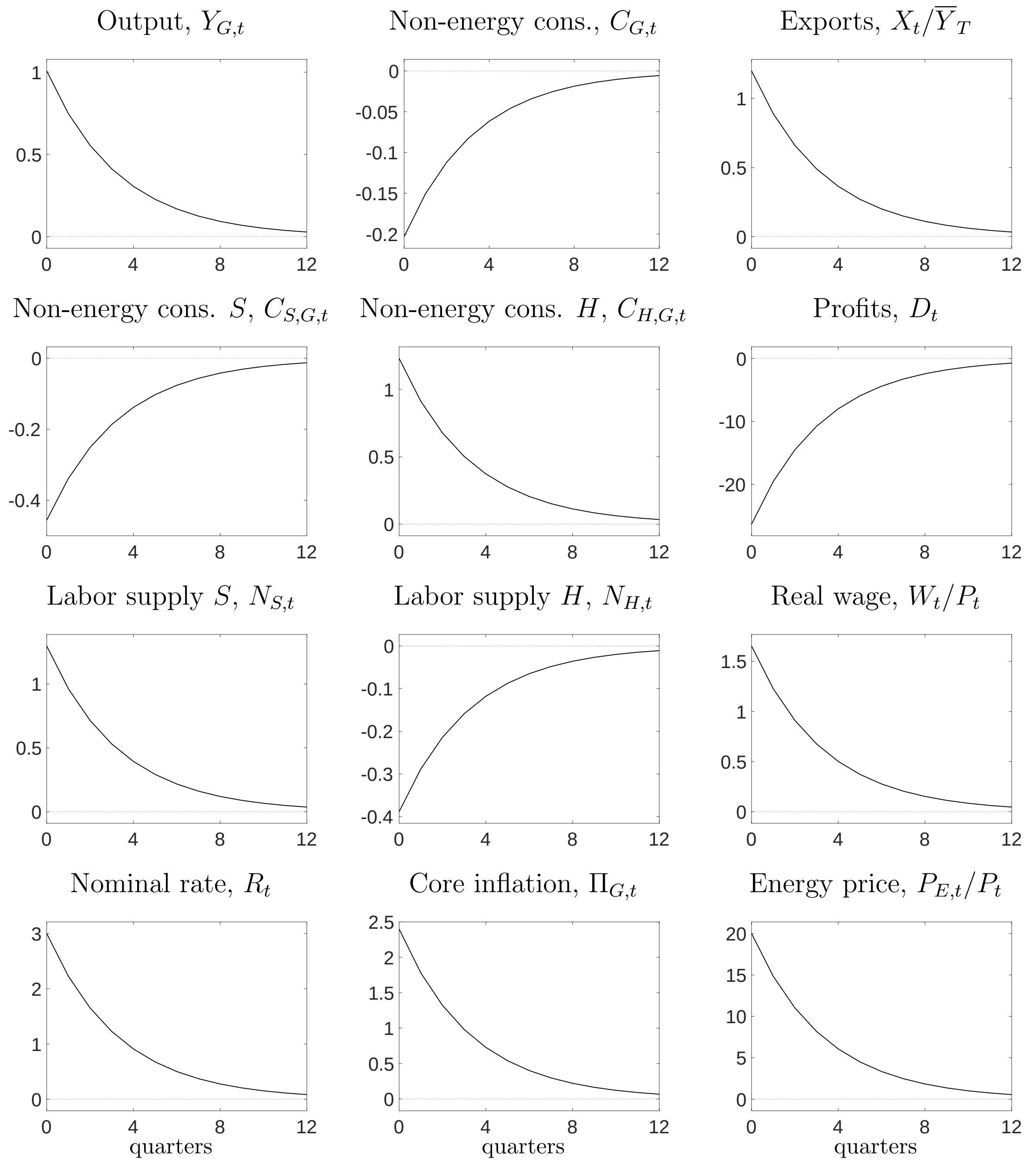
As before, we can analyze a simpler model without energy consumption of households to gain intuition for the findings. We also focus on a version without redistribution, $\tau^d = 0$. In fact, log linearizing the model yields, after some manipulations, a familiar two equation representation of the model. Namely,

$$\widehat{\Pi}_t = \beta \mathbb{E}_t \widehat{\Pi}_{t+1} + \widetilde{\kappa} \widehat{Y}_{G,t},$$
$$\widehat{Y}_{G,t} = \widetilde{\delta} \mathbb{E}_t \widehat{Y}_{G,t+1} - \widetilde{\sigma}^{-1} \left(\phi_\Pi \widetilde{\Pi}_t - \mathbb{E}_t \widetilde{\Pi}_{t+1} \right),$$

i.e., we obtain a representation akin to Bilbiie (2020), with discounting or compounding in the IS curve. As before in the representative agent model, the slopes of Phillips as well as IS curve change. While the slope of the Phillips curve, $\widetilde{\kappa}$, is as before, the slope of the IS curve, $\widetilde{\sigma}$, also depends on household heterogeneity. Importantly, in the absence of a precautionary savings motive, i.e. with the probability of becoming constrained, $1 - s$, equal to zero, $\widetilde{\delta} = 1$, in line with standard TANK results.
For our quantitative calibration, we get $\widetilde{\kappa} > 0$, $\widetilde{\sigma} < 0$ and $\widetilde{\delta} \in (0, 1)$.

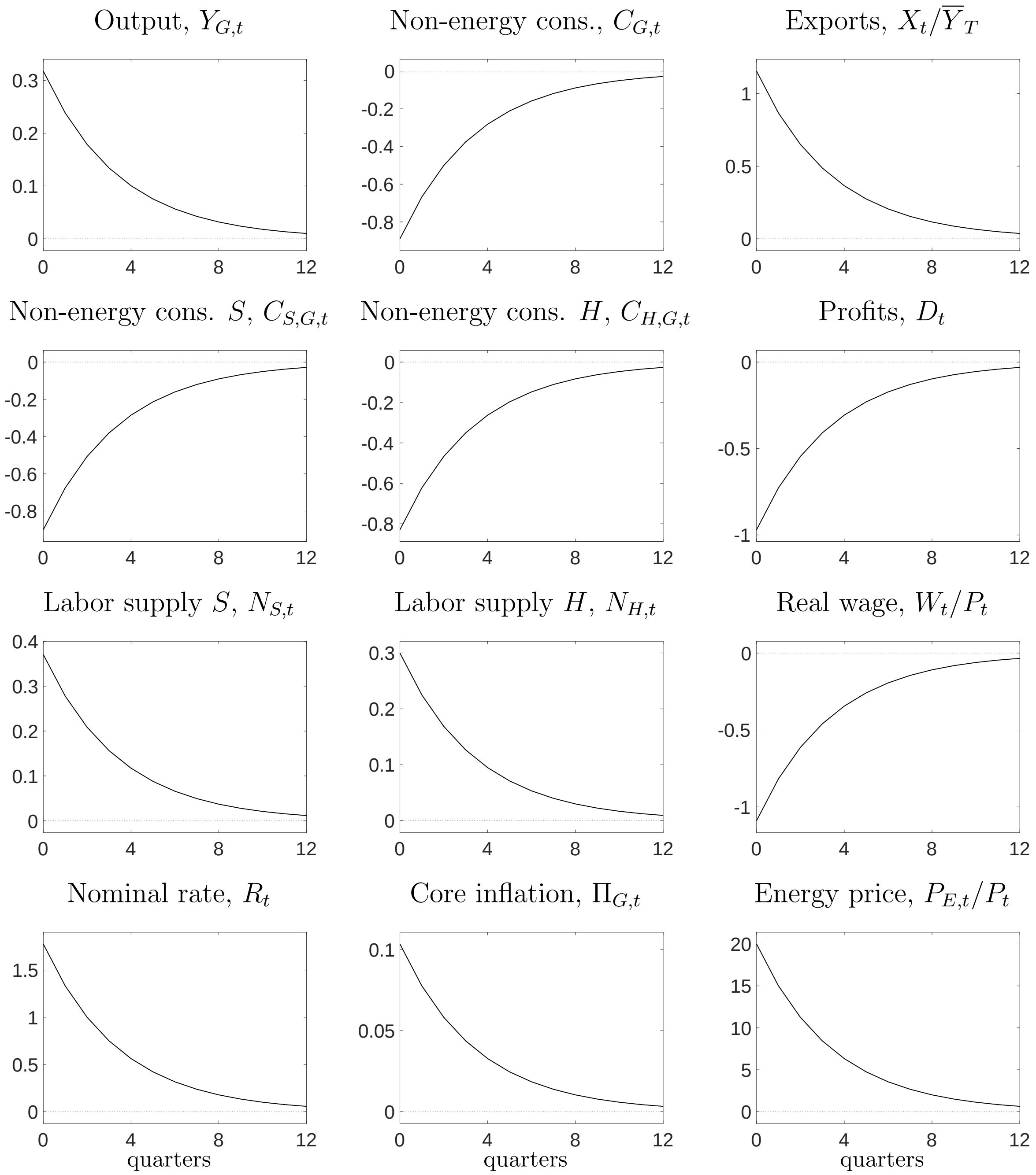
C.3 Impulse responses for the T(H)ANK model

Figure C.1 Sunspot shock amid targeting core inflation, THANK



Notes: Impulse response to a sunspot shock that raises energy prices by 20 perccent on impact. The central bank responds to core inflation, with response parameter $\phi_\Pi = 1.25$. Scaling: all response are scaled to give percentage deviations from steady state. The exception is the response of exports (percent of steady-state output). Also, interest rates and inflation rates are in annualized percentage points.

Figure C.2 Energy-supply shock under hawkish policy, THANK



Notes: Same as Figure C.1 but now the source of shock is a persistent cut in energy supply. Responses are calibrated to match a 20 percent increase in the relative energy price. The central bank responds to core inflation, with response parameter $\phi_\Pi = 17.16$. The scaling of the responses is as in Figure C.1.