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Limited (Energy) Supply, Monetary Policy, and Sunspots*

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Abstract

In a simple New Keynesian open economy setting, we analyze how local input shortages influence policy transmission and equilibrium determinacy. Shortages increase the elasticity of the local price of the scarce factor to domestic economic activity, affecting the cyclicality of marginal costs and incomes. As a result, the slope of both the Phillips and the IS curve is altered, crucially influencing monetary and fiscal policy transmission. These changes are affected by factor ownership and propensities to consume. Theoretically, shortages can also raise the risk of self-fulfilling fluctuations if a rising price of the constrained factor boosts incomes for agents with high propensities to consume. We illustrate these channels for the 2022 German energy crisis.

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

Keywords: Supply constraints, heterogeneous households, monetary transmission, transfer multiplier, sunspots

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1 Introduction

The international macroeconomic environment is increasingly affected by shortages of inputs. The underlying causes can be manifold, ranging from supply chain disruptions driven by natural disasters to policy decisions motivated by geopolitics. What these shortages have in common is a potentially substantial change in the sensitivity of prices to local demand conditions, as supply might no longer be abundant at a given price – even from the perspective of a small open economy and for imported inputs. As the local price feeds back to demand and cost conditions, shortages can have profound implications for stabilization policy.

This paper examines the implications of such supply constraints for monetary transmission and macroeconomic stability in a New Keynesian open economy model. Domestic production is assumed to use labor and another input factor. The income from the latter accrues to domestic households and to a foreign economy that demands domestic products in return. This core of the model is the same as in Blanchard and Galí (2009). We add liquidity constrained households, like in Bilbiie (2008), supply constraints for the input factor, and fiscal policy that shields households and firms from fluctuations in the input's price. In our setting supply constraints alter the cyclicality of the factor's price, which changes the slope of the Phillips curve and the cyclical distribution of income across households and countries, the demand side. Through both, supply constraints alter the effectiveness and distributional consequences of monetary and fiscal policy. In addition, macroeconomic stability might require a response to the factor's price movements because of the factor's central role in the distribution of income.

Before turning to a quantitative exploration, we use a simplified version of the model to derive with paper and pencil how different dimensions of the model shape the effect of a shortage of an input on aggregate supply and demand, monetary transmission, and equilibrium determinacy. These derivations assume that the potentially constrained factor is only used in production and that trade is balanced. These assumptions allow for a representation that has the same three equations as the textbook New Keynesian model: a Phillips curve, a dynamic IS equation, and a Taylor rule. We compare two supply regimes. In one, the factor is in abundant supply at a fixed price, a common assumption in the literature (for example, Blanchard and Galí, 2009). In the other regime, the factor's supply to the domestic economy is fixed. Instead, its price moves flexibly to clear the market. This deviation from the literature is simple but consequential.

Supply constraints tend to steepen the Phillips curve. This finding is true unless the price movements of the constrained factor are accompanied by strong wealth effects on domestic labor supply that arise on the back of redistribution between the domestic and the foreign economies. The impact of supply constraints on the IS curve and thus the aggregate demand relation depends on how the constraints affect the cyclical distribution of incomes. This in turn depends on the composition of the after-tax incomes of the model's different agents: Ricardian households (savers), hand-to-mouth households, and the foreign economy. If supply constraints render savers' incomes less procyclical – for example, because the firms they own face more procyclical energy costs – demand becomes more interest sensitive. The aggregate demand curve flattens in inflation-output space. In the extreme, we show that if supply constraints render the incomes of savers countercyclical altogether then such constraints raise the risk of indeterminacy. A response by monetary policy to inflation stronger than that prescribed by the Taylor principle would be required.[1]

In light of the fact that the distribution of income is crucial in determining the implications of supply constraints, we turn to a quantitative exploration. We calibrate the model to the German economy, associate the input factor with energy, and build a scenario reflecting the energy shortages that Germany witnessed in the run-up to and after the 2022 Russian invasion of Ukraine. Relative to the paper-and-pencil results, we allow for energy use also in consumption and allow trade not to balance period by period.

We first focus on how the effects of a monetary easing change once the supply constraints are in place. As Germany imports roughly 2/3 of its energy and uses a similar amount in

[1] The "Taylor principle" states that determinacy is ensured if the central bank responds more than one to one to inflation – that is, if $\phi_\Pi > 1$ but is arbitrarily close to 1.

production, energy supply constraints make a monetary easing both more inflationary and less effective at stimulating domestic demand, in line with a steeper Phillips curve and flatter aggregate demand curve. Taking the perspective of the "sacrifice ratio" this implies that monetary policy has to sacrifice notably less real activity and consumption in order to bring down core (or headline) inflation by a certain amount once the energy supply constraint binds. For the same reasons, we find that the energy supply constraint means that a fiscal transfer to hand-to-mouth households crowds in domestic consumption by less and, again, is more inflationary.

We also entertain one, perhaps more subjective, interpretation of the economic environment in the energy crisis. In this, energy price related fiscal interventions shield households and firms from energy price increases and a tight labor market gives rise to more flexible wages. We show that in this environment, if monetary policy looks through energy price movements by reacting only to core inflation, a sunspot equilibrium can arise in which higher (lower) energy prices go hand in hand with higher (lower) economic activity.

The intuition is as follows. Suppose that households and firms hold a *non-fundamental* (sunspot) belief of high demand for domestic products. High demand will have to be met by high output. Because energy supply is fixed, higher output requires hours worked to rise. Wages rise, and the energy price increases disproportionately such that firms substitute labor and energy. Price rigidities mean that firms cannot fully pass these costs on to consumers. If savers receive the profit income, their share of income falls. Foreign's income instead rises if Foreign owns the energy supply. Meanwhile, hand-to-mouth households' (labor) income increases as well on the back of flexible wages. Provided the foreign economy has a reasonably large marginal propensity to import goods, aggregate demand (domestic plus external) can therefore be high, supporting the non-fundamental beliefs. In this feedback loop, high energy prices are a *symptom* of high demand meeting supply constraints. Thus, the key policy implication is that monetary and fiscal policy can avoid the loop if they lean sufficiently strongly against demand. In our crisis scenario, a monetary response to headline, rather than core, inflation at conventional strengths would already be sufficient to ensure determinacy. Whether the risk of indeterminacy mattered in practice, thus, depends on one's view of the scenario and on whether or not the central bank saw through energy price movements or responded to them.

The rest of the paper is structured as follows. We review the literature next. Section 2 presents the model. Section 3 discusses our pencil-and-paper analysis. Section 4 illustrates the channels for the German energy crisis. A final section concludes.

Related literature. We analyze how supply constraints shape monetary policy transmission and equilibrium determinacy, both in theory and in an application to the German energy crisis of recent years. We pay particular attention to how these supply constraints affect aggregate outcomes through their effect on the distribution of income.

Ours, of course, is not the first paper to study the business cycle implications of supply constraints. Álvarez-Lois (2006) and Fagnart, Licandro and Portier (1999), and Kuhn and George (2019) analyze the role of capacity constraints in the propagation of aggregate shocks. Boehm and Pandalai-Nayar (2022) provide empirical evidence for sizable convexities in the supply curves of U.S. industries due to capacity constraints. Balleer and Noeller (2023) argue that constraints on inputs empirically shape the transmission of monetary policy. Comin, Johnson and Jones (2023) analyze the role of occasionally binding capacity constraints with an emphasis on supply chains. Relative to the above literature, we focus on how supply constraints affect aggregate demand and supply through the redistribution of resources across households and countries.

While our theory applies to any supply-constrained input, our quantitative application interprets the constrained factor as energy. In our calibrated model, the effect of an exogenous shock to the energy price is in line with empirical estimates of the propagation of exogenous fundamental energy shocks – provided, for example, by Baumeister and Hamilton (2019), Blanchard and Galí (2009) and Blanchard and Riggi (2013), and Känzig (2021). Such energy shocks are not the focus of our paper, however. We, instead, wish to analyze how supply constraints to energy shape the transmission of monetary and fiscal policy or may allow for the emergence of sunspot-driven fluctuations.

In terms of modeling, we rely on Blanchard and Galí (2009) and Blanchard and Riggi (2013), who point to the structural features that shape the response to fundamental shocks to the price of, in their case, oil. Meanwhile, the modeling of heterogeneity and its cyclical consequences builds on the closed economy results in Bilbiie (2008) and Bilbiie (2021). Olivi, Sterk and Xhani (2022) and Känzig (2023) have analyzed the distributional effects of *exogenous* energy price changes. All of these papers consider an environment of abundant energy supply, whereas we focus on the effect of supply constraints. Datta et al. (2021) focus on energy shock transmission amid the interest rate lower bound from which we abstract. Pieroni (2023) and Auclert et al. (2023) provide assessments of fundamental energy shocks in heterogeneous household New Keynesian models. Kharroubi and Smets (2023) study optimal fiscal policy when there are cuts in energy supply in a two-household setting with flexible prices. Relative to all these papers, we provide closed-form expressions for how supply constraints affect both the Phillips curve and the IS curve. And we highlight that supply constraints can support sunspot fluctuations, particularly, if fiscal policy works to shield households and firms from the effects of the price movements.

Our simulations assume the usual policy prescription of central banks to "see through" price movements of goods that have flexible prices, a prescription backed by ample theory.[2] With supply constraints, the price of the constrained good can be as much an indication of the state of supply as of demand. If high demand is associated with a redistribution of income to agents with higher marginal propensities to consume, fiscal policy, monetary policy, or both may need to be less accommodative to avoid self-fulfilling fluctuations. These results do not rely on fiscal policy turning active in the sense of the fiscal theory of the price level (see, for example, Leeper (1991), Schmitt-Grohé and Uribe (2007), or Kumhof, Nunes and Yakadina (2010)). Rather, they are derived under a balanced fiscal budget. In this setting

[2]On the positive side, see, for example, Carlstrom, Fuerst and Ghironi (2006) and Airaudo and Zanna (2012). On the normative side, see, for example, Aoki (2001) and Bodenstein, Erceg and Guerrieri (2008).

indeterminacy can arise when the supply constraints induce an inversion of the relationship between aggregate demand and the *ex ante* real interest rate.[3] Monetary policy remains free, though, to implement the Taylor principle.[4] This freedom sets our work apart from papers that study non-conventional transmission at the effective lower bound: under determinacy (see, for example, Eggertsson (2011)), or indeterminacy (see, for example, Mertens and Ravn (2014)).

2 Model

Consider the following infinite horizon model of two countries: Home and Foreign. The focus is on the Home economy and a generic, non-storable good E, the supply of which can be constrained. The label E is chosen to indicate that the good is "essential" to Home in that it is both consumed and used as an input in production.[5] Households in Home are heterogeneous, as in Bilbiie (2008). Firms in Home are subject to nominal rigidity. Foreign is not modeled in detail. It serves as a source of the essential good, which it exports in exchange for goods that firms in Home produce, as in Blanchard and Galí (2009). We keep the exposition concise. Appendix A provides additional details. Appendix B lists all the model equations.

2.1 Households in Home

Home is populated by two types of representative, infinitely lived households: a mass $\lambda \in [0, 1)$ of hand-to-mouth households, H, and a mass $1 - \lambda$ of saver households, S. Hand-to-mouth households do not have access to financial markets. They consume all of their income each period. Savers, however, optimize intertemporally. They can save in liquid, risk-free

[3] Bilbiie (2008) studies the determinacy implications of an inverted IS curve in a closed economy.

[4] It would be interesting to see how other mechanisms that invalidate the Taylor principle (see, for example, Kara and Yates (2021) and the references therein) interact with supply constraints.

[5] E is a fitting label for other reasons, too. In the current paper, the supply of E is an "endowment," E may be owned "externally," and, in the application later, E will be associated with "energy."

nominal bonds, the rate of return on which the central bank controls.

Preferences in the two groups are identical. For any $i \in \{H, S\}$, they are given by:

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\frac{C_{i,t}^{1-\sigma}}{1-\sigma} - \chi \frac{N_{i,t}^{1+\varphi}}{1+\varphi} \right] \right\}, \text{ with } \beta \in (0,1),\ \sigma > 0,\ \chi > 0, \text{ and } \varphi \geq 0.$$

Here, $\mathbb{E}_t$ marks the expectations conditional on period-t information; $N_{i,t}$ marks hours worked. The consumption index $C_{i,t}$ is given by the following expression:

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

Households thus derive utility from consuming the E-good and another good marked G. $\bar{e} \geq 0$ is a subsistence level for consumption of the E-good, $\gamma \in (0,1)$ the good's preference weight, and $\eta > 0$ the elasticity of substitution between the two goods.

Let $P_{E,t}^c$ and $P_{G,t}$ mark the consumer prices for the E-good and G-good, respectively. Also, define price index $P_t = \left[\gamma {P_{E,t}^c}^{1-\eta} + (1-\gamma) {P_{G,t}}^{1-\eta} \right]^{1/1-\eta}$. With this, in nominal terms, the hand-to-mouth household's budget constraint is given by the following:

$$P_{E,t}^c C_{H,E,t} + P_{G,t} C_{H,G,t} = (1+\tau^w) W_t N_{H,t} + P_t T_{H,t}. \tag{2}$$

The left-hand side features the household's consumption expenditures for the two types of goods, and the right-hand side includes the household's income. $(1+\tau^w)W_t$ is the nominal wage adjusted for a wage subsidy. $T_{H,t}$ marks real lump-sum transfers to hand-to-mouth households. The saver's budget constraint, in turn, is given by the following:

$$P_{E,t}^c C_{S,E,t} + P_{G,t} C_{S,G,t} + B_t/(1-\lambda) = (1+\tau^w) W_t N_{S,t} + P_t T_{S,t} + R_{t-1} B_{t-1}/(1-\lambda). \tag{3}$$

Savers have access to the bond market. Bonds pay a nominal gross return of R_t in period $t+1$. $B_t/(1-\lambda)$ marks the saver's period-t expenditure for bonds.[6] Budget constraints (2) and (3)

[6]Our notation already anticipates that, in equilibrium, the only counterparty to saver households for

do not mention firms' profits or the proceeds from ownership of the E-good. For tractability, the exposition subsumes such cash flows in the transfers $T_{H,t}$ and $T_{S,t}$. Section 2.4.2 will discuss the transfers and the implied ownership structure.

Both types of households allocate consumption optimally within the period, taking prices as given. Consumption demand for the two types of goods is thus given by the following:

$$C_{i,E,t} = \bar{e} + \gamma \left(P^c_{E,t}/P_t\right)^{-\eta} C_{i,t}, \quad \text{and} \quad C_{i,G,t} = (1-\gamma)\left(P_{G,t}/P_t\right)^{-\eta} C_{i,t}, \quad i \in \{H, S\}.$$

Hand-to-mouth households' consumption expenditures simply equal their income. Savers instead allocate consumption optimally over time. Defining headline inflation as $\Pi_t := P_t/P_{t-1}$, the associated Euler equation is the following:

$$C_{S,t}^{-\sigma} = \beta\, \mathbb{E}_t\{C_{S,t+1}^{-\sigma} R_t/\Pi_{t+1}\}.$$

2.2 The labor market in Home

The labor market may be characterized by rigid nominal wages. To avoid unnecessarily cumbersome notation, we state the corresponding equilibrium relationships here. Appendix A.1 provides the microfoundation, following Colciago (2011). Under nominal wage rigidity, all households supply the same amount of labor ($N_{H,t} = N_{S,t}$) and the wage, with nominal wage inflation defined as $\Pi_{W,t} := W_t/W_{t-1}$, moves according to:

$$\Pi_{W,t}(\Pi_{W,t}-1) = \frac{\varepsilon^w}{\psi^w}\left(\frac{\chi N_t^{\varphi}}{\lambda C_{H,t}^{-\sigma} + (1-\lambda)C_{S,t}^{-\sigma}} - (1+\tau^w)\frac{\varepsilon^w - 1}{\varepsilon^w}\frac{W_t}{P_t}\right)$$
$$+ \beta\, \mathbb{E}_t\left\{\frac{\lambda C_{H,t+1}^{-\sigma} + (1-\lambda)C_{S,t+1}^{-\sigma}}{\lambda C_{H,t}^{-\sigma} + (1-\lambda)C_{S,t}^{-\sigma}}\, \Pi_{W,t+1}(\Pi_{W,t+1}-1)\, \frac{N_{t+1}}{N_t}\right\}.$$

$\varepsilon^w > 1$ is the elasticity of substitution between different varieties of inputs of "labor services." $\psi^w > 0$ measures the Rotemberg-type wage adjustment costs. N_t denotes aggregate labor

savings will be Foreign.

supply.

In the case without wage rigidities, we instead assume that households choose their labor supply flexibly and without market power (or an accordingly set τ^w), meaning that $W_t/P_t = \chi C_{i,t}^{\sigma} N_{i,t}^{\varphi}$ for each $i \in \{H, S\}$.

2.3 Production in Home

There is a unit mass of producers that is indexed by $j \in [0, 1]$. Each produces one variety of a differentiated good using the essential good and labor as inputs. Production follows

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

Here, $\alpha \in (0, 1)$ governs input shares, and $\theta \in (0, 1)$ is the elasticity of substitution of the two inputs. Producers j sell their differentiated goods under monopolistic competition, to a competitive retailer that bundles goods into the final G-good according to the following:

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

Differentiated goods producers are subject to quadratic price adjustment costs. Appendix A.2 presents the price-setting problem in detail. The producers' first-order conditions give rise to a New Keynesian Phillips curve in producer price inflation, with the latter defined as $\Pi_{G,t} := P_{G,t}/P_{G,t-1}$. This curve is given by the following expression:

$$\begin{aligned}\Pi_{G,t}(\Pi_{G,t}-1) = {} & \frac{\varepsilon}{\psi}\left(\frac{\Lambda_t}{p_{G,t}} - (1+\tau^y)\frac{(\varepsilon-1)}{\varepsilon}\right) \\ & + \beta\,\mathbb{E}_t\left\{\left(\frac{C_{S,t+1}}{C_{S,t}}\right)^{-\sigma} \Pi_{G,t+1}(\Pi_{G,t+1}-1)\,\frac{Y_{G,t+1}}{Y_{G,t}}\,\frac{p_{G,t+1}}{p_{G,t}}\right\}.\end{aligned}$$

Here, τ^y is a sales subsidy. $\psi > 0$ measures the Rotemberg-type price adjustment costs. Λ_t marks real marginal costs in consumption units and $p_{G,t} := P_{G,t}/P_t$ the real goods price.[7]

[7] We apply a similar notation to other real prices later, for example, $p_{E,t}^c := P_{E,t}^c/P_t$.

The relevant marginal costs thus are expressed in units of the produced good. Letting $P^f_{E,t}$ denote the price for the E-good that *firms* pay, the optimal choice of factor inputs implies $\alpha\, W_t/P^f_{E,t} = (1-\alpha)\,(E_t/N_t)^{1/\theta}$. Real marginal costs follow

$$\Lambda_t = \left[\alpha^\theta \left(P^f_{E,t}/P_t\right)^{1-\theta} + (1-\alpha)^\theta \left(W_t/P_t\right)^{1-\theta}\right]^{1/(1-\theta)}.$$

Last, in equilibrium, the firm sector's nominal profits are given by the following equation:[8]

$$P_t D_t = (1+\tau^y) P_{G,t} Y_{G,t} - W_t N_t - P^f_{E,t} E_t.$$

2.4 Fiscal policy in Home

The government runs a balanced budget. Transfers to savers, $T_{S,t}$, are the balancing item. We consider this assumption to be the most innocuous on government funding over the business cycle that one can make. The government budget constraint is given by:

$$P_t D_t + \iota\, P_{E,t}\, \xi_{E,t} = \tau^y P_{G,t} Y_{G,t} + \tau^w W_t N_t + (P_{E,t} - P^c_{E,t}) C_{E,t} + (P_{E,t} - P^f_{E,t}) E_t + P_t T_t.$$

The left-hand side features the government's sources of revenue. The government receives all the dividends in the Home economy. In addition, the local economy also is endowed with a share $\iota \in [0,1]$ of the total supply, $\xi_{E,t}$, of the E-good. Thus, the revenues from selling this share of the good also accrue to the government. The right-hand side of the government budget constraint features the government's expenditures. The government subsidizes production and employment. It also may provide subsidies to the use of the E-good in consumption, with $C_{E,t} := \lambda C_{E,H,t} + (1-\lambda) C_{E,S,t}$, or production, E_t. In this case, the government bears the difference between the wholesale price $P_{E,t}$ that the owners of the E-good receive and the price charged to consumers or firms. Lastly, the government makes lump-sum transfers,

[8] Below, we work with the model after linearizing around a zero-inflation steady state. To keep expressions simple here, we therefore decided not to display the price and wage adjustment costs in the profits, in households' incomes, or in the resource constraint as they are zero to first order.

with $T_t := \lambda T_{H,t} + (1-\lambda) T_{S,t}$.

2.4.1 Subsidies for the E-good

If the supply of the E-good is constrained, its wholesale price fluctuates. We may allow the government to lean against the resulting fluctuations in the price that consumers and producers face. We parameterize the degree of this policy response by parameters $\tau_E^c \in [0,1]$ and $\tau_E^f \in [0,1]$, assuming the government ensures that:

$$\log(p_{E,t}^k / p_E) = (1-\tau_E^k)\log(p_{E,t}/p_E), \quad k \in \{c, f\}.$$

2.4.2 Transfers and ownership of cash flows

We assume that the transfers to all hand-to-mouth households are given by:

$$\lambda P_t T_{H,t} = P_t \overline{T}_H + \nu\big(P_t D_t - \tau^y P_{G,t} Y_{G,t}\big) + \iota\, \vartheta\, P_{E,t} \xi_{E,t} - \lambda \tau^w W_t N_{H,t} + P_t \zeta_t.$$

The transfers comprise a constant term, $\overline{T}_H$. In addition, the transfers reflect a claim to firms' profits (net of production subsidies). If $\nu < \lambda$, a hand-to-mouth household receives a smaller share of the profit income than a saver household – $\nu \in [0,1]$. Meanwhile, hand-to-mouth households receive a share $\vartheta \in [0,1]$ of Home's income from its endowment with the E-good. Note that ν and ϑ implicitly define how much of the respective streams of income hand-to-mouth households "own" (and savers do not). The government charges the households their respective share of the costs of the labor subsidy. Last, ζ_t is a zero-mean transfer shock that redistributes from savers to hand-to-mouth households.

2.5 Monetary policy in Home

The central bank controls the gross nominal interest rate R_t according to the Taylor rule

$$\log(R_t/R) = \phi_\Pi \cdot \log(\Pi_{G,t}/\Pi_G) + \upsilon_t, \text{ where } \quad \phi_\Pi \geq 0,$$

and υ_t is a monetary shock. A common prescription for the optimal response of monetary policy to relative price changes is for the central bank to focus on the inflation rates of those goods or services that are subject to nominal rigidities; see, for example, Aoki (2001). This means focusing on the inflation rate associated with the G-goods.

2.6 International trade and Foreign demand

Foreign matters as a source of supply of the E-good to Home and as a source of demand for goods produced in Home – the G-goods. Foreign's budget constraint (expressed in units of Home's currency) is the following:

$$P_{G,t}Y_t^* = P_{G,t}X_{G,t} - [B_t - R_{t-1}B_{t-1}].$$

On the left-hand side, $P_{G,t}Y_t^* := (1-\iota)\,\xi_{E,t}\,P_{E,t}$ denotes Foreign's current income from selling its share $(1-\iota)$ of the total supply of the E-good. The right-hand side marks Foreign's expenditures for imports (Home's exports of goods to Foreign, $X_{G,t}$) and the accumulation of net foreign assets (nominal bonds issued in Home's currency). This formulation reflects the fact that, in equilibrium, the savings of Home's savers must be mirrored in net foreign liabilities of Foreign. We do not seek to construct a more detailed model of the Foreign economy. Instead, we focus directly on Foreign's propensity to consume (MPC) out of any windfall gains associated with an increase in the price $P_{E,t}$.[9] Let $-b_t := -B_t/P_t$ denote Foreign's external asset position. We parameterize Foreign's demand for goods produced in

[9] What we label Foreign's "MPC" is identical to Foreign's marginal propensity to demand Home's goods when Foreign's income rises. We continue to use the familiar term "MPC."

Home as:

$$\log(X_{G,t}/X_G) = \mu_{F,1} \cdot \log(Y_t^*/Y^*) + \mu_{F,2} \cdot (-b_{t-1}/Y^*) \, .$$

Parameters $\mu_{F,1} \geq 0$ and $\mu_{F,2} \geq 0$ measure, respectively, Foreign's MPC out of current income and its MPC out of wealth.

2.7 Supply regimes for the E-good

We consider two regimes for the supply of the E-good. In the fixed-price regime, its real wholesale price, $p_{E,t}$, is constant. The good's supply, $\xi_{E,t}$ is perfectly elastic. Not having modeled the costs of producing the essential goods, this assumption serves as a point of reference, and it is in keeping with the literature, for example, Blanchard and Galí (2009). In the fixed-supply regime, however, the total supply to Home, $\xi_{E,t}$, is constant. In this case, the price of the essential good has to clear the market in Home.

2.8 Market clearing

In equilibrium, all markets clear. The labor market clears if $N_t = \lambda N_{H,t} + (1-\lambda) N_{S,t}$ – that is, labor demand of firms equals the different households' labor supply. The market for the E-good clears if $\xi_{E,t} = C_{E,t} + E_t$, that is, if supply meets the demand of households and firms. The market for domestic products clears if $Y_{G,t} = C_{G,t} + X_{G,t}$, that is, if production equals demand for consumption in Home and exports. Here $C_{G,t} := \lambda C_{H,G,t} + (1-\lambda) C_{S,G,t}$ represents total domestic consumption of the good.

3 Pencil-and-paper intuition

The departure of this paper from the literature is simple but consequential. We change the supply regime of a good that, among other possible uses, serves as an input to production –

from a regime of elastic supply to a regime of fixed supply. This change alters the relationship between firms' marginal costs and output, and it changes the cyclicality of incomes. If agents with different MPCs rely on different sources of income, the supply regime also affects the distribution of income across agents, changing the interest elasticity of aggregate demand. Importantly, this changes the transmission of shocks and may alter the conditions for determinacy. Using a simplified version of the model from Section 2, the current section provides intuition by discussing a sequence of propositions. Appendix C presents all the derivations related to the model variant used in this section. Appendix D provides the proofs of the propositions.

3.1 Notation, parametric assumptions, and steady-state targets

Notation. The notation we will use is as follows. For a generic variable Z_t, let Z mark its steady-state value. Let $\widehat{Z}_t$ denote the percent deviation from the steady state. Below, we also rely heavily on the following notation: Let the convolute of parameters Γ_Z be defined such that, in equilibrium, $\widehat{Z}_t = \Gamma_Z \widehat{Y}_{G,t}$ – that is, Γ_Z marks the cyclical elasticity of $\widehat{Z}_t$ with respect to output $\widehat{Y}_{G,t}$. If we want to make explicit that Γ_Z depends on the supply regime, we add superscripts. Thus, Γ_Z^P marks the elasticity of $\widehat{Z}_t$ to output in the fixed-price regime and Γ_Z^Q denotes it in the fixed-supply regime ("Q" signifies a constrained quantity). The Γ_Z elasticities are general equilibrium elasticities. They are invariant to the shocks entertained in this section – that is, to monetary shocks or sunspot shocks. Another way to explain what Γ_Z is would be to describe it as the "cyclical sensitivity" of Z_t with respect to output.

Parametric assumptions. The aim of the current section is to provide closed-form intuition. Toward this aim, we abstract from the use of the E-good in consumption ($\gamma \to 0$, $\bar{e} \to 0$). We also abstract from subsidies for the E-good ($\tau_E^f = \tau_E^c = 0$) and from wage rigidity or wage markups. We set $1 + \tau^y = \epsilon/(\epsilon - 1)$ to remove price markups. If the E-good is not only owned domestically, $\iota < 1$, we assume that trade is balanced ($\mu_{F,1} = 1$) to avoid an endogenous state variable. And, only for the convenience of exposition, we let $\beta \to 1$. Throughout the section, the monetary policy shock v_t is white noise and we abstract from fiscal shocks, so $\zeta_t = 0$.

Steady-state targets. We consider a particular steady state that simplifies the exposition. We focus on a zero-inflation steady state ($\Pi_G = \Pi_W = 1$), and we assume that fiscal transfers to households in the steady state are such that consumption by the two types of households is symmetric in the steady state ($C_H = C_S$). The scaling parameter of the disutility of work χ sets $N_H = N_S = 1$. These assumptions imply that the slope of the Phillips curve is not affected by the distribution of income within the country. Finally, we normalize the steady-state output to $Y_G = 1$. The chosen value for τ^y then implies $E = 1$. For all that follows, we will look at a linear approximation of the equilibrium around the non-stochastic steady state. Appendix C.1.1 provides the nonlinear equilibrium conditions for the model variant used here, and Appendix C.1.2 provides the linearized equations. Appendix C.1.3 provides the steady state.

3.2 Determinacy and monetary transmission

Under the assumptions above, the linearized economy can be expressed in conventional form: a Phillips curve, a dynamic IS equation, and a Taylor rule.[10] Because producer price and consumer price inflation here coincide, the linearized Taylor rule is given by:

$$\widehat{R}_t = \phi_\Pi \widehat{\Pi}_t + v_t. \tag{4}$$

The Phillips curve and IS equation are given by the following textbook representation of the New Keynesian model:

$$\widehat{\Pi}_t = \mathbb{E}_t\{\widehat{\Pi}_{t+1}\} + \widetilde{\kappa}\, \widehat{Y}_{G,t} \qquad \text{and} \qquad \widehat{Y}_{G,t} = \mathbb{E}_t\{\widehat{Y}_{G,t+1}\} - \frac{1}{\widetilde{\sigma}} \left(\widehat{R}_t - \mathbb{E}_t\{\widehat{\Pi}_{t+1}\} \right). \tag{5}$$

[10] Appendix C.2 provides the steps involved.

Defining the "slope of the Phillips curve" as $\widetilde{\kappa}$ and the "slope of the IS curve" as $1/\widetilde{\sigma}$, the values of both slopes depend on the supply regime for the E-good.[11] Next, we spell out how the slopes link to monetary transmission and local determinacy. Section 3.3 discusses how the supply regime affects the cyclicality of the E-good's price which is at the core of the results. Sections 3.4 and 3.5 thereafter discuss the economic determinants that govern each of these slopes.

Monetary transmission. Suppose the monetary response to inflation, ϕ_Π, is set to a value high enough to ensure determinacy. Then, (4) and (5) give that in equilibrium:

$$\widehat{\Pi}_t = -\frac{\widetilde{\kappa}}{\widetilde{\sigma} + \widetilde{\kappa}\phi_\Pi}\, v_t \qquad \text{and} \qquad \widehat{Y}_{G,t} = -\frac{1}{\widetilde{\sigma} + \widetilde{\kappa}\phi_\Pi}\, v_t. \tag{6}$$

Thus, to the extent that the supply regime affects $\widetilde{\kappa}$ and $\widetilde{\sigma}$, the supply regime also matters for the effectiveness of monetary stimulus and the trade offs that monetary policy faces. In other words, supply constraints affect the "sacrifice ratio," that is, how much real activity the central bank has to forfeit to reduce inflation by a certain amount.[12]

Determinacy. The following provides the conditions for determinacy that apply:

Proposition 1. *Consider the model of Section 2 and apply the assumptions listed in Section 3.1. Then, two cases summarize the conditions for local determinacy:*

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

$$\phi_\Pi > \max\left(1, -4\,\frac{\widetilde{\sigma}}{\widetilde{\kappa}} - 1\right). \tag{7}$$

Proof. The proof follows Woodford (2003, p. 670 ff) and is in Appendix D.1. □

[11] Note that the "slope of the IS curve" refers to the slope in output-real rate space. An "aggregate demand curve" arises from combining Taylor rule (4) and the IS curve in (5). It is usually drawn in inflation-output space, where its slope is inversely related to the "slope of the IS curve" as defined here.

[12] By equation (6) and the definition of Γ_C as the cyclical sensitivity of consumption with respect to output, the sacrifice ratio with respect to consumption is given by $\Gamma_C/\widetilde{\kappa}$, for example, where both Γ_C and $\widetilde{\kappa}$ depend on the supply regime.

The "Taylor principle" states that determinacy is ensured if the central bank responds more than one to one to inflation – that is, if $\phi_\Pi > 1$ but is arbitrarily close to 1. Inequality (7) shows that such a response may not be sufficient here, as the supply regime can affect $\widetilde{\kappa}$ and $\widetilde{\sigma}$. Namely, if $\widetilde{\sigma}/\widetilde{\kappa} < 0$, determinacy may require a notably stronger monetary reaction: $\phi_\Pi >> 1$. Below, we provide conditions under which the supply constraint itself can render $\widetilde{\kappa} < 0$ or $\widetilde{\sigma} < 0$.

3.3 The cyclical sensitivity of the E-good's price

Shortages of an input factor change the sensitivity of prices to local demand conditions. As the local price feeds back to demand and cost conditions, shortages can have profound implications for stabilization policy. At the heart of our analysis thus lies a change of the sensitivity of the factor's price to demand. The fixed-price regime introduced in Section 2.7 means that quantities clear the market for the essential good. In this regime, the sensitivity of demand for the E-good to output is increasing (Γ_E^P greater) in the substitutability of the essential good (θ greater) and the sensitivity of marginal costs to output (Γ_Λ^P greater):

$$\Gamma_{p_E}^P = 0 \qquad \text{and} \qquad \Gamma_E^P = 1 + \theta\,\Gamma_\Lambda^P. \tag{8}$$

In the fixed-supply regime, however, the price must move to equalize demand for the E-good with a fixed supply ($\Gamma_E^Q = 0$). In this regime, the price is elastic to output, and the more so ($\Gamma_{p_E}^Q$ greater) the more sensitive marginal costs are to output (Γ_Λ^Q greater) and the less substitutable the essential good is (θ smaller). We have:

$$\Gamma_{p_E}^Q = \Gamma_\Lambda^Q + \frac{1}{\theta} \qquad \text{and} \qquad \Gamma_E^Q = 0. \tag{9}$$

3.4 Supply constraints and the slope of the Phillips curve

The supply constraint causes a change in the cyclicality of the E-good's price. The constraint also changes the cyclicality of marginal costs. This is important for inflation dynamics. Appendix C.2.5 derives that

$$\widetilde{\kappa} = \frac{\epsilon}{\psi}\,\Gamma_\Lambda. \tag{10}$$

Equation (10) means that the slope of the Phillips curve in (5) depends on the supply regime precisely through the elasticity of marginal costs to output, Γ_Λ. We summarize the effect of the supply regime on Γ_Λ in Proposition 2.

Proposition 2. *Consider the model of Section 2 and the assumptions of Section 3.1. Compare the elasticity of marginal costs with respect to output, Γ_Λ, in the two supply regimes (superscripts P and Q) for the following two cases of ownership of the E-good.*

1. *If the* essential good (the E-good) is owned domestically *($\iota = 1$), then*

$$\Gamma_\Lambda^Q = \sigma + \frac{\varphi}{1-\alpha} + \frac{\alpha/\theta}{1-\alpha} \quad > \quad \frac{(1-\alpha)(\sigma+\varphi)}{1+\alpha\theta\varphi} = \Gamma_\Lambda^P \quad > \quad 0. \tag{11}$$

2. *If the* essential good (the E-good) is owned abroad *($\iota = 0$), then*

$$\Gamma_\Lambda^Q = \frac{\sigma+\varphi-\frac{\alpha}{\theta}(\sigma-1)}{1+\alpha(\sigma-1)}, \qquad \text{and} \qquad \Gamma_\Lambda^P = \frac{(1-\alpha)(\sigma+\varphi)}{1+\alpha\theta(\sigma+\varphi)} > 0. \tag{12}$$

   In this case,

$$\Gamma_\Lambda^Q \ \underset{(<)}{>}\ \Gamma_\Lambda^P \qquad \text{if and only if} \qquad \sigma+\varphi \ \underset{(<)}{>}\ \frac{\sigma-1}{\theta}. \tag{13}$$

Proof. The proof is provided in Appendix D.2. □

Supply constraints make the constrained factor's price more responsive to demand; compare $\Gamma_{p_E}^P$ and $\Gamma_{p_E}^Q$ in (8) and (9). All else being equal, this steepens the Phillips curve, meaning $\Gamma_\Lambda^Q > \Gamma_\Lambda^P$. Indeed, when the constrained factor is owned domestically, this is the supply regime's only effect on the slope of the Phillips curve (Case 1 above). In contrast, with foreign ownership (Case 2), there also is a wealth effect on labor supply. This can be seen from the terms in (11) and (12). Absent the wealth effect (for $\sigma = 0$), the terms Γ_Λ^Q and Γ_Λ^P in Case 1 and 2 are identical – they do not depend on ownership. For $\sigma > 0$, this is no longer the case. Higher output means a higher price for the constrained factor. If the proceeds accrue to Foreign, a higher price means that the domestic economy becomes less productive in converting labor into consumption, dampening the elasticity of the wage to output. The conditions in (13) show that with foreign ownership and if $\sigma > 1$, the Phillips curve may even flatten because of supply constraints, and the slope may potentially turn negative. This can arise when θ is small (such that the price of the constrained factor rises steeply with output) and labor supply is fairly elastic (φ is small) but households are unwilling to intertemporally substitute consumption (σ is large).[13]

Summing up, supply constraints raise $\widetilde{\kappa}$ (the slope of the Phillips curve) if either the constrained factor is owned domestically or the constrained factor is held abroad and the wealth effects on labor supply are weak. Then, from the supply side, supply constraints make any monetary stimulus more inflationary – see (6) – and, from the supply side, they *reduce* the risk of indeterminacy by Proposition 1.

3.5 Supply constraints and the slope of the IS curve

Supply constraints, however, also have a differential effect on different types of income. Emphasizing this is an important contribution of the current paper. Supply constraints directly affect the cyclicality of revenue from the constrained factor. And, indirectly, they affect the cyclicality of labor income through input substitution. In the setting here, this matters for aggregate demand (and the slope of the IS curve) because different agents can have different sources of income and have different marginal propensities to consume. Appendix C.2.12 shows that the slope of the IS curve in (5) relates to the elasticity of savers' consumption to

[13] While we document the effect of supply constraints for an arbitrary elasticity of substitution (θ), Blanchard and Riggi (2013) discuss the role of the wealth effect for long-run labor supply only and with a Cobb Douglas production function ($\theta = 1$) and only for what we call the fixed-price regime.

aggregate output, Γ_{C_S}, through the following relationship:

$$\frac{1}{\widetilde{\sigma}} = \frac{1}{\sigma\,\Gamma_{C_S}}. \tag{14}$$

In the current setting, the supply of bonds in equilibrium is zero,[14] so all agents in equilibrium consume exactly their own income. The intuition then is familiar from, for example, Bilbiie (2008). The only agents whose demand is directly interest elastic are the saver households. A higher real interest rate raises savers' demand for bonds. For the bond market to clear, savers' incomes in equilibrium then have to fall to reduce the demand for bonds. The more procyclical the savers' income is (the more positive Γ_{C_S} is), the less of a fall in aggregate income is needed to bring this about. If, however, savers' income is countercyclical ($\Gamma_{C_S} < 0$), in equilibrium a higher real interest rate must go hand in hand with *higher* output. The next few lines highlight how the cyclicality of savers' income, in turn, is related to the incomes of the economy's other agents – namely, the hand-to-mouth households and the Foreign economy. Thereafter, we discuss how the exposure to different income streams shapes the demand-side effects of supply constraints. In the economy at hand, the domestic distribution of income is governed by

$$\Gamma_C = (1-\lambda)\,\Gamma_{C_S} + \lambda\,\Gamma_{C_H}. \tag{15}$$

Domestic income (C is aggregate consumption, which here is equal to GDP) is shared between savers (mass $1-\lambda$) and hand-to-mouth households (mass λ). The international distribution of income, in turn, is given by the following:

$$1 = [1-\alpha(1-\iota)]\,\Gamma_C + \alpha\,(1-\iota)\,\left[\Gamma_{p_E} + \Gamma_E\right]. \tag{16}$$

[14]This is by virtue of the assumption of balanced trade, which is needed for analytical tractability. Both hand-to-mouth households and Foreign, thus, have an MPC of 1. The numerical simulations in Section 4 will use a Foreign MPC that is less than 1, so that trade no longer is balanced.

Foreign's source of income is the E-good. Thus, $\alpha(1-\iota)$ is the steady-state share of Home's output that goes to Foreign. How a marginal increase in output ("1" on the left-hand side) is allocated between domestic income, Γ_C, and foreign income (the second term on the right-hand side) directly relates to how cyclical the revenues from the E-good are, term $[\Gamma_{p_E}+\Gamma_E]$; this cyclicality of the revenues in turn depends on the supply regime – recall the expression for Γ_{p_E} and Γ_E in (8) and (9).

Focus on (15) first. In Proposition 3, we look at the case of domestic ownership of the E-good ($\iota = 1$) – where, by (16), $\Gamma_C = 1$ – and spell out how ownership of the different income sources *across* domestic households but *within* the same country shapes the effect of supply constraints on aggregate demand (the slope of the IS curve).

Proposition 3. *Consider the model in Section 2 and the assumptions listed in Section 3.1. In addition, suppose that all of the essential good (the E-good) is owned domestically ($\iota = 1$). Let $\Gamma_{C_S}^{Q,(i)}$ and $\Gamma_{C_S}^{P,(i)}$ mark the elasticity of savers' income with respect to output in cases $i = 1, 2, 3$ below in the two supply regimes for the E-good (superscripts P and Q).*

1. *$\nu = \vartheta = 0$: hand-to-mouth households do not receive profits or revenues from the essential good. Then,*
$$\Gamma_{C_S}^{Q,(1)} - \Gamma_{C_S}^{P,(1)} \quad < \quad 0.$$

2. *$\nu = 0$, $\vartheta > 0$: hand-to-mouth households do not receive profits, but a share of revenues from the essential good. Then,*
$$\Gamma_{C_S}^{Q,(2)} - \Gamma_{C_S}^{P,(2)} \quad < \quad \Gamma_{C_S}^{Q,(1)} - \Gamma_{C_S}^{P,(1)}.$$

3. *$\nu = \vartheta > 0$: hand-to-mouth households receive the same positive share of profits as of revenue from the essential good. Then,*
$$\Gamma_{C_S}^{Q,(3)} - \Gamma_{C_S}^{P,(3)} \quad > \quad \Gamma_{C_S}^{Q,(1)} - \Gamma_{C_S}^{P,(1)}.$$

Proof. The proof is provided in Appendix D.3. □

All else being equal, higher output means higher demand for the essential good and for labor. Labor income and income from the E-good rise disproportionately, particularly if the supply of one of the factors of production is constrained; they rise directly or because of substitution. Profit income thereby falls when output rises and even more so when there are supply constraints. Case 1 shows that if savers own all non-labor sources of income (and hand-to-mouth households none, $\nu = \vartheta = 0$), supply constraints unambiguously render savers' income less procyclical – the IS curve steepens, that is, demand becomes more interest sensitive. Indeed, supply constraints might turn Γ_{C_S} negative. This effect is even stronger (Case 2) if hand-to-mouth households share in the revenue from the essential good (a procyclical source of income). On the other hand, the effect is weaker if hand-to-mouth households not only share in the revenue from the essential good but also in profit income (Case 3).

Next, Proposition 4 focuses on the effect of supply constraints on the distribution of income *across* countries, recall (16). For ease of exposition, the E-good here is entirely owned by Foreign so that none of the income from the E-good accrues to households in Home ($\iota = 0$). The value of ϑ then is irrelevant, and we look at different cases for the ownership of domestic profits only.[15]

Proposition 4. *Consider the model in Section 2 and the assumptions listed in Section 3.1. In addition, suppose the essential good (the E-good) is fully owned by Foreign ($\iota = 0$). The superscripts below refer to the two supply regimes for the E-good (superscripts P and Q) and the following three cases:*

1. *$\nu = \lambda$: representative household in Home.*
2. *$\nu = 0$: hand-to-mouth households do not receive profits.*
3. *$\nu > 0$: hand-to-mouth households receive a positive share of profits.*

With these definitions of the cases, the following are true:

$$\Gamma_{C_S}^{P,(1)} > 0 \qquad \text{and} \qquad \Gamma_{C_S}^{Q,(1)} < \Gamma_{C_S}^{P,(1)}, \tag{17}$$

and

$$\Gamma_{C_S}^{Q,(3)} - \Gamma_{C_S}^{P,(3)} \underset{(<)}{>} \Gamma_{C_S}^{Q,(2)} - \Gamma_{C_S}^{P,(2)} \qquad \text{if and only if} \qquad \sigma + \varphi \underset{(<)}{>} \frac{\sigma - 1}{\theta}. \tag{18}$$

[15]Note that the cases specified in Proposition 3 and 4 are thus not identical.

Proof. The proof is provided in Appendix D.4. □

Equation (17) focuses on the case where there is heterogeneity across borders but not domestically. This case is important because one can show that in the fixed-price scenario the slope of the IS curve is strictly positive, $\Gamma^{P,(1)}_{C_S} > 0$. Supply constraints, however, reduce the procyclicality of savers' income – $\Gamma^{Q,(1)}_{C_S} < \Gamma^{P,(1)}_{C_S}$ – thus, steepening the IS curve; in fact, the constraints may cause the slope of the IS curve to invert. The inequalities in (18), in turn, show that if the revenue from the essential good accrues to Foreign, the wealth effect on labor supply also matters for the slope of the IS curve, provided there is heterogeneity in Home. The reason is simple. A strong wealth effect can reverse the countercyclicality of profits, with a corresponding effect on the cyclicality of the income of those who claim the profits.

Summing up, we have derived conditions under which supply constraints tend to steepen the IS curve (making aggregate demand more interest sensitive) since they reduce the procyclicality of savers' incomes.[16] These conditions are savers' ownership of the income from profits and other agents' ownership of the income from the good subject to supply constraints. The degree of cyclicality of the income streams and of marginal costs depends in turn on the model's deep parameters: the elasticity of substitution in production, θ, intertemporal substitution, $1/\sigma$, the Frisch elasticity $1/\varphi$, the weight of the E-good in production, α, and nominal rigidities, ψ.[17] It is important to keep in mind that what matters for the above mechanisms is after-tax income. This means that fiscal policy, too, would shape the results.

Next, we turn to a quantitative assessment of the full model. There, energy is used in both consumption and production. Furthermore, we allow for wage rigidity, a marginal propensity to consume of Foreign that is less than unity, and for energy-related subsidies.

[16]The same conditions, thus, flatten the aggregate demand relation in inflation-output space.

[17]Appendix E shows directly how these parameters affect the validity of the Taylor principle in a special case where $\iota = 0$ and $\nu = \lambda$. As suggested by result (17) of Proposition 4, in this case indeterminacy can arise even when the central bank adheres to the Taylor principle – but only if there are supply constraints.

4 Numerical analysis and policy implications

This section calibrates the model to the German economy and associates the E-good with energy. We analyze the working of the model through three scenarios. In the “fixed price” scenario, the baseline, energy is supplied perfectly elastically at a given price. In the “fixed supply” scenario, instead, the supply of energy is fixed. All other features remain unchanged; these two scenarios reflect rather “normal” times. Finally, we design what we call the “crisis” scenario. This is aimed at capturing further aspects important for the German energy crisis that began in the run-up to Russia’s 2022 invasion of Ukraine.[18]

4.1 Parameterization

Table 1 provides the parameterization for all three scenarios. We start with the baseline calibration – the “fixed price” scenario. One period in the model is taken to be a quarter. Turning first to preferences, the discount factor β implies a two percent annualized real rate

Table 1 Parameterization

Preferences		Production		Energy, Foreign		Government	
β	0.995	ε	11	ι	0.333	τ^y	0.1
σ	2	ψ	507	p_E	0.101	τ^w	0.1
φ	3	α	0.077	$\mu_{F,1}$	0.25	ν	0
χ	0.778	θ	0.1	$\mu_{F,2}$	0.02	ϑ	0
λ	0.24					$\overline{T}_H$	0.012
$\bar{e}$	0.125	Labor market				ϕ_Π	1.5
γ	0.239	ε^w	11			τ_E^c	0
η	0.1	ψ^w	507			τ_E^f	0
Change for fixed-supply scenario				Additional changes for crisis scenario			
p_E	flexible	$\xi_{E,t}$	1.5 const.	$\xi_{E,t}$	1.379 const.	τ_E^c	0.33
				ψ^w	0	τ_E^f	0.33

Notes: “Fixed-price” calibration in top panel. Changes relative to baseline for scenario “fixed-supply”, and relative to that for scenario “crisis” in bottom panel. See main text for details. “Flexible” indicates that in the fixed-supply and crisis scenarios p_E is determined in equilibrium, while it is constant in the “fixed-price” scenario. “const.” indicates that ξ_E is constant in the “fixed supply” and “crisis” scenarios, while it is determined in equilibrium in the “fixed price” scenario.

[18] All the impulse responses that we show will be based on a linearization of the model.

of interest in the steady state. We set σ equal to 2. This value implies an intertemporal elasticity of substitution of 1/2, which is at the upper end of the range reported in Havránek (2015). We calibrate φ to 3, giving a Frisch elasticity of 1/3, which is in the middle of the range reported in Elminejad et al. (2023).[19] The disutility of work χ is set to normalize the steady-state labor supply of households to 1. The share of hand-to-mouth households is $\lambda = 0.24$, which follows estimates for Germany in Slacalek, Tristani and Violante (2020). $\bar{e}$ is set so that subsistence energy consumption is 25 percent of steady-state energy consumption, following Fried, Novan and Peterman (2022). We set γ so that, in the baseline steady state, households spend 4 percent of GDP on energy.[20] The elasticity of substitution in consumption η is set to 0.1, which is within the range reported in Bachmann et al. (2022).

Turning to production next, the own-price elasticity of demand is $\varepsilon = 11$, a conventional value. The price adjustment costs ψ match a slope of the pencil-and-paper Phillips curve of 0.1. In a Calvo setting this would map onto prices for *non-energy goods* being adjusted, on average, once a year. We set the elasticity of substitution between different types of labor (ε^w) and wage adjustment costs (ψ^w) to the same values as for prices. Energy's weight in production (α) is set to obtain costs of energy in production of 8 percent of GDP. The elasticity of substitution in production (between energy and labor) is the same as in consumption – namely, $\theta = 0.1$ – and is in line with Bachmann et al. (2022).

Regarding the supply of energy, we assume that a share $\iota = 0.333$ of energy is owned by domestic households – in line with German import shares for primary energy. In the fixed price baseline, the price is set such that (along with the assumptions made about preferences and production) firms' energy usage takes on a value of $E = 1$ in the steady state. This gives $p_E = 0.101$. In the baseline, this price is fixed. As for the demand by Foreign, we set $\mu_{F,1}$ equal to 0.25. This means that for each additional euro in energy revenue, Foreign orders a

[19] Using the expression derived in Swanson (2012) the implied risk aversion is $(1/\sigma + 1/\varphi)^{-1} = 1.2$.

[20] The parameterization here considers sources of energy with local markets (natural gas, coal, and electricity, but not oil). We calibrate the expenditure shares relative to GDP using 2021 German data on primary energy usage, see BDEW (2023). The relative share of households and firms follows from Eurostat's data on energy consumption by sector (product code: ten00124).

fourth of a euro's worth of goods produced in Home.[21] Next, we set the debt elasticity of foreign demand to a value that is small but large enough to stabilize net foreign assets at the targeted long-run value of zero; $\mu_{F,2} = 0.02$.

Turning to the government, we assume that it sets τ^y and τ^w so that – in the steady state – there are no distortions associated with firms' or workers' market power. We do so primarily because the propositions in Section 3 do so as well. Further, we assume that hand-to-mouth households do not receive any profits in the economy ($\nu = 0$) nor any revenues associated with domestic energy ownership ($\vartheta = 0$). The government provides a transfer of $\overline{T}_H = 0.012$ to hand-to-mouth households that ensures that both household types have the same baseline steady-state income. We do this to make the results easy to understand. Turning to monetary policy, we set the response to core inflation to $\phi_\Pi = 1.5$. The government does not implement energy price subsidies.

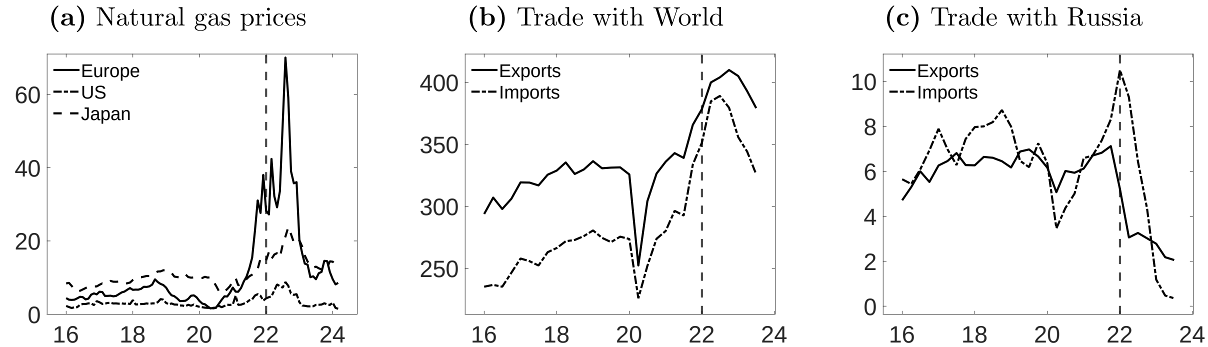
Fixed-supply scenario. This scenario shares all parameter and steady-state values with the fixed-price baseline. However, it keeps the supply of energy fixed over the cycle.

The crisis scenario. Section 3 provided conditions under which the Taylor principle can be invalidated. To obtain those results, the following were important elements: (1) a factor of production owned externally receiving notable weight in production, (2) the factor being in scarce supply so that prices are responsive, and (3) income streams supporting aggregate demand. The energy crisis that afflicted Germany in the run-up to and after the Russian invasion of Ukraine arguably provided some of these elements:

In recent years Germany imported roughly two thirds of its primary energy. Before the war, Russia alone provided one-third of German primary energy, natural gas in particular. Panel (a) of Figure 1 shows wholesale prices of natural gas in Europe, Japan, and the US; all

[21] Drechsel and Tenreyro (2018) discuss the effects of commodity price booms on commodity exporters and find a sizable increase in imports after an increase in commodity prices, speaking in favor of high MPCs out of energy revenues. Arroyo Marioli and Vegh (2023) document a large procyclicality of fiscal policy for commodity exporters. Johnson, Rachel and Wolfram (2023) consider a unit MPC for an energy exporter, alluding to borrowing constraints and risks associated with accumulating financial assets (the risk of sanctions, say). In light of this, we consider our parametrization as conservative.

Figure 1 Natural gas prices and trade flows of Germany



Notes: Panel (a) plots monthly natural gas prices in US dollars per mmbtu. Europe: Netherlands Title Transfer Facility; US: spot price at Henry Hub, Louisiana. Japan: Liquefied natural gas import price. Source: World Bank Commodity Price Data. Panels (b) and (c) plot quarterly nominal trade flows of Germany in billions of euros with the rest of the world and Russia, respectively. Source: International Monetary Fund Direction of Trade Statistics. The vertical dashed line marks the end of 2022Q1.

denoted in US$. The vertical dashed line marks the end of 2022Q1 (the Russian invasion of Ukraine began on February 24, 2022). European prices show a run-up starting in 2021. To date, they still are about twice as high as before 2021. What is more, the fluctuations in prices after 2021 are unique to the European market. They suggest (or are at least consistent with) conditions of inelastic supply. This is perfectly in line with the frantic rerouting of supply and trade that followed the Russian invasion. Panels (b) and (c) plot the value of German trade – imports and exports alike. Panel (b) shows Germany's exports to and imports from the rest of the world in nominal terms. Both rose from 2021 onward, peaking in mid-2022 before falling in lockstep. Panel (c) focuses on the value of direct trade with Russia, which rose sharply before the war on the back of higher energy prices. Thereafter, with sanctions in place, trade with Russia fell precipitously.[22] The crisis scenario thus entertains a regime of fixed energy supply and adds to this a permanent cut of supply of 8 percent (calibrated so that energy prices are twice as high as in the baseline). This relates to conditions (1) and (2) mentioned above.

The final element, condition (3) concerns how – once the supply constraint binds – the costs

[22] In spite of the shortages, the remaining three German nuclear power plants were decommissioned only 3.5 months later than was originally planned, namely, in mid-April 2023. The supply of nuclear fuel, too, came historically from Russia.

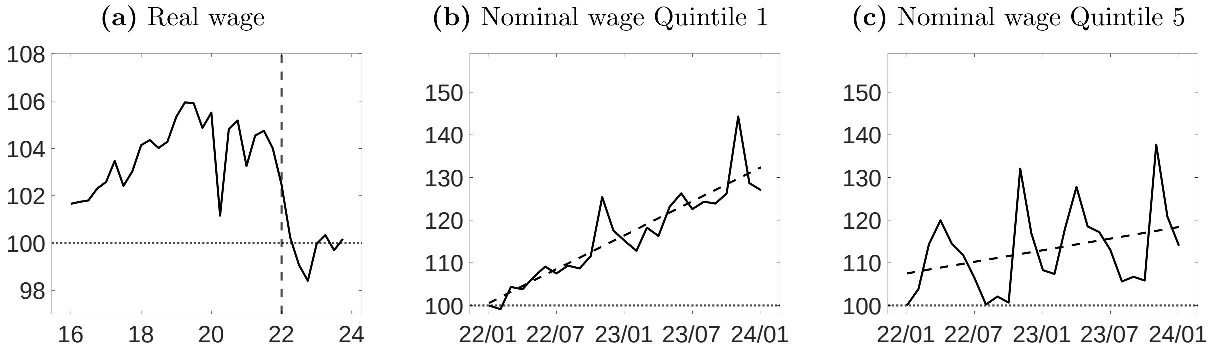
and incomes of agents with high marginal propensities to consume move with a still higher energy price. On the negative side, for hand-to-mouth households the expenditures for energy rise. On the positive side, this may be cushioned by fiscal transfers and labor income may rise if the rise in energy prices is due to demand. Regarding fiscal transfers, the number of programs that the German government implemented to "protect" households and firms from higher energy costs is legion. The crisis scenario assumes that fiscal policy lets two thirds of price changes pass through to households or firms, "protecting" households and firms from the remainder – that is, it sets $\tau_E^c = \tau_E^f = 0.33$. The scenario is conservative in that it only refers to prices in deviation from the new higher-price steady state.[23] Lastly, and perhaps most contentiously, the crisis scenario assumes that nominal wage rigidities no longer restrain wage demand so that $\psi^w = 0$. The scenario is built around a tight labor market in Germany, in which the unemployment rate for prime-aged workers stood at 3 percent at the end of 2021 – falling further to 2.8 percent by 2023Q1.[24] In addition, in this environment, wage flexibility may have been actively encouraged politically.[25] Wage developments are shown in Figure 2. On the back of higher energy costs, real wages fell sharply from mid-2021 to mid-2022, but then rapidly stabilized (Panel (a)) while inflation remained elevated. The recovery of real wages came with strong increases in nominal wages. Nominal wages rose about ten percent more for the lowest earnings quintile (Panel (b)) than for the top quintile (Panel (c)). The crisis scenario we build entertains the reading that this may be indicative of both wage flexibility and of wage pressures that support demand.

[23]The International Energy Agency's policy database lists energy price related policy measures. Among several, they include: double-digit cuts to taxes on natural gas and to electricity surcharges; postponing CO2-surchanges; energy cost transfers to poorer households, students, pensioners; and non-targeted transfers to all ("Energiepreispauschale"), besides transfers to energy-intensive firms, culminating in explicit price caps on electricity/natural gas/heating costs for households and firms ("Energiepreisbremsen").

[24]ILO definition. Similar patterns emerge for employment rates or participation, or other age groups.

[25]For example, since October 2022, employers in Germany have been able to grant their employees an amount of up to 3,000 euros free of tax and contributions as a voluntary benefit over and above the regular wage–the so-called "inflation compensation bonus", which the federal government has introduced by law. Also, the minimum wage was increased repeatedly.

Figure 2 Tight labor market in Germany



Notes: Panel (a) plots the seasonally adjusted quarterly real wage index. The vertical dashed line marks the end of 2022Q1. Panels (b) and (c) show the monthly nominal wage index for the lowest and highest quintiles of the wage distribution. The series we use start in 2022. Therefore, we did not seasonally adjust the series. This explains the seasonal spikes in Panels (b) and (c) (summer gratification and Christmas gratification). Source: German Federal Statistical Office.

4.2 Steady states

Table 2 reports the steady state of the economy. In each block, the left column refers to the baseline fixed-price scenario and the fixed-supply scenario which share the same steady state. The right column shows the "crisis" scenario's steady state. In the crisis scenario, the reduction in energy supply and the ensuing energy price increase mean that the expenditure share for energy in GDP doubles from 12 to 24 percent. Firms and households reduce their use of energy. Hand-to-mouth households reduce consumption of goods and energy by more than savers. This is the case even though the hand-to-mouth households raise their labor supply more. Consumption inequality increases, and GDP falls. All of this is in line with a sharp fall of the real wage.

4.3 Transmission of energy shocks in normal times

In order to allow a comparison with the literature, Figure 3 shows the transmission of an *exogenous* increase in the energy price in the fixed-price scenario (solid lines) and the transmission of a cut to energy supply with fixed supply (dashed-dotted lines). The shocks are calibrated to deliver a twenty percent increase in the energy price and have a persistence of

Table 2 Steady states in the scenarios

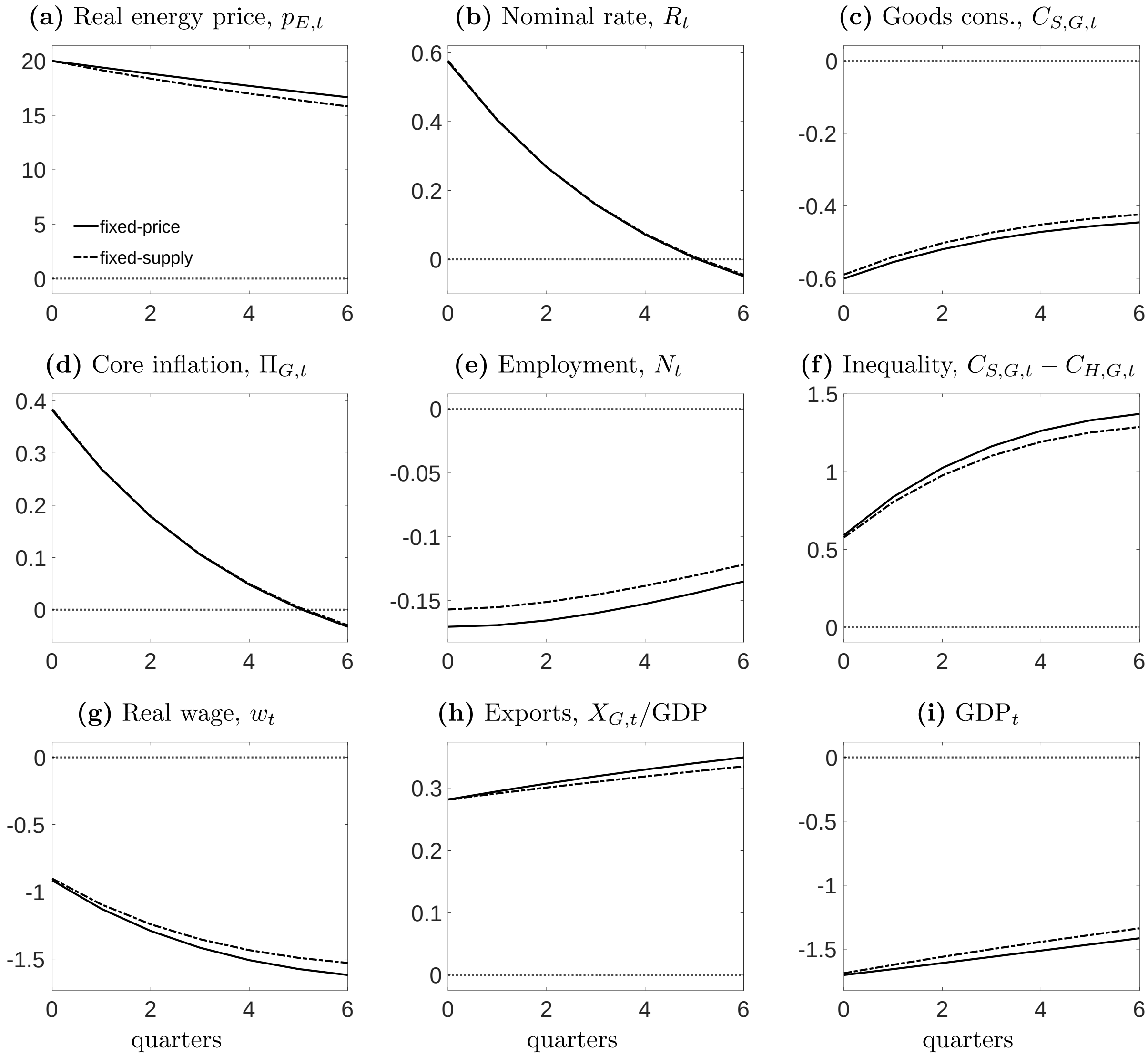
	Scenario				Scenario		
	P/Q	crisis			P/Q	crisis	
Consumption				Production, firms			
$C_{H,E}$	0.5	0.44	Energy cons. spender	GDP	1.259	1.176	
$C_{S,E}$	0.5	0.45	Energy cons. saver	Y_G	1	1.003	Production
C_E	0.5	0.448	Total energy cons.	p_G	1.309	1.269	Real goods price
$C_{H,G}$	0.923	0.835	Goods cons. spender	Λ	1.309	1.269	Real marginal costs
$C_{S,G}$	0.923	0.861	Goods cons. saver	D	0.131	0.127	Real profits
C_G	0.923	0.855	Total goods cons.				
Labor market				Energy, Foreign			
N_H	1	1.028	Labor spender	ξ_E	1.5	1.379	Energy supply
N_S	1	1.007	Labor savers	E	1	0.932	Energy used in prod.
N	1	1.012	Aggregate labor	p_E	0.101	0.205	Real energy price
w	1.209	1.069	Real wage	X_G	0.077	0.148	Real exports
Government				Implied ratios, in percent			
T_H	-0.071	-0.06	Lump-sum spender	$\frac{p_E C_E}{\text{GDP}}$	4	7.788	energy cons./GDP
T_S	-0.071	0	Lump-sum saver	$\frac{p_E E}{\text{GDP}}$	8	16.212	energy cost/GDP
R	1.005	1.005	Gross nominal rate	$\frac{p_E \xi_E}{\text{GDP}}$	12	24	total energy exp./GDP

Notes: The table reports steady-state values for all variables in the respective scenarios. P/Q refers to the fixed-price and fixed-supply scenarios. Note that T_H and T_S include taxes, profit income, and revenue from domestic energy ownership. GDP is as defined in Appendix B.4. Furthermore, in each steady state, $p_E^c = p_E^f = p_E$, $\Pi = \Pi_G = \Pi_W = 1$, and $b = 0$. In addition, steady-state values for C_H and C_G could be derived from equation (1), the value of Y^* from the definition of foreign income in Section 2.6.

0.97 – following Blanchard and Galí (2009). Because the two shocks are calibrated to have the same price effect, they also come with similar implications for quantities. A twenty percent increase in energy prices (Panel (a)) is associated with a decline in GDP of about 1.5 percent (Panel (i)). This is broadly in line with empirical estimates.[26] Not only does GDP fall, but so do wages (Panel (g)) and employment (Panel (e)). The distributional impact of the shock is pronounced. Savers' consumption (Panel (c)) falls but hand-to-mouth households' falls more than twice as much. To show this immediately, Panel (f) plots a measure of consumption inequality, namely, the difference between the consumption response of savers and of hand-to-mouth households. The reason is that hand-to-mouth households exclusively rely on

[26]See, for example, the effect of inventory demand shocks on global activity in Baumeister and Hamilton (2019), the SVAR-based findings in Blanchard and Galí (2009) and Blanchard and Riggi (2013), and the oil supply news shocks identified by Känzig (2021).

Figure 3 Fundamental energy shock under elastic and inelastic energy supply



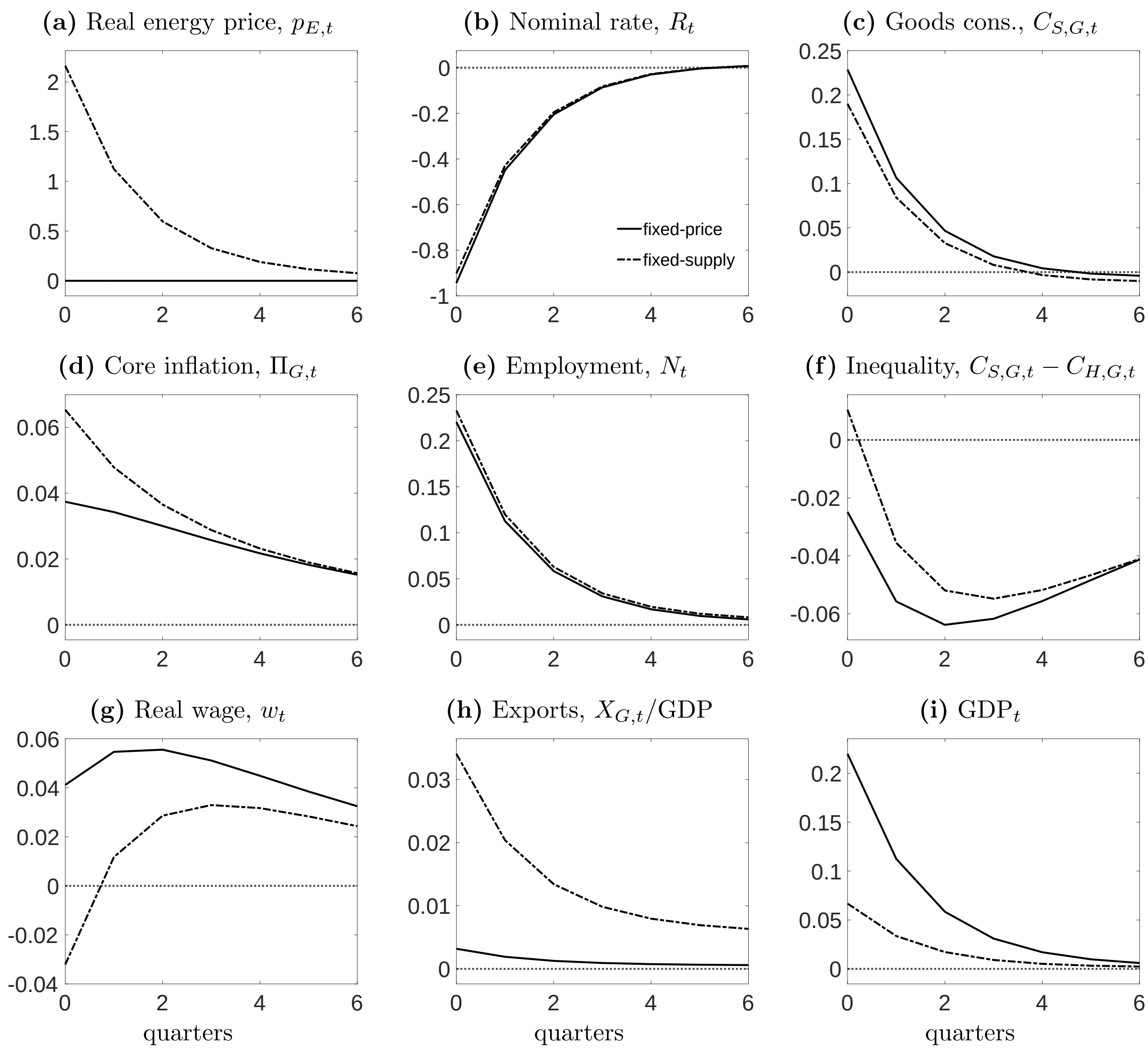
Notes: The figure plots impulse responses to an energy price shock in the fixed-price regime and an energy supply shock in the fixed-supply regime; scaled to raise the real energy price by twenty percent on impact and with persistence of 0.97. All responses give percentage deviations from the steady state. The exception is the response of exports (in percent of steady-state GDP). Interest rates and inflation rates are in annualized percentage points. Inequality is the difference between the responses of consumption of savers and hand-to-mouth households.

falling labor income whereas savers' incomes are partially cushioned by rising markups and energy revenues. Inflation (Panel (d)), meanwhile, rises. Clearly, such fundamental energy shocks are supply shocks. We, instead, wish to analyze how supply constraints, once they are in place, shape the business cycle and the transmission of monetary and fiscal policy, in particular. We do this next.

4.4 Monetary and fiscal transmission and the supply regime

The current section explores how the supply constraints change the economy's response to monetary and fiscal policy. As discussed in Section 3, the constraints affect the transmission of policy both through the supply side and the demand side, affecting the slope of both the Phillips curve and the IS curve. Figure 4 plots the dynamics in response to a monetary

Figure 4 Monetary policy shock under elastic and inelastic energy supply



Notes: The figure plots impulse responses to a 25 basis point (not annualized) monetary easing in the fixed-price and the fixed-supply regime with persistence of 0.5. For a definition of the variables see the notes to Figure 3.

easing. The solid line in each panel represents the baseline where the energy price is fixed and the energy supply potentially abundant. The dashed line instead represents the fixed-supply situation where energy supply is constrained and the energy price is assumed to be responsive to economic activity.[27]

In either supply regime, the monetary easing (Panel (b)) induces savers to increase demand for goods (Panel (c)). Production rises on the back of rising aggregate demand, and so does employment (Panel (e)). Wage rigidity means that real wages move little (Panel (g)). While this rigidity alone dampens the distributional impact, hand-to-mouth households still tend to be more positively affected by the easing than savers: consumption of hand-to-mouth households rises by more than the consumption of savers (the entries in Panel (f) are negative). The reason is that savers lose from falling markups.

When energy supply is fixed (dashed lines), instead, the cyclical distribution of income changes markedly, with reverberations on the demand side. Now the energy market clears through a rise in the energy *price* (Panel (a)). For consumers and firms this is akin to a tax on the use of energy, a tax to the benefit of the owners of energy (savers and the foreign economy). As a result, the distributional consequences of the easing are less favorable for hand-to-mouth households (Panel (f)) and the rise in aggregate consumption is weaker. GDP (Panel (i)) rises by notably less, too, since a rising real value of imports more than compensates for the rise in exports (recall that Foreign's MPC is less than unity).

The Phillips curve, furthermore, clearly steepens (recall Section 3.4) upon a change toward a fixed-supply regime.[28] With energy prices responding to local activity, marginal costs become more responsive as well. For the same monetary easing, core inflation (Panel (d)) rises twice as much as in the regime with a fixed price of energy.

Taking the effects on the supply and demand side together, the fixed supply regime here means that a monetary easing is less expansionary and more inflationary. The impulse responses above are based on a linearized model. A monetary tightening then would have implications that are just of opposite sign. Framed in terms of the "sacrifice ratio" Figure 4,

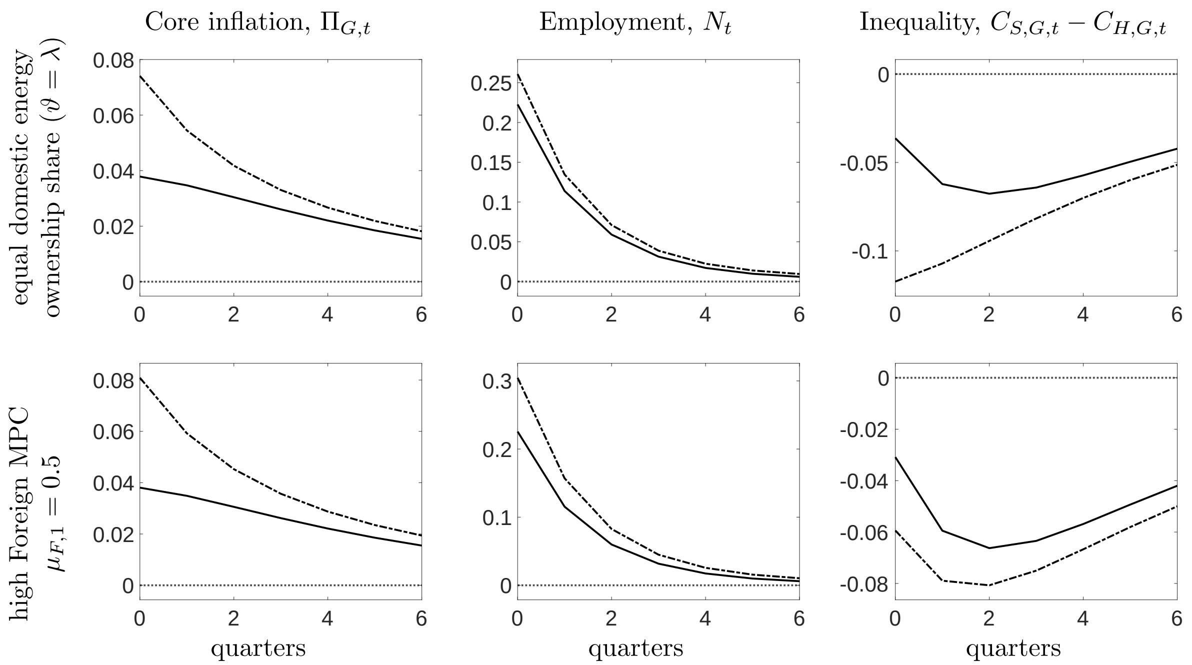
[27] Recall that the steady state level and steady state price of energy are the same in both scenarios.

[28] For visual impression, Appendix F plots the Phillips curve's slope under the assumptions of Section 3.

thus, shows that in order to bring down core (or headline) inflation by a certain amount, once energy supply constraints are in place monetary policy has to sacrifice notably less real activity and consumption.

Figure 5 zooms in further on the role of two of the demand-side determinants of the transmission of monetary shocks. The first row assumes that the domestic energy supply is owned

Figure 5 Monetary shock: Supply regime and distribution of income

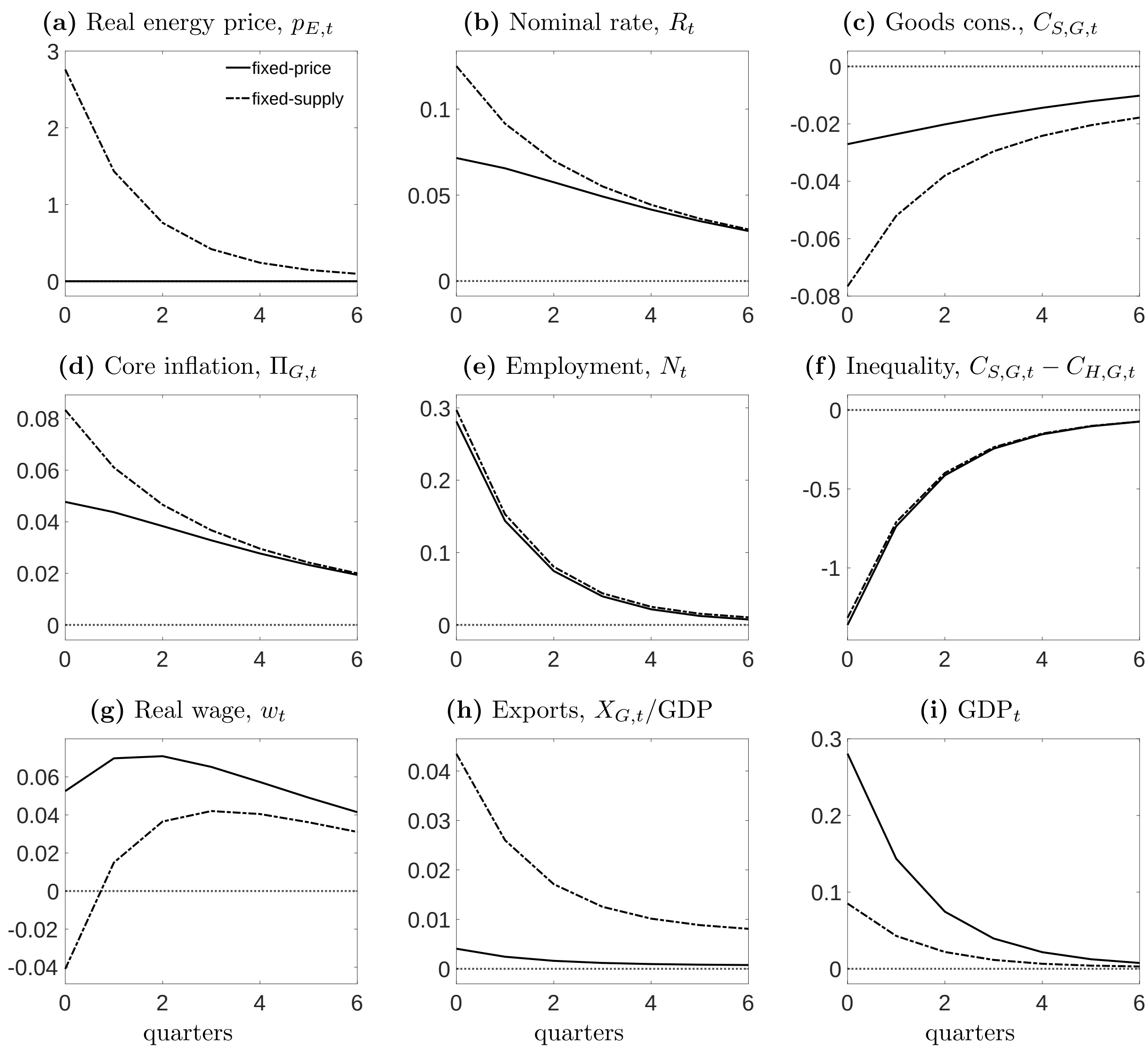


Notes: Same as Figure 4, but varying parts of the calibration.

not only by savers but in equal measure by hand-to-mouth households. This assumption, therefore, means that hand-to-mouth households no longer pay an implicit tax when energy prices rise. The second row shows the transmission of monetary policy if Foreign's MPC out of energy revenues is larger than in the baseline. A higher foreign MPC means that when energy prices rise foreign demand rises more strongly. Both of these alternative assumptions mean that supply constraints amplify the distributional and aggregate effects of monetary policy more than in the baseline parameterization. A monetary easing would be relatively more favorable for hand-to-mouth households.

The above discussion has dissected the implications of the supply constraint for a monetary policy shock. Figure 6 focuses on a temporary fiscal transfer to hand-to-mouth households, a common policy measure in recent years. The transfer is scaled to amount to one percent of hand-to-mouth households' steady state income. The fiscal transfer first and foremost directly

Figure 6 Transfer shock under elastic and inelastic energy supply



Notes: The figure plots impulse responses to a fiscal transfer of one percent of steady-state income of hand-to-mouth households from savers to hand-to-mouth households in the fixed-price and the fixed-supply regime with persistence of 0.5. For a definition of the variables see the notes to Figure 3.

benefits hand-to-mouth households. The transfer, thus, reduces "consumption inequality" between savers and hand-to-mouth households (Panel (f)) in either supply regime. However, with supply constraints, the same fiscal stimulus leads to higher core inflation (Panel (b)) at virtually the same employment response and at a substantially muted response of consumption (Panel (c)) and GDP (Panel (i)): the transfer multiplier is curtailed in this scenario. The reason for this is that with supply constraints redistributing from low- to high-MPC households increases demand and thereby the energy price (Panel (a)). This raises firms' marginal costs so that core inflation increases by more. At the same time, the higher energy price redistributes resources to the Foreign economy, which dampens the expansion of GDP. Local supply constraints render the constrained factor's price endogenous to local economic activity. For the case of energy, the current section showed that such constraints, thereby, likely make a given monetary or fiscal stimulus more inflationary, less expansionary, and less favorable for constrained (hand-to-mouth) households.

4.5 A feedback loop during a crisis?

Next, we turn to the "crisis scenario." This scenario renders the distributional dimensions of the supply constraint more important, for three reasons: first, the constrained factor has a larger weight in GDP to start with; second, wages are more flexible than usual so that domestic redistribution is more important and, third, fiscal policy shields households' and firms' budgets from movements in the constrained factor's price meaning that – at an individual level – these agents are not subject to the same transfer of income to the owners of energy when energy prices rise. The section underscores the theoretical result from Section 3 that supply constraints can give rise to self-fulfilling cyclical fluctuations.

The mechanism for this is as follows. Consider a demand-driven boom for the sake of exposition. The crisis scenario has a fixed supply of energy. Aggregate demand in our environment comes from three types of agents: domestic hand-to-mouth households, the energy-exporting foreign economy, and domestic Ricardian households – ranked here from highest MPC out of income to lowest. The key to a demand-driven boom is that incomes are redistributed from savers to the former two types of agents. In the boom, wages rise to entice workers to supply labor, while energy prices (and, thus, Foreign's income) increase further amid high aggregate demand. As a result, markups fall. This leads to redistribution away from savers. Meanwhile, energy price related subsidies help sustain aggregate demand and the demand for energy in spite of high energy prices.

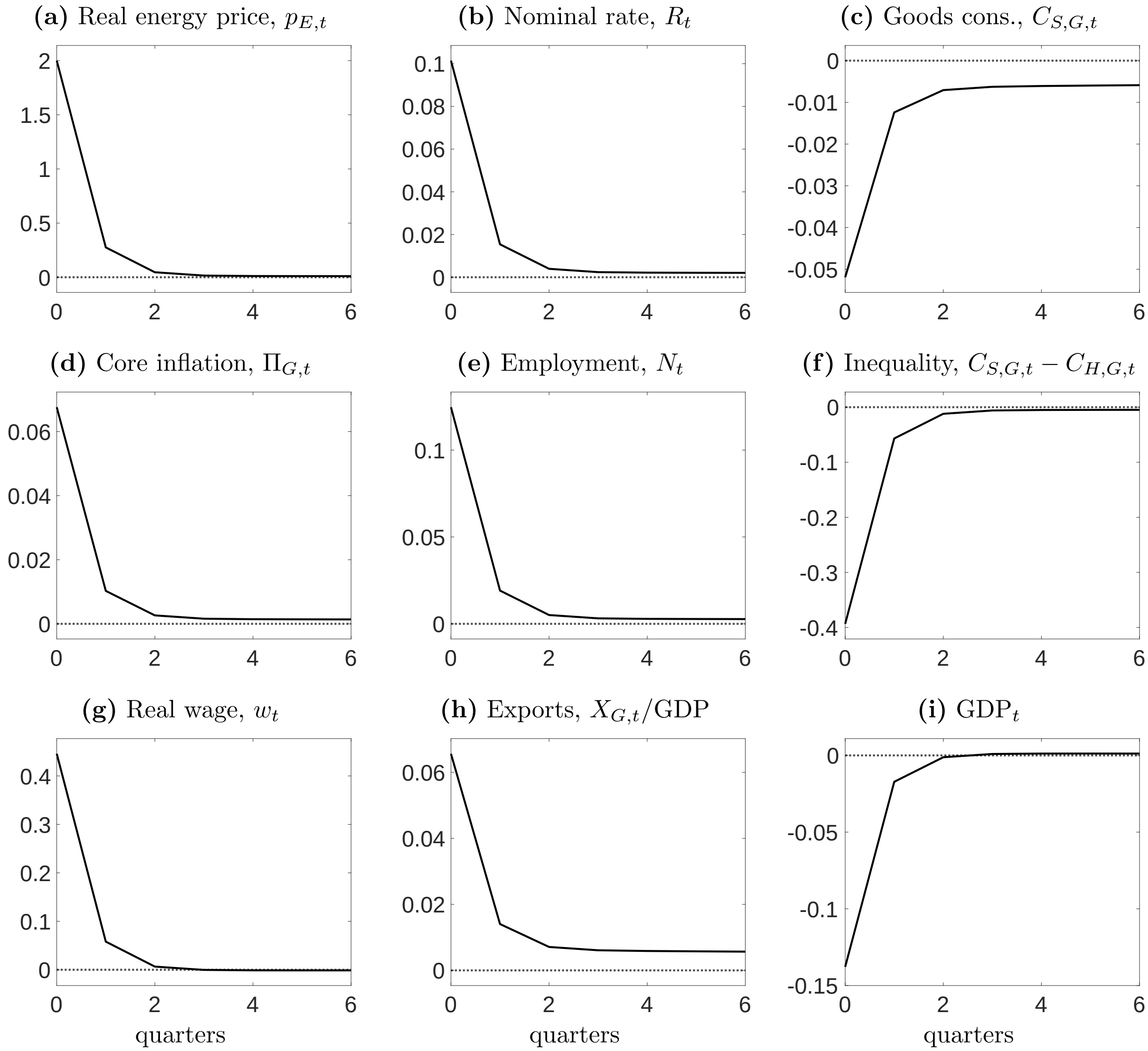
To see this mechanism at work graphically, we plot in Figure 7 impulse responses to a sunspot shock in the "crisis" scenario where numerically exactly one explosive root is missing to satisfy the Blanchard-Kahn conditions. Thus, there is exactly one degree of indeterminacy and room for exactly one possible sunspot shock. To compute the impulse responses to this shock, we use the methodology of Bianchi and Nicolò (2021). Theory determines the persistence of the sunspot shock, but not its magnitude – nor does it pin down the sign of the shock. The reader could, thus, just as well turn around the sign of the impulse responses and think of a recessionary sunspot shock.[29] In the figure, we somewhat arbitrarily anchor the shock's size such that it comes along with an increase in the energy price of two percent (Panel (a)), with the magnitude of the price increase thus being a tenth of what we plot in Figure 3.[30]

With a 33 percent energy subsidy in place, energy prices for domestic users (households and firms) rise 1.3 percent. The sunspot supports higher core inflation for about three quarters (Panel (d)) reflecting the fact that firms face higher marginal costs. In line with the Taylor principle, the central bank raises the nominal interest rate more than one for one with core inflation (Panel (b)). A higher real interest rate means that savers' consumption falls (Panel (c)). Nevertheless, under the sunspot beliefs, output in Home rises about 0.1 percent (not shown). This increase requires a rise in employment (Panel (e)) even if the fact that households reduce their energy consumption (not shown) means that firms can increase their use of energy somewhat. On the demand side, the increase in economic activity is supported by two developments, each linked to the distribution of income. First, under the sunspot belief of higher energy prices, Foreign's revenues rise. In our calibration, Foreign uses one-fourth of the rise in revenues for buying goods from Home (Panel (h)). A second effect,

[29] Recall that we look at a linear approximation of the model.

[30] It is important to bear in mind that Figure 3 shows the effect of a fundamental shock to the energy price. Figure 7, instead, shows the response to a sunspot shock when the supply of energy is fixed. In Figure 7, the energy price rises *endogenously* with the higher price being a symptom of higher demand.

Figure 7 Sunspot shock in the "crisis" scenario



Notes: The figure plots impulse responses to a sunspot shock in the wake of which energy prices by two percent in the crisis scenario. For a definition of the variables see the notes to Figure 3.

which is directly linked to the heterogeneity of households, is that the domestic demand for consumption goods as a whole does not fall until sometime after the shock (not shown). The reason is the following: While savers retrench their consumption demand, the hand-to-mouth households' budgets initially are supported by a stronger labor market. Namely, labor demand rises – and so does the real wage (Panel (g)). Accordingly, the measure of "consumption inequality" decreases (Panel (f)). That said, in all these dynamics GDP falls because value added falls on the back of higher costs for energy imports (Panel (i)).

In the feedback loop, high energy prices are a *symptom* of high demand meeting supply constraints. Thus, the key policy implication is that monetary and fiscal policy can avoid the loop if they lean sufficiently strongly against demand (being tighter in a boom and looser in a recession). Appendix G provides a detailed discussion of the fiscal and monetary policy options that prevent the feedback loop. A key result is that a monetary response to headline, rather than core, inflation at conventional strengths would be sufficient to ensure determinacy in our crisis scenario, as would a response to input price inflation.

5 Conclusions

What is the effect of supply constraints on monetary transmission and macroeconomic stability? To provide an answer, we use a tractable New Keynesian open economy model with heterogeneous households in which the supply of an essential input factor is constrained. In this setting, the supply constraint changes the cyclicality of marginal costs and inflation. Moreover, through input substitution the supply constraint also affects the cyclicality of wages and profits and – of course – it directly affects the cyclicality of revenue from the constrained factor itself. We show how, depending on the ownership of these streams of income, supply constraints dampen or amplify the cyclicality of aggregate demand and the effectiveness of stabilization policy.

Next to theory, we provide a quantitative application to the German economy. Here we look at the supply constraints of energy that emerged at the beginning of 2022, around the time of the Russian invasion of Ukraine. In light of the ownership structure and use of energy in the German economy, energy supply constraints make both monetary and fiscal stimulus more inflationary and less effective at stimulating domestic demand.

We also entertain one, perhaps more subjective, interpretation of the economic environment in the energy crisis. Here, subsidies shield households and firms from energy price increases and a tight labor market gives rise to more flexible wages. We show that in this environment the conventional wisdom that the central bank should "see through" energy price movements could give rise to a sunspot equilibrium in which higher (lower) energy prices go hand in hand with higher (lower) economic activity. In sum, our analysis highlights that supply constraints make calibrating the fiscal and monetary response to the business cycle more difficult as the constraint shifts key macroeconomic elasticities.

References

Airaudo, M. and Zanna, L.-F. (2012). Equilibrium Determinacy and Inflation Measures for Interest Rate Rules. *Review of Economic Dynamics* **15** (4), 573–592.

Álvarez-Lois, P. P. (2006). Endogenous Capacity Utilization and Macroeconomic Persistence. *Journal of Monetary Economics* **53** (8), 2213–2237.

Aoki, K. (2001). Optimal Monetary Policy Responses to Relative-Price Changes. *Journal of Monetary Economics* **48** (1), 55–80.

Arroyo Marioli, F. and Vegh, C. A. (2023). Fiscal Procyclicality in Commodity Exporting Countries: How Much Does It Pour and Why? NBER Working Paper 31431.

Auclert, A., Monnery, H., Rognlie, M. and Straub, L. (2023). Managing an Energy Shock: Fiscal and Monetary Policy. NBER Working Paper 31543.

Bachmann, R., Baqaee, D., Bayer, C., Kuhn, M., Löschel, A., Moll, B., Peichl, A., Pittel, K. and Schularick, M. (2022). What If? The Economic Effects for Germany of a Stop of Energy Imports from Russia. ECONtribute Policy Brief.

Balleer, A. and Noeller, M. (2023). Monetary Policy in the Presence of Supply Constraints: Evidence from German Firm-Level Data. CESifo Working Paper Series 10261.

Baumeister, C. and Hamilton, J. D. (2019). Structural Interpretation of Vector Autoregressions with Incomplete Identification: Revisiting the Role of Oil Supply and Demand Shocks. *American Economic Review* **109** (5), 1873–1910.

BDEW (2023). Die Energieversorgung 2022 – Jahresbericht. Bundesverband der Energie- und Wasserwirtschaft e.V.

Bianchi, F. and Nicolò, G. (2021). A Generalized Approach to Indeterminacy in Linear Rational Expectations Models. *Quantitative Economics* **12** (3), 843–868.

Bilbiie, F. O. (2008). Limited Asset Market Participation, Monetary Policy and (Inverted) Aggregate Demand Logic. *Journal of Economic Theory* **140** (1), 162–196.

– (2021). Monetary Policy and Heterogeneity: An Analytical Framework. Mimeo, Cambridge University.

Blanchard, O. J. and Galí, J. (2009). The Macroeconomic Effects of Oil Shocks: Why Are the 2000s so Different from the 1970s. In: Galí, J. and Gertler, M. (eds.). *International Dimension of Monetary Policy.* University of Chicago Press, 373–428.

Blanchard, O. J. and Riggi, M. (2013). Why Are the 2000s so Different from the 1970s? A Structural Interpretation of Changes in the Macroeconomic Effects of Oil Prices. *Journal of the European Economic Association* **11** (5), 1032–1052.

Blanchard, O. J. and Kahn, C. M. (1980). The Solution of Linear Difference Models under Rational Expectations. *Econometrica* **48** (5), 1305–1311.

Bodenstein, M., Erceg, C. and Guerrieri, L. (2008). Optimal Monetary Policy with Distinct Core and Headline Inflation Rates. *Journal of Monetary Economics* **55**, 18–33.

Boehm, C. E. and Pandalai-Nayar, N. (2022). Convex Supply Curves. *American Economic Review* **112** (12), 3941–3969.

Carlstrom, C. T., Fuerst, T. S. and Ghironi, F. (2006). Does It Matter (for Equilibrium Determinacy) What Price Index the Central Bank Targets? *Journal of Economic Theory* **128** (1), 214–231.

Colciago, A. (2011). Rule-Of-Thumb Consumers Meet Sticky Wages. *Journal of Money, Credit and Banking* **43** (2-3), 325–353.

Comin, D. A., Johnson, R. C. and Jones, C. J. (2023). Supply Chain Constraints and Inflation. NBER Working Paper 31179.

Datta, D., Johannsen, B., Kwon, H. and Vigfusson, R. (2021). Oil, Equities, and the Zero Lower Bound. *American Economic Journal: Macroeconomics* **13** (2), 214–253.

Drechsel, T. and Tenreyro, S. (2018). Commodity Booms and Busts in Emerging Economies. *Journal of International Economics* **112**, 200–218.

Eggertsson, G. B. (2011). What Fiscal Policy Is Effective at Zero Interest Rates? *NBER Macroeconomics Annual* **25** (1), 59–112.

Elminejad, A., Havranek, T., Horvath, R. and Irsova, Z. (2023). Intertemporal Substitution in Labor Supply: A Meta-Analysis. *Review of Economic Dynamics* **51**, 1095–1113.

Fagnart, J.-F., Licandro, O. and Portier, F. (1999). Firm Heterogeneity, Capacity Utilization, and the Business Cycle. *Review of Economic Dynamics* **2** (2), 433–455.

Fried, S., Novan, K. and Peterman, W. B. (2022). Understanding the Inequality and Welfare Impacts of Carbon Tax Policies. Mimeo, FRBSF.

Havránek, T. (2015). Measuring Intertemporal Substitution: The Importance of Method Choices and Selective Reporting. *Journal of the European Economic Association* **13** (6), 1180–1204.

Johnson, S., Rachel, L. and Wolfram, C. (2023). A Theory of Price Caps on Non-Renewable Resources. NBER Working Paper 31347.

Känzig, D. R. (2021). The Macroeconomic Effects of Oil Supply News: Evidence from Opec Announcements. *American Economic Review* **111** (4), 1092–1125.

– (2023). The Unequal Consequences of Carbon Pricing. NBER Working Paper 31221.

Kara, E. and Yates, T. (2021). A Case against a 4% Inflation Target. *Journal of Money, Credit and Banking* **53** (5), 1097–1119.

Kharroubi, E. and Smets, F. (2023). Energy Shocks As Keynesian Supply Shocks: Implications for Fiscal Policy. BIS Working Paper 1120.

Kuhn, F. and George, C. (2019). Business Cycle Implications of Capacity Constraints under Demand Shocks. *Review of Economic Dynamics* **32**, 94–121.

Kumhof, M., Nunes, R. and Yakadina, I. (2010). Simple Monetary Rules under Fiscal Dominance. *Journal of Money, Credit and Banking* **42** (1), 63–92.

Leeper, E. M. (1991). Equilibria under 'Active' and 'Passive' Monetary and Fiscal Policies. *Journal of Monetary Economics* **27** (1), 129–147.

Mertens, K. R. S. M. and Ravn, M. O. (2014). Fiscal Policy in an Expectations-Driven Liquidity Trap. *The Review of Economic Studies* **81** (4), 1637–1667.

Olivi, A., Sterk, V. and Xhani, D. (2022). Monetary Policy during a Cost-Of-Living Crisis. Mimeo, UCL.

Pieroni, V. (2023). Energy Shortages and Aggregate Demand: Output Loss and Unequal Burden from HANK. *European Economic Review* **154**, 104428.

Schmitt-Grohé, S. and Uribe, M. (2007). Optimal Simple and Implementable Monetary and Fiscal Rules. *Journal of Monetary Economics* **54** (6), 1702–1725.

Slacalek, J., Tristani, O. and Violante, G. L. (2020). Household Balance Sheet Channels of Monetary Policy: A Back of the Envelope Calculation for the Euro Area. *Journal of Economic Dynamics and Control* **115**, 103879.

Swanson, E. T. (2012). Risk Aversion and the Labor Margin in Dynamic Equilibrium Models. *American Economic Review* **102** (4), 1663–91.

Woodford, M. (2003). *Interest and Prices*. Princeton University Press.