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A Foreign Economy Model for MAKRO

Emil H. Partsch and Tamas Vasi

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Emil Holst Partsch* Tamas Vasi†
DREAM, Copenhagen DREAM, Copenhagen

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Abstract

This paper presents a foreign economy model designed for integration into the MAKRO framework, capturing plausible dynamics of foreign economic variables for small open economies like Denmark. The model assumes the rest of the world operates as a closed economy, providing external input values such as foreign prices, output, and interest rates.

[1]DREAM, Danish Research Institute for Economic Analysis and Modelling, Landgreven 4, Copenhagen K, DK-1301 Denmark. E-mail: emipar@dreamgruppen.dk.

[2]DREAM, Danish Research Institute for Economic Analysis and Modelling, Landgreven 4, Copenhagen K, DK-1301 Denmark. E-mail: tamvas@dreamgruppen.dk. The authors thank Jeppe Kinslev for outstanding research assistance.

1 Introduction

This paper presents a foreign economy model for use with MAKRO. Since all foreign variables in MAKRO are exogenous, any shock to variables like foreign interest rates requires corresponding adjustments to foreign prices and output. Our framework guides these adjustments by combining a medium-scale DSGE model in the tradition of Smets and Wouters (2003) with a VAR-system for the oil sector, both estimated using U.S. data.

Following the convention of policy models for small open economies, we model the rest of the world as a single closed economy.[1] This approach assumes that Denmark's relatively small size allows us to disregard trade interactions between Denmark and the world. The resulting foreign variables—including prices, output, and oil prices—can serve as inputs for MAKRO, enabling plausible foreign economy movements for various counterfactual exercises, both medium-term and long-term transitionary trends.[2]

The remainder of the paper proceeds as follows: Section 2 presents the structural foreign economy model, Section 3 presents our dynamic calibration through impulse response matching against an identified monetary policy shock, Section 4 describes the estimated VAR system for the U.S. oil market, and finally Section 5 demonstrates how the foreign economy outputs map to the MAKRO model for an interest rate shock.

2 Structural Model

We first present a structural model of the world economy.

2.1 Households

Infinitely-lived households enjoy utility from consumption and holding liquid wealth, the latter implying a soft credit constraint on liquidity.

$$\sum_{t=0}^{\infty} \beta \left[\frac{\left(C_t - h\tilde{C}_{t-1} - \gamma_c Y_t^{\text{liquid}} \right)^{1-\sigma}}{1-\sigma} + \xi \frac{B_{t-1}^{1-\sigma}}{1-\sigma} \right] \tag{1}$$

where h is a parameter that controls the degree of (external) consumption habits over aggregate consumption, γ_c is a weight on a reference consumption term that tracks liquid income ("splurge" or "hand-to-mouth" factor), $\tilde{C}$ is the (external) reference consumption stock, β is

[1] See for example the Swedish Ministry of Finance model, SELMA, Akkaya et al. (2024).

[2] The source code for MAKRO is available on GitHub, where the foreign economy is located in the "Foreign_Economy" subfolder.

the discount rate, and C is a bundle of consumption. The household budget constraint is given by (in real terms, i.e. deflated by the goods price)

$$C_t + B_t + K_t = W_t L_t + R_t^B B_{t-1} + R_t^K K_{t-1} + T_t \tag{2}$$

where W_t are wages, L_t is labor supply (described later), and where we let government bonds be liquid assets with return $R_t^B = 1 + r_t^b$ and capital with return $R_t^K = r_t^k - q_t\delta$. Note that q_t is the price of capital, and δ depreciation. T_t are taxes and transfers (dividends from firms). Finally, let liquid income be defined as liquid "cash-on-hand":

$$Y_t^{\text{liquid}} = W_t L_t + R_t^B B_{t-1} - \tau_t + \gamma_{he}\pi_t \tag{3}$$

where τ_t are taxes, with π_t being the consumption bundle inflation rate and γ_{he} a weight. The latter term is a short-hand modeling device to capture home equity liquidity from house price gains (since housing is implicitly a part of consumer price indices), which helps with pro-cyclical model properties. We do not include capital in the splurge term, as empirically, marginal propensities to consume are small out of capital gains (cf. Auclert et al. (2020)). Our setup yields Euler equations in both bonds and capital

$$\left(C_t - h\tilde{C}_{t-1} - \gamma_c Y_t^{\text{liquid}}\right)^{-\sigma} = \beta R_t^B \left(C_{t+1} - h\tilde{C}_t - \gamma_c Y_{t+1}^{\text{liquid}}\right)^{-\sigma} + \beta\xi B_t^{-\sigma} \tag{4}$$

$$\left(C_t - h\tilde{C}_{t-1} - \gamma_c Y_t^{\text{liquid}}\right)^{-\sigma} = \beta R_t^K \left(C_{t+1} - h\tilde{C}_t - \gamma_c Y_{t+1}^{\text{liquid}}\right)^{-\sigma} \tag{5}$$

2.2 Firms

2.2.1 Price setting

Consider a continuum of monopolistically competitive firms that set prices in a staggered manner following *Calvo (1983)*. Each period, a fraction $1-\theta$ of firms can reset their prices, while the remaining fraction θ keeps prices unchanged.

Firm's Problem A firm that resets its price P_t^* in period t maximizes expected discounted profits:

$$\max_{P_t^*} \sum_{k=0}^{\infty} \theta^k \beta^k \mathbb{E}_t \left[\beta \left(P_t^* Y_{t+k|t} - MC_{t+k} Y_{t+k|t}\right)\right], \tag{6}$$

where: β is the discount factor, $Y_{t+k|t}$ is the demand given by *Dixit-Stiglitz aggregation*:

$$Y_{t+k|t} = \left(\frac{P_t^*}{P_{t+k}}\right)^{-\varepsilon} Y_{t+k}, \tag{7}$$

and MC_{t+k} is marginal cost.

Using the demand function, the firm's optimization problem becomes:

$$\max_{P_t^*} \sum_{k=0}^{\infty} \theta^k \beta^k \mathbb{E}_t \left[\beta Y_{t+k} \left(\left(\frac{P_t^*}{P_{t+k}}\right)^{1-\varepsilon} - MC_{t+k}\left(\frac{P_t^*}{P_{t+k}}\right)^{-\varepsilon}\right)\right]. \tag{8}$$

Taking the first-order condition (FOC):

$$\sum_{k=0}^{\infty} \theta^k \beta^k \mathbb{E}_t \left[\beta Y_{t+k} P_{t+k}^{-\varepsilon} \left((1-\varepsilon) + \varepsilon MC_{t+k} P_{t+k}^{-1}\right)\right] = 0. \tag{9}$$

Defining real marginal cost as $m_t = MC_t / P_t$, we get:

$$\sum_{k=0}^{\infty} \theta^k \beta^k \mathbb{E}_t \left[\beta Y_{t+k} P_{t+k}^{-\varepsilon} \left((1-\varepsilon) + \varepsilon m_{t+k} P_{t+k}^{-1}\right)\right] = 0. \tag{10}$$

Log-Linearization For numerical simplicity, we work with log-linearized Phillips curves.

Define inflation as $\pi_t = \log P_t - \log P_{t-1}$. The aggregate price level evolves as:

$$P_t^{1-\varepsilon} = \theta P_{t-1}^{1-\varepsilon} + (1-\theta) P_t^{*1-\varepsilon}. \tag{11}$$

Taking logs and using a first-order approximation:

$$p_t^* - p_t \approx \frac{\theta}{1-\theta}(p_{t-1} - p_t). \tag{12}$$

Approximating further, we obtain:

$$p_t^* - p_t \approx \kappa m_t, \tag{13}$$

where $\kappa \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta}$.

Standard Phillips-curve expression The standard expression is:

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \lambda mc_t, \tag{14}$$

where $\lambda = \kappa \times$ elasticity of marginal cost with respect to output.

Hybrid Phillips curve Galí and Gertler (1999) find that the standard New-Keynesian Phillips Curve (NKPC) has too little persistence as compared to data. Therefore, following them, we introduce a backward looking sticky price component. Specifically, a subset of firms ω have backward-looking behavior such that the aggregate price level is

$$p_t = \theta p_{t-1} + (1-\theta)\bar{p}_t^* \tag{15}$$

where $\bar{p}_t^*$ is now an index of prices based on both backward and forward looking behavior, that is

$$\bar{p}_t^* = \omega p_t^b + (1-\omega) p_t^f \tag{16}$$

where p_t^f is the standard forward-looking price and p_t^b is the price set by a backward-looking rule of thumb as

$$p_t^b = \bar{p_{t-1}}^* - \pi_{t-1} \tag{17}$$

Backward-looking price setting behavior is then that prices are fixed to their equilibrium level in the previous period, corrected for past inflation.

This setup yields a **Hybrid** NKPC as

$$\pi_t = \lambda mc_t + \gamma_f E_t \{\pi_{t+1}\} + \gamma_b \pi_{t-1} \tag{18}$$

where $\lambda = \frac{(1-\omega)(1-\theta)(1-\beta\theta)(1-\alpha)}{\phi[1+\alpha(\varepsilon-1)]}$, with $\gamma_f = \beta\theta\phi^{-1}, \gamma_b = \omega\phi^{-1}$ and $\phi = \theta + \omega[1-\theta(1-\beta)]$.

2.2.2 Real side

The production side of the economy uses Cobb-Douglas technology and has capacity utilization, u_t, of total-factor productivity.

The maximization problem is

$$\max_{L_t, K_t, u_t} u_t Z_t K_t^{\alpha} L_t^{1-\alpha} - W_t L_t - r_t^k K_t - \chi_1 (u_t - \tilde{u}) - \frac{\chi_2}{2} (u_t - \tilde{u})^2 \tag{19}$$

where α is the capital share of production, Z_t is total-factor productivity, $\chi_1 > 0, \chi_2 > 0$ are capacity utilization adjustment costs and $\tilde{u}$ is zero-cost level of technology utilization.

Aggregate output is:

$$Y_t = u_t Z_t K_t^{\alpha} L_t^{1-\alpha} \tag{20}$$

The setup implies that the marginal cost is:

$$MC_t = \frac{W_t^{1-\alpha} r_t^{k\alpha}}{u_t Z_t}. \tag{21}$$

Firms demand labor until the marginal product of labor equals the real wage:

$$u_t Z_t (1-\alpha) \frac{Y_t}{L_t} = W_t. \tag{22}$$

Firms demand capital until the marginal product of capital equals the real rental rate:

$$u_t Z_t \alpha \frac{Y_t}{K_t} = r_t^k. \tag{23}$$

For ease of implementation, we can work with relative factor prices as

$$\frac{W_t}{r_t^k} = \frac{1-\alpha}{\alpha} \frac{K_t}{L_t} \tag{24}$$

Finally, the first-order condition with respect to capacity utilzation yields

$$u_t = \frac{Z_t K_t^{\alpha} L_t^{1-\alpha} - \chi_1 + \chi_2 \tilde{u}}{\chi_2} \tag{25}$$

2.3 Capital producers

Following Bayer et al. (2023), we introduce investment adjustment costs in a simple way by letting there be a capital producer.

Capital producers choose investment, I_t, and take the price of capital, q_t, as given. Investments are subject to quadratic adjustment costs, and capital producers objective is given as

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t I_t \left\{ q_t \left[1 - \frac{\phi}{2} \left(\log \frac{I_t}{I_{t-1}} \right)^2 \right] - 1 \right\} \tag{26}$$

Optimality implies (dropping higher order terms)

$$q_t \left[1 - \phi \log \frac{I_t}{I_{t-1}}\right] = 1 - \beta \mathbb{E}_t \left[q_{t+1} \phi \log \left(\frac{I_{t+1}}{I_t}\right)\right]. \tag{27}$$

For numerical stability, we work directly with the log-linearized version as (converted to decimal deviations)

$$q_t - q = \phi(1+\beta)\frac{I_t - I}{I} - \phi \frac{I_{t-1} - I}{I} - \beta\phi \mathbb{E}t \left[\frac{I_{t+1} - I}{I}\right] \tag{28}$$

Note that the q_{t+1} term cancels out as it is a higher-order term (product of two small deviations), which can be ignored in the first-order approximation.

Assuming that investment adjustment costs are virtual, the law of motion for capital is trivially given by

$$I_t = K_t - (1-\delta) K_{t-1} \tag{29}$$

Letting δ be the rate of depreciation on capital, this setup implies that the households' gross return on capital is given by $R_t^K = 1 + r_t^k - q_t \delta$, where r_t^k is the capital interest rate.

2.4 Labor unions

As is common in policy models, we also introduce wage stickiness (see e.g. Auclert et al. (2020), Christiano et al. (2005) and Smets and Wouters (2007)).

In particular, each household provides differentiated labor services, which are transformed into aggregate effective labor, L_t, by perfectly competitive labor packers, using the technology

$$L_t = \left(\int_0^1 L_{i,t}^{\frac{\epsilon_w - 1}{\epsilon_w}} di\right)^{\frac{\epsilon_w}{\epsilon_w - 1}} \tag{30}$$

for each individual household, i. A union sells labor services at the nominal wage W_t (equalized across production sectors) to the labor recruiter, who minimizes costs given the aggregate demand for labor, implying

$$\mathcal{L}_t = \mathcal{L}\left(W_t; W_t, L_t\right) = \left(\frac{W_{i,t}}{W_t}\right)^{-\varepsilon_w} L_t \tag{31}$$

and where the equilibrium nominal wage amounts to

$$W_t = \left(\int_0^1 W_{i,t}^{1-\varepsilon_w} di\right)^{\frac{1}{1-\varepsilon_w}}. \tag{32}$$

Unions can only update wages for each of their workers in a Calvo manner with probability $1-\theta_w$. Unions re-optimize individual wages in period t maximizing total household utility subject to the CES demand for their labor. This implies the standard F.O.C.

$$\sum_{k=0}^{\infty} (\beta\theta_w)^k E_t \left\{ \frac{L_{t+k|t}}{C_t^{\sigma}} \left(\frac{W_t^*}{P_{t+k}} - M^w MRS_{t+k|t} \right) \right\} = 0 \tag{33}$$

where MRS is the marginal rate of substitution and $M^w = \frac{\varepsilon_w}{1-\varepsilon_w}$ is the wage-markup.

Log-linearizing around a zero-inflation steady-state yields

$$w_t^* = \mu^w + (1-\beta\theta_w) \sum_{k=0}^{\infty} (\beta\theta_w)^k E_t \left\{ mrs_{t+k|t} + p_{t+k} \right\} \tag{34}$$

In log-linear terms, the wage index is

$$w_t = \theta_w w_{t-1} + (1-\theta_w) w_t^* \tag{35}$$

Thus, by combining equations (34) and (35), the Wage Phillips Curve is in log-linear terms[3]

$$\pi_t^w = \beta E_t \left\{ \pi_{t+1}^w \right\} - \lambda_w \left(\mu_t^w - \mu^w \right) \tag{36}$$

where $\pi_t^w \equiv w_t - w_{t-1}$ denotes wage inflation, $\mu_t^w = w_t - p_t - mrs_t$ is the average wage markup, and $\lambda_t^w \equiv \frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w(1+\varphi\varepsilon_w)} > 0$.

We let disutility of work be described as standard by $U(L_t) = -\psi_N \frac{L_t^{1+\varphi}}{1+\varphi}$, where φ is the inverse Frisch disutility of hours and ψ_N is a utility shifter. We assume that the unions do not observe household habits, and thus optimize for total consumption. Then we have from the unions perspective that

$$\begin{aligned} U_L' &= \psi_N L_t^{\varphi} \\ U_C' &= C_t^{-\sigma} \end{aligned} \tag{37}$$

Hence, the MRS is given by $\psi_L L_t^{\varphi} \cdot C_t^{\sigma}$.

2.5 Policy

2.5.1 Government budget

It is well known that the specific assumptions about how the government budget constraint adjusts outside the steady state matter in economies where transitory income shocks have

[3] Note that in the GAMS code implementation, we also added an option for backward looking wage inflation, but we do not use it, hence it is not described here.

persistent effects (i.e., the HANK literature). Here, due to utility of bonds and "HtM" consumption out of liquid income, we have similar concerns. Especially when governments balance their budget period-by-period. Thus, we introduce the realistic feature of deficit financing as in Auclert et al. (2020) such that the government budget constraint for one-period bonds is given by:

$$\begin{aligned} (1+r_t)\, B^g_{t-1} &= \tau_t + B^g_t, \\ \tau_t &= \tau + \phi_\tau \left(B^g_{t-1} - B^g\right), \end{aligned} \tag{38}$$

where τ and B^g denote steady-state taxes and government bonds, respectively, while ϕ_τ determines how fast deficits are closed.

2.5.2 Central bank

Monetary policy sets the nominal bond rate according to a Taylor rule that features a non-systematic component r^*_t and persistence through $\rho_{\text{Taylor}} \in (0,1)$:

$$i_t = (1-\rho_{\text{Taylor}})\left(r^*_t + \phi_\pi \pi_t + \phi_y \hat{y}_t\right) + \rho_{\text{Taylor}} i_{t-1}, \tag{39}$$

where $\phi_\pi > 1$ is the degree of reaction to inflation deviations, ϕ_y is the degree of reaction to output deviations from steady-state, $\hat{y}$, $\pi_t = \log \Pi_t$ with $\Pi_t = \frac{P_t}{P_{t-1}}$, and r^*_t is a shock parameter.

The (linearized) Fisher equation implies

$$r^b_t = i_t + \pi_{t+1} \tag{40}$$

2.6 Market clearing

Goods market clearing is given by

$$Y_t = I_t + C_t \tag{41}$$

Asset market clearing for bonds obtains as

$$B^g_t = B_t \tag{42}$$

and capital market clearing is implied by household capital supply and firm optimality.

2.7 Full equation system

Let variables with no time-subscript denote steady-state values. The full dynamic equation system is then given by

$$\left(C_t - h\tilde{C}_{t-1} - \gamma_c Y_t^{\text{liquid}}\right)^{-\sigma} = \beta R_t^B \left(C_{t+1} - h\tilde{C}_t - \gamma_c Y_{t+1}^{\text{liquid}}\right)^{-\sigma} + \beta\xi B_t^{-\sigma} \tag{43}$$

$$\left(C_t - h\tilde{C}_{t-1} - \gamma_c Y_t^{\text{liquid}}\right)^{-\sigma} = \beta R_t^K \left(C_{t+1} - h\tilde{C}_t - \gamma_c Y_{t+1}^{\text{liquid}}\right)^{-\sigma} \tag{44}$$

$$Y_t^{\text{liquid}} = W_t L_t + R_t^B B_{t-1} - \tau_t + \gamma_{he}\pi_t \tag{45}$$

$$D_t = P_t Y_t - W_t L_t - r_t^K K_t \tag{46}$$

$$Y_t = Z_t u_t K_t^{\alpha} L_t^{1-\alpha} \tag{47}$$

$$\pi_t = \kappa\left[\log(MC_t) - \log(MC)\right] + \gamma_f \pi_{t+1} + \gamma_b \pi_{t-1} \tag{48}$$

$$u_t = \frac{Z_t K_t^{\alpha} L_t^{1-\alpha} - \chi_1 + \chi_2 u_{target}}{\chi_2} \tag{49}$$

$$\frac{W_t}{r_t^k} = \frac{1-\alpha}{\alpha}\frac{K_t}{L_t} \tag{50}$$

$$MC_t = \frac{1}{Z_t u_t}\left(\frac{r_t^k}{\alpha}\right)^{\alpha} \cdot \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha} \tag{51}$$

$$q_t\left[1 - \phi\log\frac{I_t}{I_{t-1}}\right] = 1 - \beta\mathbb{E}_t\left[q_{t+1}\phi\log\left(\frac{I_{t+1}}{I_t}\right)\right] \tag{52}$$

$$I_t = K_t - (1-\delta)K_{t-1} \tag{53}$$

$$\pi_{w,t} - \beta\pi_{w,t+1} + \kappa_w\left(\log(W_t) - \log(MRS_t)\right) \tag{54}$$

$$MRS_t = \frac{\psi_L L_t^{\varphi}}{C_t^{-\sigma}} \tag{55}$$

$$\left(1 + r_t^b\right) B_{t-1}^g = \tau_t + B_t^g \tag{56}$$

$$\tau_t = \tau + \phi_\tau \left(B_{t-1}^g - B^g\right) \tag{57}$$

$$i_t = (1 - \rho_{\text{Taylor}}) \left(r_t^* + \phi_\pi \pi_t + \phi_y \hat{y}_t\right) + \rho_{\text{Taylor}} i_{t-1}, \tag{58}$$

$$\pi_{w,t} = \log(W_t) - \log(W_{t-1}) + \pi_t \tag{59}$$

$$\tilde{C}_t = C_t \tag{60}$$

$$Y_t = I_t + C_t \tag{61}$$

$$B_t = B_t^g \tag{62}$$

Thus, we have 20 equations in 20 unknowns, where the asset markets clear residually due to Walras' law (so that the goods market clearing condition implies that the budget constraint holds).

2.8 Solving the steady-state

We numerically solve for the (zero-inflation) quarterly steady-state as follows:

- **We exogenize:** K, L, B^g, setting them as $K = 1$, $L = 1/4$ and $B^g = 0.26 \cdot Y$.[4]
- **We endogenize:** ξ_b, ψ_L to solve the bond Euler equation, and to ensure that the steady-state Wage Phillips Curve holds.
- We impose $\tau = r^b B^g$ in steady-state, replacing the deficit financing rule equation.
- The log-linearized price Phillips curve holds by definition in steady-state and is therefore not included in the equation system.

The remaining variables are solved numerically for $t = t + 1$, given the full equation system.

[4] For details on these choices, see Section 3.1.

Walras' law We need to check that the asset market clears by using the budget constraint and the goods market clearing equation:

$$\begin{aligned} C + B + K &= WL + R^b B + R^k K - \tau + D \\ \Rightarrow C + \cancel{B} + K &= \cancel{WL} + (\cancel{1} + \cancel{r^b})B + (\cancel{1+r^k} - \delta)K - \cancel{r^b B} + Y - \cancel{WL} - \cancel{(1+r^k)K} \\ &\Rightarrow Y = C + \underbrace{\delta K}_{I} \end{aligned} \tag{63}$$

That is, by insertion of taxes and profits, the budget constraint yields the goods market clearing condition and thus Walras' law holds and the model is balanced.

3 Impulse Response Matching

To calibrate model dynamics we impulse response match our structural model to an identified U.S. monetary policy shock. We focus on a monetary policy shock as there is a large and established literature on these, cf. Ramey (2016). Since responses give general equilibrium paths for all variables of interest, the shock can describe well the rigidities in both supply and demand structures. This shock is taken from previous literature and are estimated on US data. It is typical to calibrate the "large closed economy" as the U.S., see e.g. Druedahl et al. (2022). [5]

Our measure of Federal Reserve (Fed) monetary policy shocks is constructed by Romer and Romer (2004) for the period 1967Q1 to 2007Q4.[6] The estimation of monetary policy shocks is done through the so called narrative approach, a frontier method which delivers impulse responses for the US economy that generally align well with expected outcomes, for further discussion see Ramey (2016).

Impulse responses are constructed from the following local projection (LP) regression as suggested by Jordà (2005):

$$y_{t+h} = \beta_0 + \beta_{1,h} shock_t + \Psi X_{t-1} + e_{t,h} \tag{64}$$

where the outcome variable of interest is y_{t+h}, h is the projection period, $shock_t$ is the estimated monetary policy shock, and $\mathbf{X}_{t-j}$ is a vector of controls while $e_{t,h}$ is a potentially serially correlated error term. We are interested in estimating $\beta_{1,h}$ as it measures the impulse response to the monetary policy at horizon h. We estimate the quarterly LP with four lags (p=4).

After obtaining the impulse responses from equation 64, we calibrate the model to best fit the shock. The variables used for IRF matching are denoted in Table 3.1.1. Additionally,

[5] We have thoughts to extend our calibration to hit a panel of our most important trading-partners.
[6] The series is extended by Wieland (2021).

we include the persistence parameter of the shocks in our calibration exercise to capture the nature of the underlying shock.

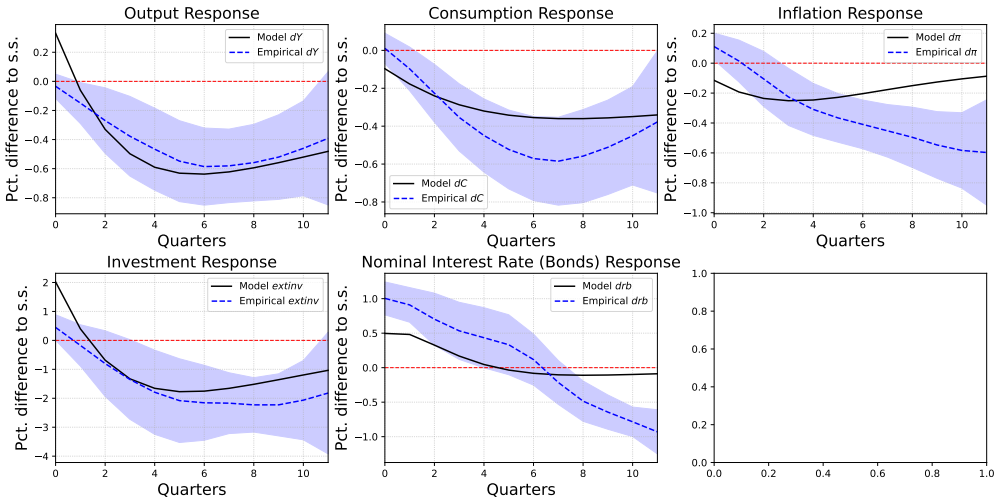

Figure 3.0.1: Impulse Response Functions for an Interest Rate Shock

Note: This figure presents model and empirical impulse response functions following a 1 percentage point interest rate shock with persistence 0.76. Shaded areas are 95% bootstrapped confidence intervals.

Figure B2 presents the model fit.[7]

3.1 Calibrated model values

Table 3.1.1 presents the model calibration. The model parameters are calibrated based on three main sources: (i) standard values commonly used in the literature, (ii) values chosen to match impulse response functions (IRFs), and (iii) values taken from external studies.

The parameters classified as *standard values* are set according to commonly accepted values in the DSGE literature. These include the discount factor β, risk aversion σ, inverse Frisch elasticity φ, capital depreciation rate δ, capital share in production α, price elasticity of demand ε, and wage elasticity of demand ε_w.

Several parameters are calibrated to match impulse response functions (*IRF match*) from Section 3. In particular, the scaling of all variables that introduce "stickiness" are sensitive to the exact model formulation and cannot easily be taken from the literature without introducing significant bias. Parameters used to IRF match include habit formation in consumption h, the "HtM" reference consumption parameter, γ_c, the short-hand "HtM" parameter on house equity γ_{he}, the labor disutility parameter ψ_L, investment adjustment costs ϕ_{inv}, the price rigidity parameter θ, the wage rigidity parameter θ_w, the Taylor rule coefficients ϕ_π, ϕ_y, the Taylor rule persistence parameter ρ_{taylor}, and the TFP utilization parameters χ_1, χ_2, and $\tilde{u}$.

[7] To see a longer time path, refer to Appendix A.

Note that the quarterly habit formation parameter is both in line with what is estimated yearly in MAKRO, and inf line with what is common in the HANK literature where transitory effects of liquidity gains matter, cf. Auclert et al. (2020).[8] Lastly, the government debt-to-output ratio B^g/Y is taken from Kaplan et al. (2018), in which it is interpreted as being total liquid assets in the economy, as in this model.

Finally, we set a set of initial values for steady-state endogenous variables, see Table 3.1.2. Here, most values are set as initial values that only affect the scaling of the economy, while the steady-state nominal rate is taken from Debortoli and Galí (2018).

4 VAR system

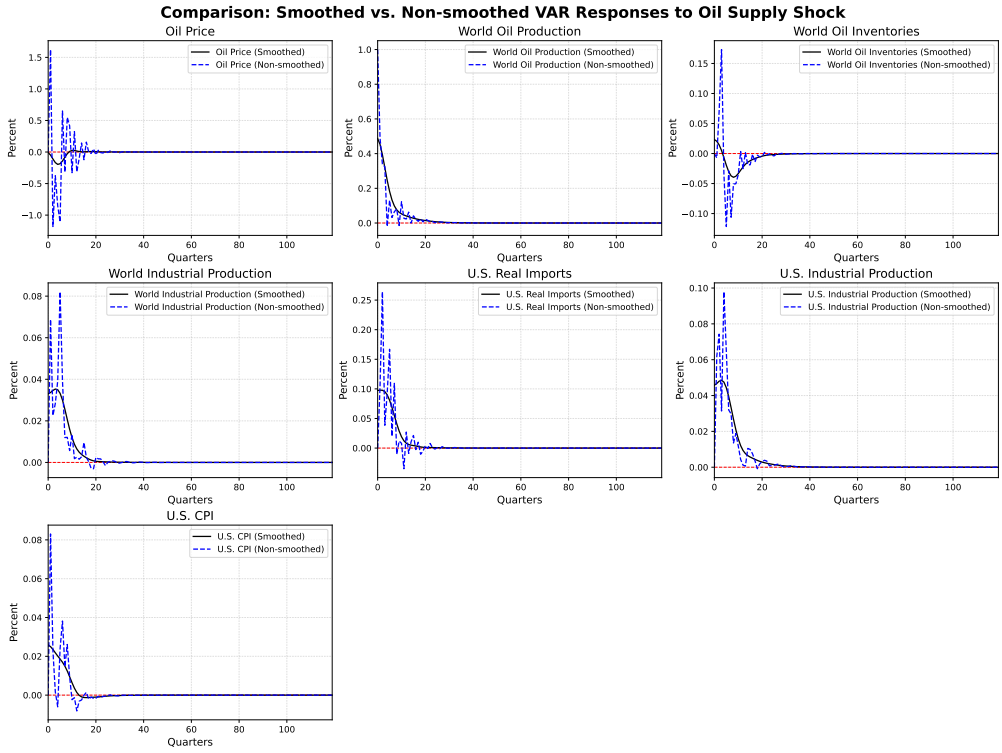

Figure 4.0.1: Smoothing of VAR System Output from an Oil Supply Shock

Note: This figure presents VAR impulse response functions following a 1 pct. increase in the oil supply, which is a direct shock to the VAR, with persistence 0.5 (AR(1)). We smooth using a Gaussian filter with standard deviation 3.

It is quite typical in e.g. central bank policy DSGE models to model the foreign economy given

[8] In Auclert et al. (2020) they use sticky expectations rather than habits, but the size order is roughly translatable to habits. Their stickiness parameter is set to 0.935 to match a similar empirical monetary policy shock.

a VAR system. We follow a similar route by incorporating a VAR into our structural model. Additionally, a key advantage of this method is its flexibility in incorporating observed data without requiring a strict match to the causal relationships in the model. However, since we specify an unrestricted VAR, our analysis is limited to examining dynamic correlations between variables, without making causal inferences. Our structural model adds discipline to this as it i) spells out the theorized linkages and ii) is estimated against a causally identified shock. Given that a VAR model represents a linear system, we apply it to relevant macroeconomic variables that can be integrated into the broader model framework. This allows us to derive a system of simultaneous equations for the variables of interest.

A key determinant of a small open economy's state is energy prices. Therefore, we focus is on an oil (energy) VAR. Specifically, we set up the same VAR model as suggested by Känzig (2021). The specification includes six variables: the real price of oil, world oil production, world oil inventories, world industrial production, U.S. industrial production and the U.S. consumer price index (CPI). The first four variables are standard in oil market VAR models while the last two variables are included to analyze the effects of oil prices on the U.S. economy.[9] The lag order is set to 4 and in terms of deterministics only a constant term is included. In order to achieve a stable VAR system, we first take the logarithmic difference of the variables and then standardize them. [10] All variables are transformed back into their log-difference state before entering the model (the foreign or MAKRO). Finally, we smooth the resulting VAR output using a Gaussian filter with standard deviation 3. Note that because the systems is quite erratic, we have to smooth the data by quite a bit to ensure reasonable properties for insertion into structural models, see Figure 4.0.1.

Figure 4.0.2 illustrates the baseline scenario, where the model is subjected to a 1 percentage point monetary policy rate shock. As expected, the U.S. economy experiences a mild recession, with the CPI declining by approximately 25 basis points. Additionally, Figure 4.0.3 extends the previous analysis, showing the VAR-implied correlations in response to a 1 percentage point federal funds rate shock in the structural model.[11]

A Fed rate hike dampens global economic activity, leading to a decline in world industrial production. The resulting contraction in global demand reduces oil prices, prompting a cut in world oil production and an increase in global oil inventories. U.S. real imports initially decline in the first few quarters before experiencing a temporary rebound. The initial drop likely reflects the direct effect of weakened domestic demand due to the interest rate hike, while the subsequent rise may be attributed to currency dynamics—specifically, the appreciation of the U.S. dollar relative to other currencies. The stronger dollar, coupled with weaker foreign demand, makes imports relatively cheaper, contributing to the observed rebound.[12]

[9] A detailed overview on the data and its sources can be found in Känzig (2021).

[10] In addition to this, we may want to give the Euro area special treatment.

[11] The VAR output is smoothed. See the previous section for details on the method.

[12] For discussion about theory and empirical results regarding consequences of U.S. import after Fed rate hikes, please see Georgiadis and Jarocinski (2023)

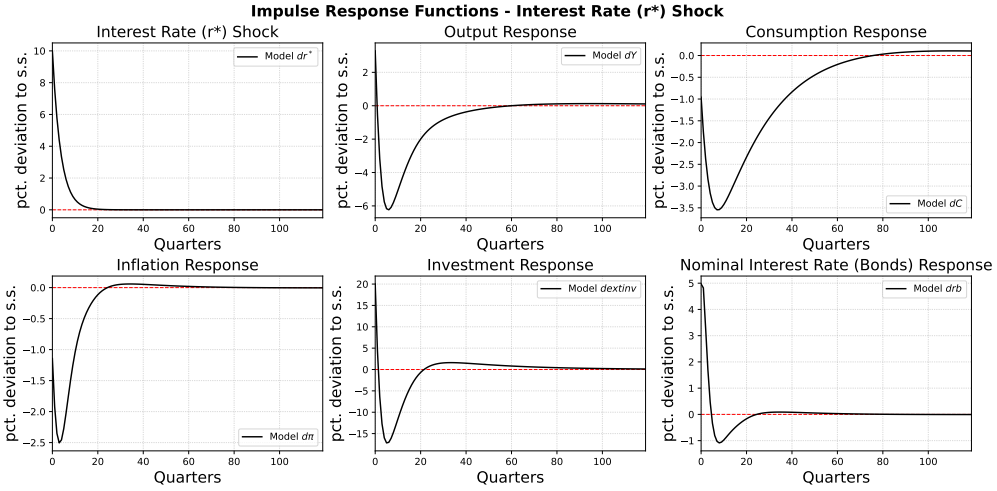

Figure 4.0.2: Impulse Response Functions for an Interest Rate Shock

Note: This figure presents model impulse response functions following a 1 percentage point interest rate shock with persistence 0.76 (AR(1)).

5 Translating the monetary policy shock to MAKRO

We now feed in the shock to which the foreign economy has been matched into the MAKRO model, that is the interest rate shock.[13] To do so, we let the deviations in imports (from the VAR), consumption and the goods price index shock the corresponding MAKRO variables feeding into 1. the MAKRO foreign demand (Armington) equation and 2. the interest rate relations and the import prices.[14] The MAKRO Armington equation is given by

$$X_{x,t}^{y} = \mu_{x,t}^{Xy} q_t^x q_t^{\text{Scale}} \left(R_{x,t}^{Xy} \right)^{-\eta_x^X} \tag{65}$$

where for each export group, there exists a corresponding foreign demand function. Each export group, indexed by subscript x, is directly supplied from domestic production, denoted by the superscript y, as $X_{x,t}^{y}$. The volume of exports depends on the price ratio $R_{x,I}^{Xy}$, which represents the relative price of the exported good compared to its world market price. This relationship follows an elasticity of demand η_x^X and is influenced by the market size q_t^x. Additionally, q_t^{Scale} serves as a scaling parameter that captures the overall growth of the domestic economy. The relative price is given by

$$R_{x,t}^{Xy} = \frac{P_{x,t}^{Xy}}{P_{x,t}^{XF}} + \text{relative price adjustment cost terms} \tag{66}$$

[13] We use the developer model as of 21-02-2025.

[14] See the MAKRO model documentation, Bonde et al. (2023).

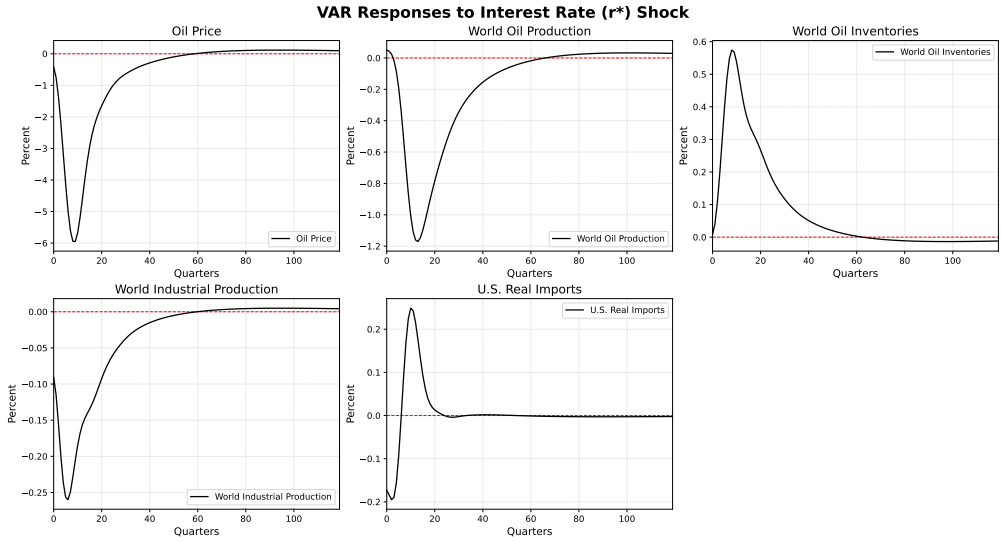

Figure 4.0.3: VAR System Impulse Response Functions for an Interest Rate Shock

Note: This figure presents VAR impulse response functions following a 1 percentage point interest rate shock in the structural model with persistence 0.76 (AR(1)). To generate the VAR responses, we feed in the paths of output and inflation from the structural model to the VAR system and scale them appropriately. Finally, the VAR output is smoothed.

where $P^{XF}_{x,t}$ is the foreign price.

We shock each variable by their log deviations from the foreign economy equally for each export group: q_t by foreign output, P^{XF}_t by the foreign goods price and import prices, in MAKRO denoted as P^M_t summing out sectors, s.[15] Finally, we let the bond rate, "rRente['Obl']" be shocked by the deviation in the foreign (nominal) interest rate. Note that while this is a transitory shock, it is trivially possible to look at more persistent shocks to inspect longer run transitions. The results of doing this are reported in Figure 5.0.1.

[15]We are working on letting import prices and export competing prices be a function of CPI instead, either assuming constant sectoral shares or using data on these prices under structural restrictions that relative prices cannot change in the long run from a transitory shock.

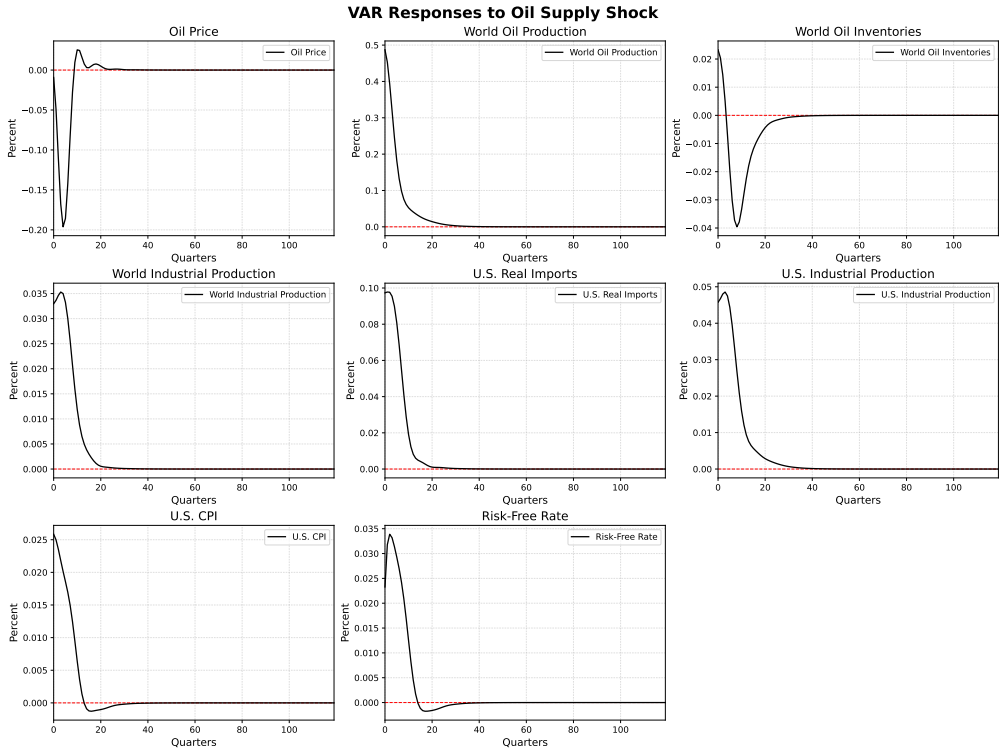

Figure 4.0.4: VAR System Impulse Response Functions for an Oil Supply Shock

Note: This figure presents VAR impulse response functions following a 1 pct. increase in the oil supply, which is a direct shock to the VAR, with persistence 0.5 (AR(1)).

Table 3.1.1: Baseline Model Calibration

Parameter	Value	Target/Source
Household Preferences		
β	0.99	Standard value
σ	1.00	Standard value
φ	1.00	Standard value
h	0.94	IRF match
γ_c	0.015	IRF match
γ_{he}	1.70	IRF match
ψ_L	13.29	Steady-state adjustment
Production		
δ	0.025	Standard value
α	0.30	Standard value
χ_1	1.00	IRF match
χ_2	0.95	IRF match
$\tilde{u}$	0.98	IRF match
ϕ_{inv}	49.00	IRF match
Price Rigidity		
θ	0.30	IRF match
ε	6.00	Standard value
ω	0.40	IRF match
Wage Rigidity		
ε_w	6.00	Standard value
θ_w	0.53	IRF match
Policy Parameters		
ϕ_π	1.10	IRF match
ϕ_y	0.00	IRF match
B^g / Y	0.26	Kaplan et al. (2018)
ρ_{taylor}	0.40	IRF match
ϕ_t	0.10	IRF match

Table 3.1.2: Exogenized Steady-State Values

Parameter	Value	Description
L	$\frac{1}{4}$	Only affects scaling of economy
i	$\frac{0.03}{4}$	Debortoli and Galí (2018)
r^b	i	Real bond interest rate
r^k	0.035	Steady-state adjustment
r^*	i	Natural rate of interest
K_t	1.00	Steady-state capital, K_0
π	0.00	Steady-state inflation
π_w	0.00	Steady-state wage inflation

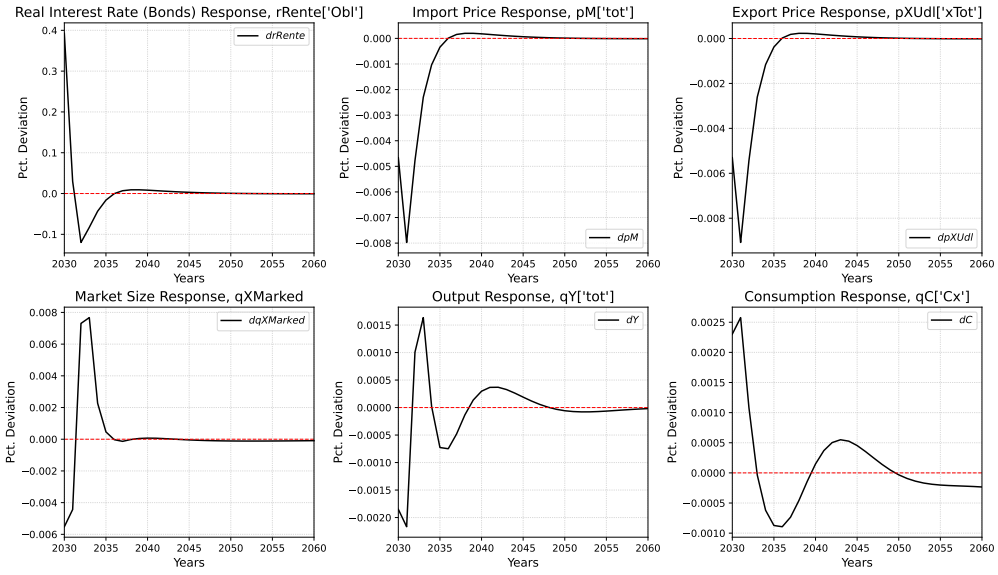

Figure 5.0.1: MAKRO Impulse Responses When Feeding in the Foreign Economy Interest Rate shock

Note: This figure presents impulse responses of the MAKRO model from feeding in foreign output, prices and the foreign nominal policy rate following a 1 percentage point (quarterly) interest rate shock with persistence 0.76 to the foreign economy. All foreign variables have been transformed from quarterly to yearly deviations as to be fed into MAKRO. The first four variables in the subplot are exogenous shocks to MAKRO.

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Appendices

A Foreign economy impulses over 30 years

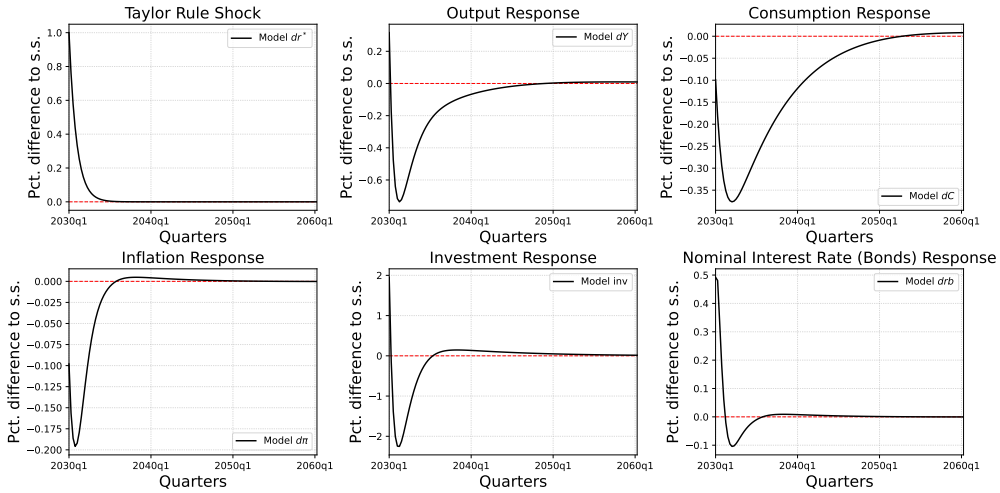

Figure A1: Impulse Response Functions for an Interest Rate Shock, 30 years

Note: This figure presents quarterly model impulse responses following a 1 percentage point (quarterly) interest rate shock with persistence 0.76, start period 2030 first quarter, end 2060 first quarter.

B A 1 pct. TFP shock with persistence 0.5 (AR(1))

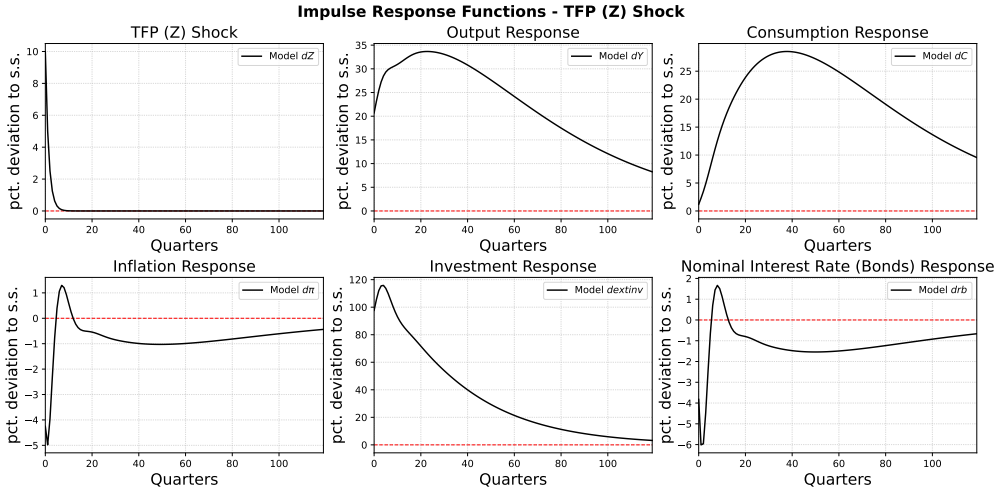

Figure B1: Impulse Response Functions for a TFP Shock

Note: This figure presents model impulse response functions following a 1 percentage point TFP shock in the structural model with persistence 0.5

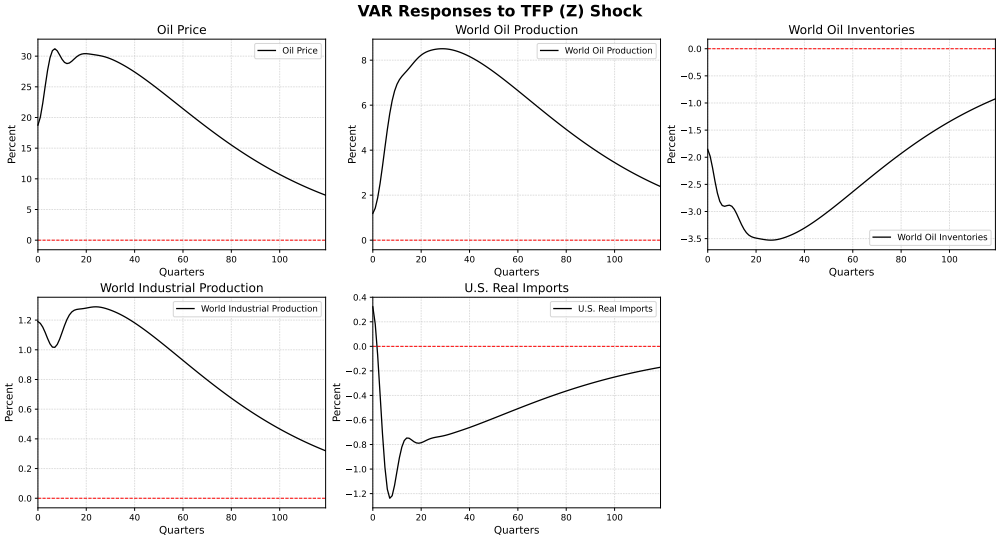

Figure B2: VAR System Impulse Response Functions for a TFP Shock

Note: This figure presents VAR impulse response functions following a 1 percentage point TFP shock in the structural model with persistence 0.5. To generate the VAR responses, we feed in the paths of output and inflation from the structural model to the var system and scale appropriately. Finally, the VAR output is smoothed.