Mitigating the Impact of Fuel Subsidy Removal in an Oil-Producing Emerging Economy

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Motivation

- **Global Context:** Analyzing macroeconomic effects of fuel subsidy reforms in an oil-producing emerging economy
- **Rising Concerns:** Fiscal costs and negative externalities prompt scrutiny on fuel subsidies
- **Distorted Price Signals:** Subsidies distort prices, complicating monetary policy
- **Dynamic Volatility:** Oil price fluctuations impact inflation, requiring nuanced policy responses
- **Tailored Policies:** Context-driven policy formulation crucial for subsidy and volatility dynamics

Research questions

1. How does subsidy removal impact macroeconomic indicators under changing oil price volatility?
2. What are the historical and counterfactual implications of subsidy policies on economic performance?
3. What are the welfare consequences of optimal policy responses versus non-adjustment by the central bank?
4. How should central bank policy rules adapt to mitigate the effects of removal and oil price volatility?
5. What lessons can be drawn from Nigeria's subsidy removal for similar economies facing similar challenges?

The literature I

- **Oil-macroeconomy relationship**: Barsky and Kilian (2004), Kilian (2009), Kilian and Vigfusson (2011), Ramey and Vine (2011), Holm-Hadulla and Hubrich (2017) and Rahman and Serletis (2010): Nonlinear effects of oil shocks

- **Episodic switches in DSGE frameworks**: Schorfheide (2005), Liu *et al.* (2011), Liu and Mumtaz (2011), Chen and Macdonald (2012), Bianchi (2013), Davig and Doh (2014) and Bjornland *et al.* (2018): Substantial evidence for episodic switches in volatility and parameters

- **SOE models with oil prices and policy**: Medina and Soto (2005), Allegret and Benkhodja (2015), Ferrero and Seneca (2019), Bergholt and Larsen (2016), Algozhina (2022) and Omotosho (2022): Factors contribute to exacerbating the shock's procyclicality

The literature II

- **Fuel subsidy reforms**: Clements *et al.* (2013), Siddig *et al.* (2014), Dennis (2016), Rentschler *et al.* (2017), Coady *et al.* (2019), Omotosho (2019) and Fan and Wang (2022): Non-trivial implications for the response and volatility of macroeconomic variables

- Research Gaps: Existing studies primarily focus on the macroeconomic response to subsidy reforms but often overlook the dynamic nature of economic conditions, particularly **the role of stochastic regime shifts**, which are essential considerations in the design of subsidy policies

- It leaves *unanswered*, the more fundamental question of what leads the policymaker to behave differently over time

Modeling the dynamics of fuel subsidy removal: Angle of attack I

- **Framework:** SOE-DSGE model
- **Economic Context:** Tailored for the Nigerian economy
- **Methodology:** Bayesian estimation and simple Taylor rules using the RISE Toolbox

Key features

- Incorporation of stochastic regime shifts: Oil price volatility and monetary policy rule coefficients
- Focus on oil price volatility: Analysis examines the interplay between oil price volatility and monetary policy adjustments

Modeling the dynamics of fuel subsidy removal: Angle of attack II

Objectives

- Assessing the impact of subsidy removal: Analyzing macroeconomic implications under alternative policy scenarios
- Understanding central bank behavior:
  - Evaluating the extent of adjustments in response to oil price volatility
  - Assessing it's role in mitigating the consequences of subsidy removal

Significance: Insights into optimal policy responses and welfare consequences of subsidy removal in an oil-producing emerging economy

Preview of results I

- **Dynamic Monetary Policy Response:** Time-varying monetary policy adjustments synchronize with high-variance states (uncertainty)
- **Central Bank Behavior:** During highly volatile periods, the central bank adjusts interest rates faster, responds less to inflation, exchange rate stabilization, and places greater emphasis on the output gap
- **Key Volatile Episodes:** Major volatile episodes in oil prices observed during 2008-2009, 2014-2016, and 2020-2021
- **Welfare Implications:** The welfare cost of business cycles increases following subsidy removal
- **Macroeconomic Indicators:** Impact of subsidy removal increases macroeconomic instability (GDP growth, inflation, consumption, exchange rates, etc.)

Preview of results II

- **Counterfactual scenarios:** Comparison of the economic performance under different scenarios where subsidies were not in place historically
    - Scenario 1: Actual economy
    - Scenario 2: Simulated economy with $\nu = 1$, all else equal
- **Sensitivity analysis:** Explore the robustness of the results based on posterior distributions

Plan for the rest of the presentation

1. The Regime-switching DSGE model
2. Model parameterization & filtration implications
3. Macroeconomic implications
4. Macroeconomic stabilization and optimal policy
5. Policy implications
6. Statistical validation
7. Summing up

The Regime-switching DSGE model

The model in brief

1. An oil sector owned by government and foreign direct investors
2. Oil in consumption basket ▸ More details and production technology ▸ More details
3. Non-Ricardian consumers to capture credit constraints ▸ More details
4. A fuel pricing rule that connotes an implicit subsidy regime ▸ More details
5. A fiscal policy rule that responds to oil revenues and subsidies ▸ More details
6. LOP gap in imports and incomplete exchange rate pass-through into import prices
7. Economy switches exogenously between regimes of oil price volatility and the monetary policy rule over time

Monetary policy: Switching Taylor rule

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_r(s_t^{vol})} \left[\left(\frac{\pi_t}{\bar{\pi}}\right)^{\omega_\pi(s_t^{vol})} \left(\frac{Y_{h,t}}{\bar{Y}_h}\right)^{\omega_y(s_t^{vol})} \left(\frac{\Delta\varepsilon_t}{\overline{\Delta\varepsilon}}\right)^{\omega_\varepsilon(s_t^{vol})}\right]^{1-\rho_r(s_t^{vol})} \exp\left(\sigma_r \xi_t^r\right)$$

- Parameters governed by the same Markov process and switch together with $\sigma_{p_o^*}(s_t^{vol})$
- To study the behavior of policy affected by the **heteroskedasticity of oil prices**

$$\begin{aligned} \rho_r(s_t^{vol}) &= \bar{\rho}_r + \hat{\rho}_r(s_t^{vol}) \\ \omega_x(s_t^{vol}) &= \bar{\omega}_x + \hat{\omega}_x(s_t^{vol}) \end{aligned}$$

- This hybrid, flexible specification splits the behavior of policy into the systematic and regime-dependent components
- An explicit role to oil price volatility (increasing uncertainty faced by policymakers)

The generic problem to solve

$$E_t \sum_{s_{t+1}=1}^{h} p_{s_t,s_{t+1}}(\mathcal{I}_t) f_{s_t}\left(x_{t+1}(s_{t+1}), x_t(s_t), x_{t-1}, \theta_{s_t}, \theta_{s_{t+1}}, \varepsilon_t\right) = 0$$

- $p_{s_t,s_{t+1}}(I_t)$: probability of going from state s_t in the current period to state s_{t+1} in the next one
- f_{s_t} : (potentially) nonlinear function of its arguments
- $x_t(s_t)$: vector of all endogenous variables in the current regime r_t
- θ_{s_t} : parameters in the current regime
- $\varepsilon_t \sim N(0, I)$: vector of stochastic shocks

Perturbation solution of the RS-DSGE model

The exact solution

We consider minimum state variable solutions of the form

$$x_t = \mathcal{T}_{s_t}(x_{t-1}, \varepsilon_t)$$

Now the solution also depends on the regime s_t

p-order perturbation of $x_t = \mathcal{T}^{s_t}(z_t)$

$$\mathcal{T}^{s_t}(z_t) \simeq \mathcal{T}^{s_t}(\bar{z}_{s_t}) + \mathcal{T}_z^{s_t}(z_t - \bar{z}_{s_t}) + \frac{1}{2!}\mathcal{T}_{zz}^{s_t}(z_t - \bar{z}_{s_t})^{\otimes 2} + \ldots + \frac{1}{p!}\mathcal{T}_{z^{(p)}}^{s_t}(z_t - \bar{z}_{s_t})^{\otimes p}$$

State variables (χ: perturbation parameter)

$$z_t \equiv \left[\begin{array}{ccc} x'_{t-1} & \chi & \varepsilon'_t \end{array}\right]'$$

Model parameterization & filtration implications

The data and sample

- **Domestic variables:** real GDP growth ($\Delta y_{h,t}$), real consumption growth (Δc_t), real investment growth ($\Delta i_{no,t}$), real effective exchange rate (q_t), headline CPI inflation (Δp_t), core CPI inflation ($\Delta p_{no,t}$), nominal interest rate (R_t), oil output ($\Delta y_{o,t}$), government debt growth (Δb_t), change in tax revenue (Δtx_t) and government consumption growth ($\Delta g_{c,t}$)

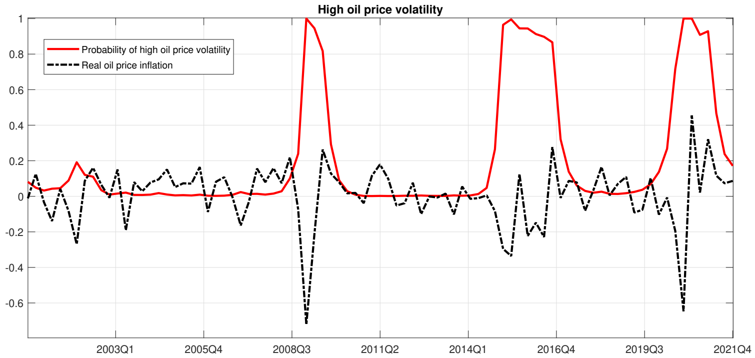
- **Foreign variables:** trade-weighted real GDP growth (Δy_t^*), aggregate CPI inflation (Δp_t^*), and interest rate (R_t^*). The data set used for the computation of the trade-weighted foreign variables as well as the inflation of the real price of oil ($\Delta p_{o,t}^*$)

- Sample: 2000Q2-2021Q4

Bayesian estimation

Parameter	Prior distribution			Posterior mode
	Density	Mean	SD	
Monetary policy: systematic				
$\bar{\omega}_\pi$	$\mathcal{G}$	1.5	0.25	3.492
$\bar{\omega}_y$	$\mathcal{G}$	0.125	0.05	0.108
$\bar{\omega}_\varepsilon$	$\mathcal{G}$	0.125	0.05	0.177
$\bar{\rho}_r$	$\mathcal{B}$	0.5	0.25	0.162
Monetary policy: regime-dependent				
$\hat{\omega}_\pi(s_t^{vol} = L)$	$\mathcal{N}$	0	0.25	0.609
$\hat{\omega}_\pi(s_t^{vol} = H)$	$\mathcal{N}$	0	0.25	**0.206**
$\hat{\omega}_y(s_t^{vol} = L)$	$\mathcal{N}$	0	0.25	-0.077
$\hat{\omega}_y(s_t^{vol} = H)$	$\mathcal{N}$	0	0.25	**0.161**
$\hat{\omega}_\varepsilon(s_t^{vol} = L)$	$\mathcal{N}$	0	0.25	0.866
$\hat{\omega}_\varepsilon(s_t^{vol} = H)$	$\mathcal{N}$	0	0.25	**0.363**
$\hat{\rho}_r(s_t^{vol} = L)$	$\mathcal{N}$	0	0.25	0.002
$\hat{\rho}_r(s_t^{vol} = H)$	$\mathcal{N}$	0	0.25	**-0.092**
Standard deviation and persistence of shock				
$\sigma_{p_o^*}(s_t^{vol} = L)$	$\mathcal{IG}$	0.1	4	0.100
$\sigma_{p_o^*}(s_t^{vol} = H)$	$\mathcal{IG}$	0.1	4	**0.226**
$\rho_{p_o^*}(s_t^{vol} = L)$	$\mathcal{B}$	0.5	0.28	0.994
$\rho_{p_o^*}(s_t^{vol} = H)$	$\mathcal{B}$	0.5	0.28	0.548
Transition probability				
p_{12}^{vol} [L, H]	$\mathcal{B}$	0.5	0.28	0.045
p_{21}^{vol} [H, L]	$\mathcal{B}$	0.5	0.28	0.178

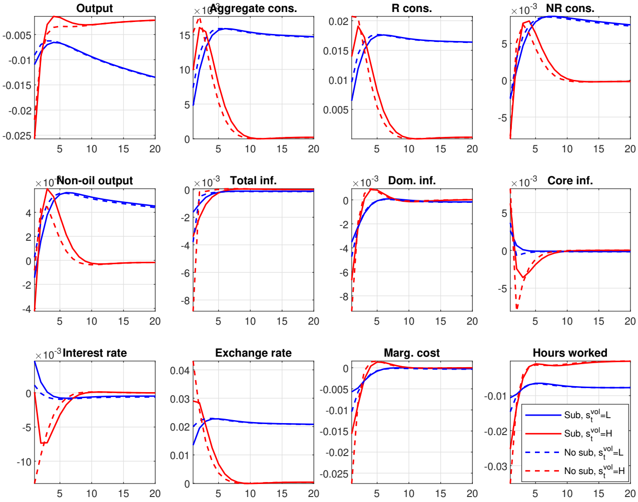
Smoothed probability of high volatility regime ($s_t^{vol} = H$)



- 2008-09: US credit crisis
- 2014-16: US shale oil revolution
- 2020-21: Drop in oil demand due to COVID-19

Macroeconomic implications

Responses to a negative oil price shock



- Sub: $\nu = 0.526$ (solid); No sub: $\nu = 1$ (dashed)
- Low volatility: $s_t^{vol} = L$ (blue); High volatility: $s_t^{vol} = H$ (red)

Implications for volatility and co-movement

If the central bank does not change its policy in the $\nu = 1$ economy?

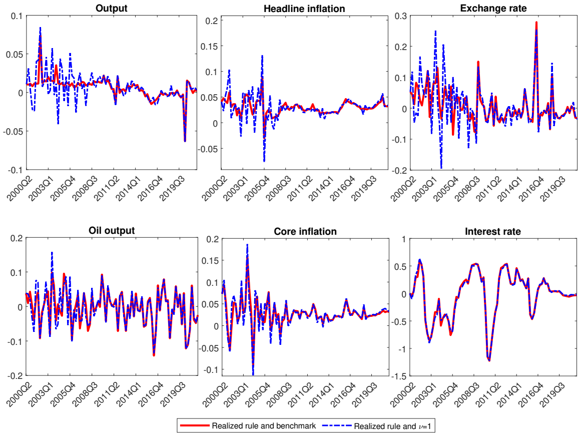
std. dev.	$\Delta y_{h,t}$	Δc_t	$\Delta i_{no,t}$	π_t	R_t	q_t	$\pi_{c,t}$	$\Delta y_{o,t}$	Δb_t	Δtx_t	$\Delta g_{c,t}$
Benchmark	0.146	0.182	0.092	0.109	0.429	0.143	0.107	0.457	0.551	0.444	0.233
$\nu = 1$	0.147	0.186	0.092	0.113	0.432	0.159	0.109	0.458	0.550	0.454	0.235

cross-corr.	$\Delta y_{h,t}$	Δc_t	$\Delta i_{no,t}$	π_t	R_t	q_t	$\pi_{c,t}$	$\Delta y_{o,t}$	Δb_t	Δtx_t	$\Delta g_{c,t}$
Benchmark	-	0.324	0.033	0.015	-0.069	0.241	0.042	0.543	0.610	0.152	0.444
$\nu = 1$	-	0.341	0.034	-0.020	-0.081	0.272	0.057	0.543	0.608	0.176	0.455

- Non-adjustment by the central bank is associated with higher volatility
- Performs poorly in capturing the countercyclicality of inflation

Economic performances under counterfactual scenarios

Had subsidy removal been implemented historically with realized rule?



1. Actual (historical) economy with realized rule and benchmark parameterization
2. Simulated economy with realized rule and $\nu = 1$

Macroeconomic stabilization and optimal policy

The Central Bank's role

- In a no-subsidy economy, monetary policy is more important for stabilizing economic activity

  1. We do not know whether the central bank has behaved optimally
  2. Agents are more vulnerable to price fluctuations which can be exacerbated by subsidy removal

- Evaluate policy rules using a simple quadratic loss function, penalizing variability in key macroeconomic variables (welfare-relevant).

$$\Omega_0 = (1-\beta)E_0\left[\sum_{t=0}^{\infty}\beta^t(\lambda_\pi\pi_t^2+\lambda_y y_{h,t}^2+\lambda_r\Delta R_t^2+\lambda_\varepsilon\Delta\varepsilon_t^2)\right]$$

- Parameter estimates are used to seek optimized Taylor rules that involve switching parameters

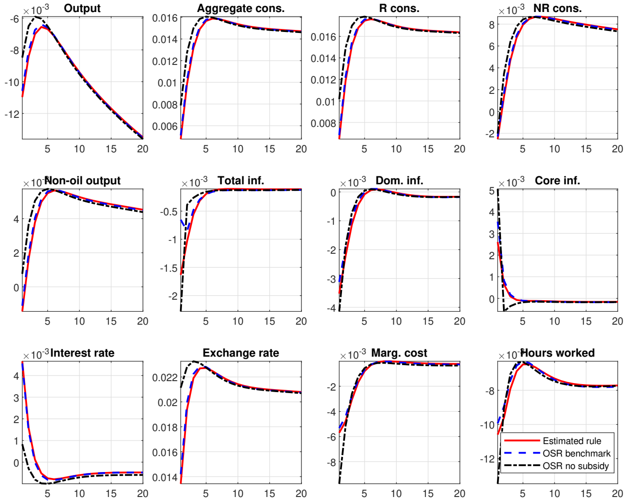
Optimized Taylor rules

- $\lambda_\pi = 1$, $\lambda_y = 0.2$, $\lambda_r = 0.1$, $\lambda_\varepsilon = 0.1$

Parameter	Prior distribution			Posterior mode		
	Density	Lower quartile	Upper quartile	Estimated rule	OSR $\nu = 0.526$	OSR $\nu = 1$
$\bar{\omega}_\pi$	$\mathcal{G}$	1	10	3.492	6.782	**6.897**
$\bar{\omega}_y$	$\mathcal{G}$	0.1	4	0.108	0.153	**0.144**
$\bar{\omega}_\varepsilon$	$\mathcal{G}$	0.1	4	0.177	0.824	0.801
$\bar{\rho}_r$	$\mathcal{B}$	0.5	0.95	0.162	0.783	0.781
	Density	Mean	SD			
$\hat{\omega}_\pi(s_t^{vol} = L)$	$\mathcal{N}$	0	0.5	0.609	0.060	0.060
$\hat{\omega}_\pi(s_t^{vol} = H)$	$\mathcal{N}$	0	0.5	0.206	0.023	0.024
$\hat{\omega}_y(s_t^{vol} = L)$	$\mathcal{N}$	0	0.5	-0.077	-0.036	-0.047
$\hat{\omega}_y(s_t^{vol} = H)$	$\mathcal{N}$	0	0.5	0.161	-0.008	-0.012
$\hat{\omega}_\varepsilon(s_t^{vol} = L)$	$\mathcal{N}$	0	0.5	0.866	0.115	0.114
$\hat{\omega}_\varepsilon(s_t^{vol} = H)$	$\mathcal{N}$	0	0.5	0.363	0.044	0.043
$\hat{\rho}_r(s_t^{vol} = L)$	$\mathcal{N}$	0	0.5	0.002	-0.345	-0.351
$\hat{\rho}_r(s_t^{vol} = H)$	$\mathcal{N}$	0	0.5	-0.092	-0.232	-0.235
Ω_0				0.0417	0.0251	0.0262

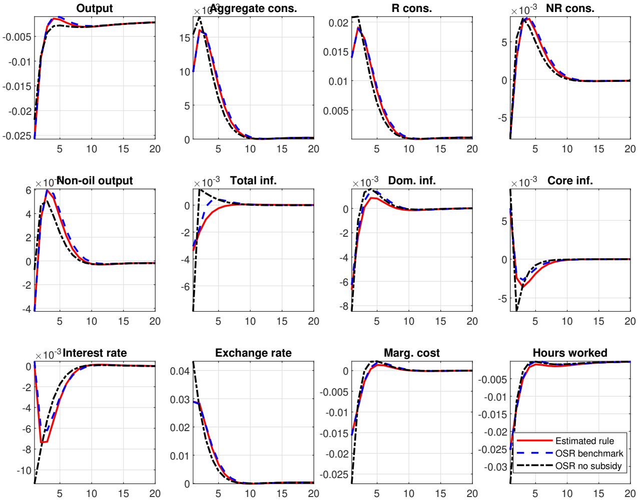
- Relative to the estimated rule, OSR prescribes more aggressive responses
- More focused on preserving price stability with complete subsidy removal
- The best welfare achieved under the subsidy program

Responses a negative oil price shock with $s_t^{vol} = L$



- Interest rate dynamics consistent with estimated rule
- NR HHs experience delayed and smaller increases in Δc_t

Responses a negative oil price shock with $s_t^{vol} = H$



- Initial interest rate cuts to cushion recessionary impact
- NR HHs experience delayed and smaller increases in Δc_t

Insights into optimal policy operation

- OSR predicts initial interest rate cuts in response to shocks, mitigating contractionary output effects
- Policy variables exhibit significantly larger responses in certain scenarios ($s_t^{vol} = H$), indicating aggressive reaction function in these states
- Initially, consumption rises under OSR, but low-income consumers experience comparatively *smaller* increases
- In the no-subsidy economy, both output and consumption see larger increases, contributing to welfare differences
- The central bank's trade-off severity is influenced by the impact of subsidy removal (and volatility) ▸ Standard deviation

Policy implications

Implications for macroeconomic policy I

- **Design of Monetary Policy Frameworks:** The best rules are aggressive on inflation and exchange rates and much more inertial with subsidies or not
- **Response to Economic Shocks:** When shocks are small, following a negative oil price shock, the central bank increases interest rates, consistent with the estimated rule, but when shocks are large, the best response prescribes an initial cut to interest rates
- **Trade-offs and Objectives:** Trade-offs (inflation vs output volatility) can be less severe when subsidy is removed, but are amplified in the high volatility regime
- **Flexibility and Adaptability:** The best policy framework required to effectively respond to changing economic conditions should exhibit flexibility and adaptability
- **Policy Coordination:** Potential benefits of coordination between monetary and fiscal authorities in achieving macroeconomic stability, particularly in periods of stress and high volatility

Statistical validation

Model comparisons

MDD	Non-switching	Switching ($\nu = 0.526$)	Switching ($\nu = 1$)
Meng and Wong's Bridge	919.26	922.20	899.31
MHM	915.07	918.30	893.62

- Two parallel chains of 100,000 random draws from the posterior density ▶ Post. median
- Draw 10,000 random parameters from the posterior simulation
  1. Smoothed probabilities with median response with the 90% credibility interval ▶ Smoothed prob.
  2. Median IRFs with the 90% credibility intervals ▶ Additional IRFs

Summing up

Summing up

- **Insights:** Subsidy removal may lead to welfare losses due to increased volatility, highlighting the need for careful policy consideration
- **Policy Role:** Central bank intervention may be crucial in mitigating the impacts of subsidy removal, underscoring the importance of coordinated policy responses
- **Challenges:** Designing a flexible framework capable of adapting to economic shifts while balancing inflation and output stabilization
- **Recommendations:** Emphasize the importance of proactive policy measures to manage economic volatility and safeguard welfare
- **Future Research:** Explore asymmetries in the effects of oil price changes, considering potential differential impacts on the economy

Thank You!

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Appendix A: Further details on the model

Oil in consumption basket

- Household consumption comprises of oil and non-oil consumption bundles

$$C_t = \left[(1-\gamma_o)^{\frac{1}{\eta_o}} \left(C_{no,t} \right)^{\frac{\eta_o - 1}{\eta_o}} + \gamma_o^{\frac{1}{\eta_o}} \left(C_{o,t} \right)^{\frac{\eta_o - 1}{\eta_o}} \right]^{\frac{\eta_o}{\eta_o - 1}}$$

- Core consumption bundle combines imported bundle and domestically produced goods

$$C_{no,t} = \left[(1-\gamma_c)^{\frac{1}{\eta_c}} \left(C_{h,t} \right)^{\frac{\eta_c - 1}{\eta_c}} + \gamma_c^{\frac{1}{\eta_c}} \left(C_{f,t} \right)^{\frac{\eta_c - 1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c - 1}}$$

- Expenditure minimization yields the demands for $C_{no,t}$, $C_{o,t}$, $C_{h,t}$ and $C_{f,t}$

- The **headline CPI**

$$P_t = \left[(1-\gamma_o) P_{no,t}^{1-\eta_o} + \gamma_o P_{ro,t}^{1-\eta_o} \right]^{\frac{1}{1-\eta_o}}$$

- The core CPI

$$P_{no,t} = \left[(1-\gamma_c) P_{h,t}^{1-\eta_c} + \gamma_c P_{f,t}^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}}$$

Go Back

Oil production and pricing

- Employs a Cobb-Douglas extraction technology

$$Y_{o,t} = A_{o,t} K_{o,t}^{\alpha_o^k} M_t^{\alpha_o^m}$$

- The oil-related capital is accumulated by FDI_t^*

$$K_{o,t} = (1 - \delta_o) K_{o,t-1} + FDI_t^*$$

- FDI inflows to the oil sector responds to the **real international price of oil**

$$FDI_t^* = \left(FDI_{t-1}^*\right)^{\rho_{fdi}} \left(P_{o,t}^*\right)^{1-\rho_{fdi}}$$

- $P_{o,t}^*$ and $A_{o,t}$ evolve as follows

$$P_{o,t}^* = \left(P_{o,t-1}^*\right)^{\rho_{p_o^*}(s_t^{vol})} \exp\left(\sigma_{p_o^*}(s_t^{vol}) \xi_t^{p_o^*}\right), \quad A_{o,t} = \left(A_{o,t-1}\right)^{\rho_{a_o}} \exp\left(\sigma_{A_o} \xi_t^{A_o}\right)$$

- Allows the **volatility and persistence** of the oil price shock to change from one regime to another

Go Back

Rule of thumb consumers

- A proportion $(1-\gamma_R)$ of households are **credit-constrained** and have no income from monopolistic retail firms

$$C_t = \underbrace{(1-\gamma_R)C_{1,t}}_{\text{Non-Ricardian}} + \underbrace{\gamma_R C_{2,t}}_{\text{Ricardian}}$$

$$C_{1,t} = \frac{W_t h_t}{P_t} = \text{Wage Income}$$

- $C_{2,t}$ given by the standard Euler-consumption equation

- Total hours are given by

$$L_t = (1-\gamma_R)L_{1,t} + \gamma_R L_{2,t}$$

Go Back

Fuel subsidy

- Aggregate refined oil, O_t, is imported at a landing price, $P_{lo,t}$, by the government which sells the imported fuel at a regulated price, $P_{ro,t}$, based on a **fuel pricing rule**

$$P_{ro,t} = P_{ro,t-1}^{1-\nu} P_{lo,t}^{\nu}$$

- $P_{lo,t}$ (expressed in domestic currency) is given by

$$P_{lo,t} = \varepsilon_t \frac{P_{o,t}^*}{P_t^*} \Psi_t^o$$

  where Ψ_t^o measures the LOP gap associated with the import price of fuel; ε_t is the nominal exchange rate

- $0 \leq \nu \leq 1$ governs the extent to which the government subsidizes fuel consumption

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Fuel subsidy and fiscal policy

- The implicit **fuel subsidy payment**, OS_t, is given by

$$OS_t = (P_{lo,t} - P_{ro,t})\, O_t$$

- The amount of oil revenue, OR_t, accruing to the government which jointly owns the oil firm

$$OR_t = \tau \varepsilon_t P^*_{o,t} Y_{o,t}$$

- Backward-looking fiscal reaction functions respond to lagged debt, OR_t and OS_t

$$\frac{G_{c,t}}{\bar{G}} = \left(\frac{G_{c,t-1}}{\bar{G}}\right)^{\rho_g} \left[\left(\frac{Y_{o,t}}{\bar{Y}_o}\right)^{\omega_{yo}} \left(\frac{B_{t-1}}{\bar{B}}\right)^{-\omega_b} \left(\frac{OR_t}{\overline{OR}}\right)^{\omega_{or}}\right]^{1-\rho_g} \exp\left(\sigma_{gc}\xi_t^{gc}\right)$$

$$\frac{TX_t}{\overline{TX}} = \left(\frac{G_{c,t}}{\bar{G}}\right)^{\varphi_g} \left(\frac{B_{t-1}}{\bar{B}}\right)^{\varphi_b} \left(\frac{OS_t}{\overline{OS}}\right)^{\varphi_{os}} \left(\frac{OR_t}{\overline{OR}}\right)^{-\varphi_{or}} \exp\left(\sigma_{tx}\xi_t^{tx}\right)$$

where B_{t-1} serves as a stabilizing factor; ω_{yo} determines the cyclicality of $G_{c,t}$

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Appendix B: Volatility implications of optimized rules

Standard deviation of macroeconomic variables

	sd($\Delta y_{h,t}$)	sd(Δc_t)	sd($\Delta i_{no,t}$)	sd($\Delta y_{no,t}$)	sd(π_t)	sd($\pi_{c,t}$)	sd($\pi_{d,t}$)	sd($\pi_{f,t}$)	sd(R_t)	sd($\Delta \varepsilon_t$)	sd(c_t^R)	sd(c_t^{NR})
Estimated rule	0.146	0.182	0.092	0.190	0.109	0.107	0.111	0.091	0.429	0.204	0.298	0.215
OSR $\nu = 0.526$	0.142	0.178	0.092	0.186	0.068	0.070	0.088	0.064	0.388	0.168	0.285	0.207
OSR $\nu = 1$	0.144	0.183	0.092	0.186	0.070	0.072	0.088	0.064	0.392	0.177	0.288	0.209
OSR $\nu = 1$, $\lambda_y = 0.5$	0.144	0.182	0.092	0.186	0.072	0.073	0.089	0.064	0.391	0.158	0.287	0.208
OSR $\nu = 1$, $s_t^{vol} = H$	0.145	0.181	0.092	0.183	0.079	0.079	0.089	0.065	0.383	0.194	0.245	0.198

- Cost of following the estimated rule relative to OSR ($\nu = 0.526$)
- OSR ($\nu = 1$) more effectively stabilizes the economy compared to the estimated rule
- Can we obtain an OSR that can achieve better outcomes than the estimated rule when $\nu = 1$?
- What would be the level of instabilities if the economy had stayed in $s_t^{vol} = H$ when $\nu = 1$?

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Output-inflation volatility for optimized simple rules

Would monetary policy face a trade-off in the alternative economy ($\nu = 1$)?

$\lambda_y = 0.1$	sd($\Delta y_{h,t}$)	sd(π_t)	$\lambda_y = 0.5$	sd($\Delta y_{h,t}$)	sd(π_t)	$\downarrow$ sd($\Delta y_{h,t}$)	$\uparrow$ sd(π_t)
Bench	0.14226	0.06838	Bench	0.14210	0.06950	0.00016	0.00112
Alter	0.14423	0.07027	Alter	0.14397	0.07171	0.00026	0.00143
Bench in $s_t^{vol} = H$	0.14387	0.07690	Bench in $s_t^{vol} = H$	0.14377	0.07780	0.00010	0.00090
Alter in $s_t^{vol} = H$	0.14496	0.07930	Alter in $s_t^{vol} = H$	0.14478	0.08051	0.00018	0.00121

- Policy trade-offs can be less severe under OSR
- Oil price volatility operates as a source of worsening trade-offs

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Appendix C: Robustness with posterior simulations

Bayesian estimation

Parameter	Prior distribution			Posterior distribution		
	Density	Mean	SD/DoF	Mode	Median	90% HPDI
Monetary policy: systematic						
$\bar{\omega}_\pi$	$\mathcal{G}$	1.50	0.25	3.492	3.234	[2.831: 3.719]
$\bar{\omega}_y$	$\mathcal{G}$	0.125	0.05	0.108	0.115	[0.051: 0.186]
$\bar{\omega}_\varepsilon$	$\mathcal{G}$	0.125	0.05	0.177	0.199	[0.087: 0.341]
$\bar{\rho}_r$	$\mathcal{B}$	0.50	0.25	0.162	0.146	[0.020: 0.272]
Monetary policy: regime-dependant						
$\hat{\omega}_\pi(s_t^{vol} = L)$	$\mathcal{N}$	0.00	0.25	0.609	0.632	[0.378: 0.923]
$\hat{\omega}_\pi(s_t^{vol} = H)$	$\mathcal{N}$	0.00	0.25	0.206	0.011	[-0.360: 0.302]
$\hat{\omega}_y(s_t^{vol} = L)$	$\mathcal{N}$	0.00	0.25	-0.077	0.008	[-0.144: 0.200]
$\hat{\omega}_y(s_t^{vol} = H)$	$\mathcal{N}$	0.00	0.25	0.161	0.029	[-0.151: 0.258]
$\hat{\omega}_\varepsilon(s_t^{vol} = L)$	$\mathcal{N}$	0.00	0.25	0.866	1.071	[0.844: 1.327]
$\hat{\omega}_\varepsilon(s_t^{vol} = H)$	$\mathcal{N}$	0.00	0.25	0.363	0.152	[-0.167: 0.433]
$\hat{\rho}_r(s_t^{vol} = L)$	$\mathcal{N}$	0.00	0.25	0.002	0.030	[-0.090: 0.131]
$\hat{\rho}_r(s_t^{vol} = H)$	$\mathcal{N}$	0.00	0.25	-0.092	-0.009	[-0.191: 0.189]
Standard deviation and persistence of shock						
$\sigma_{p_o^*}(s_t^{vol} = L)$	$\mathcal{IG}$	0.10	4.00	0.100	0.126	[0.114: 0.137]
$\sigma_{p_o^*}(s_t^{vol} = H)$	$\mathcal{IG}$	0.01	4.00	0.226	0.325	[0.214: 0.475]
$\rho_{p_o^*}(s_t^{vol} = L)$	$\mathcal{B}$	0.50	0.28	0.994	0.957	[0.907: 0.999]
$\rho_{p_o^*}(s_t^{vol} = H)$	$\mathcal{B}$	0.50	0.28	0.548	0.587	[0.371: 0.888]
Transition probability						
p_{12}^{vol} [L, H]	$\mathcal{B}$	0.50	0.28	0.045	0.043	[0.006: 0.084]
p_{21}^{vol} [H, L]	$\mathcal{B}$	0.50	0.28	0.178	0.280	[0.103: 0.476]

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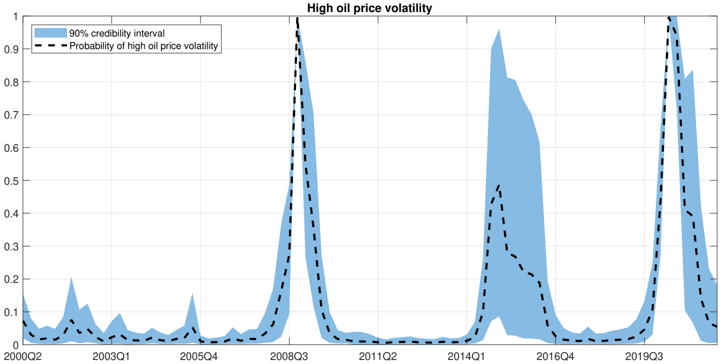
Smoothed probability of high volatility regime ($s_t^{vol} = H$)



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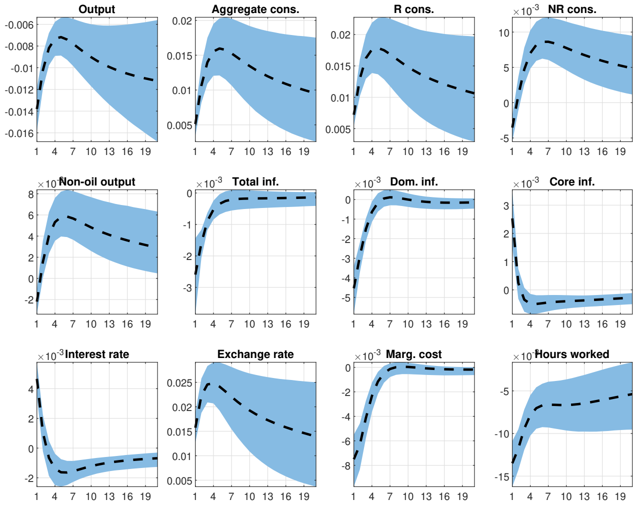
Responses a negative oil price shock with $s_t^{vol} = L$



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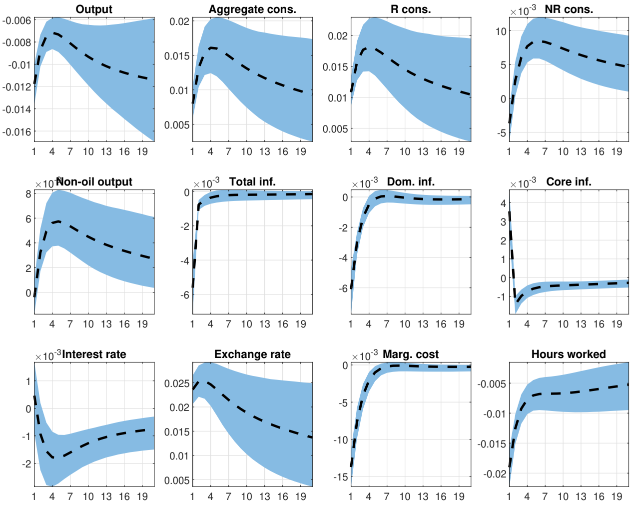
Responses a negative oil price shock with $s_t^{vol} = L$ and $\nu = 1$



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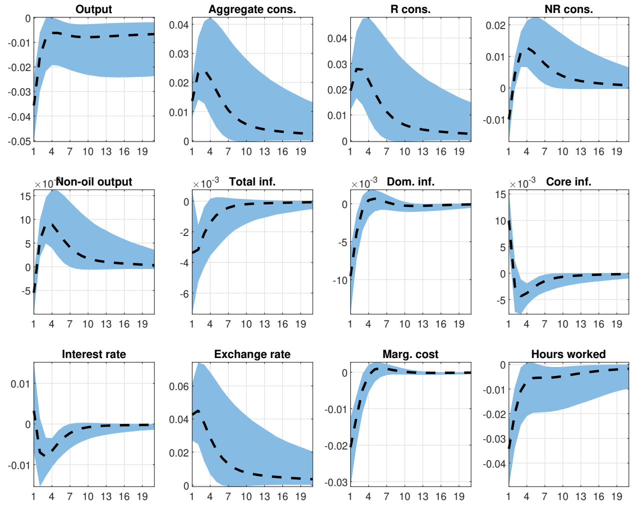
Responses a negative oil price shock with $s_t^{vol} = H$



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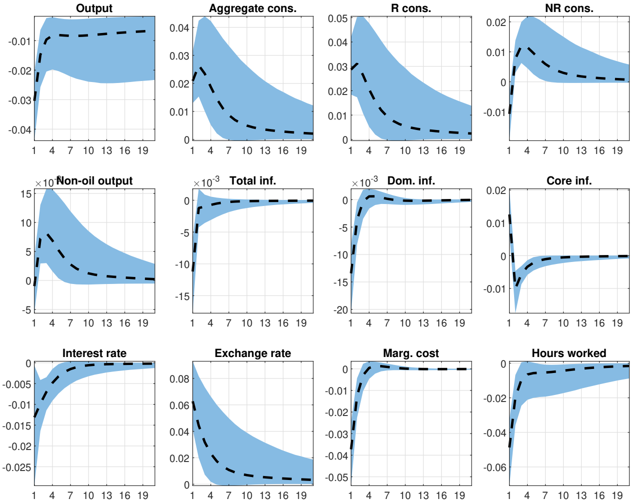
Responses a negative oil price shock with $s_t^{vol} = H$ and $\nu = 1$



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