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The Impact of Oil Shocks in a Small Open Economy New-Keynesian Dynamic Stochastic General Equilibrium Model for an Oil-Importing Country: The Case of South Africa

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ABSTRACT: This article studies the effects of foreign (real) oil price shocks on key macroeconomic variables for South Africa: a net-importer of oil. We develop and estimate a small open economy New-Keynesian dynamic stochastic general equilibrium model with a role for oil in consumption and production. The substitutability of oil for capital and consumption goods is low, import price pass-through is incomplete, domestic and foreign prices and wages are sticky, and the uncovered interest rate parity condition holds imperfectly. Foreign real oil price shocks have a strong and persistent effect on domestic production and consumption activities and, hence, are a fundamental driver of output, inflation, and interest rates in both the short- and long-run. Oil price shocks also generate a trade-off between output and inflation stabilization. As a result, episodes of endogenous tightening of monetary policy slow the recovery of South Africa's real economy. Our findings go further to suggest an important role for oil prices in predicting South African output during and after the recession that followed the 2008 global financial crisis.

KEY WORDS: DSGE model, oil shocks, small open economy, South Africa

JEL: E31, E32, E37, E52, Q43

Following the early works of Rasche and Tatom (1977), Mork and Hall (1980), Hamilton (1983), and Hickman, Huntington, and Sweeney (1987), which investigated the effects of oil shocks on the business cycles in the United States, a large international literature exists that has analyzed the impact of oil price shocks on macroeconomic variables for both developing and developed economies (see, for example, Cunado and Perez de Gracia 2003, 2005; Jiménez-Rodríguez and Sánchez2005; Cologni and Manera 2008, 2009; Baumeister, Peersman, and Van Robays 2010; Sánchez 2011; Gupta and Wohar 2017; for detailed literature reviews in this regard). Within the set of emerging economies considered, South Africa—an oil-importing and inflation-targeting small open economy—has featured prominently. A large number of studies have been devoted to analyzing the impact of oil shocks on macroeconomic variables of the South African economy (see, for example, Bellamy 2006; Dagut 1978; Kantor and Barr 1986; Kohler 2006; McDonald and van Schoor 2005; Nkomo 2006; Ajmi et al., 2015; Aye et al. 2014; Aye, Gadinabokao, and Gupta 2017; Balcilar, Uwilingiye, and Gupta 2018; Balcilar et al. 2017; Chisadza et al. 2016; De Bruyn, Gupta, and van Eyden 2015; Fofana, Chitiga, and Mabugu 2009; Gupta and Hartley 2013; Gupta and Kanda 2015; Gupta and Kotze 2017; Kin and Courage 2014; Swanepoel 2006; Tshepo 2015; Wakeford 2006, 2012). In general, these studies tend to agree with the fact that oil shocks are inflationary for the South African economy. However, the impact

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of oil shocks on the other variables are exceptionally mixed, ranging from positive to negative and even neutral (in the statistical sense), depending on the methodology, variables, and the sample periods considered.

All these studies rely on macroeconometric models comprising of either (linear or nonlinear) regressions and variations of vector autoregressive or vector error-correction frameworks. These types of models involve only a few variables and therefore tend to be misspecified (Paetz and Gupta 2016), and hence, the results from these studies could be biased and probably differ from the true magnitude of the effects of oil price shocks (Gupta and Sun 2016). In fact, unless a general equilibrium approach is considered, these effects could possibly end up being overestimated (Hou, Mountain, and Wu 2016). Further, with these approaches being atheoretical and non-structural, they suffer from the Lucas (1976) critique. Being not microfounded and not grounded in proper theory could also be the reason behind the mixed macroeconomic evidence as reported in the above-discussed South African literature involving oil price shocks. Using a theoretical framework helps identify channels through which oil price affects the economy, quantify its importance, and also provide recommendations for policymakers, especially central bankers. In addition, recent studies by Paetz and Gupta (2016) and Gupta and Sun (2016), while analyzing the impact of stock and house prices on the South African economy, show that results based on atheoretical frameworks tend to be overstated relative to those obtained under microfounded dynamic stochastic general equilibrium (DSGE) models.

Against this backdrop, we develop a small open economy New-Keynesian DSGE (SOE-NKDSGE) model for South Africa with a role for oil in household consumption and firm production activities. In production, we emphasize capital-oil substitutability (e.g. Kim and Loungani 1992; Rotemberg and Woodford 1996; Backus and Crucini 2000; Frondel and Schmidt 2002, 2004) rather than between labor and oil as in Medina and Soto (2005) and Blanchard and Riggi (2013). The substitutability of oil for physical capital and consumption goods is low. We assume that the law of one price does not hold for foreign goods and oil so that import price pass-through is incomplete (Burstein and Gopinath 2014). The domestic economy follows the standard New-Keynesian setup with nominal price and wage stickiness. Similar to Medina and Soto (2005) and Steinbach, Mathuloe, and Smit (2009), in a world of complete asset markets, we have complete international risk sharing in consumption. Importantly, stochastic risk premiums on both domestic and foreign assets mean that the uncovered interest parity (UIP) condition holds imperfectly. We estimate the model for the South African economy over the period 1995:Q1 – 2017:Q2. The foreign economy macroeconomic data are aggregated and weighted according to major trading partners. Using this model, we study the role of foreign (real) oil price shocks on output, inflation, the nominal interest rate, and exchange rates. The relationship between the real oil price and South African recessions is shown in Figure 1. As can be seen, the real oil price tends to be on the rise leading up to each recession, followed by a sharp drop. The most severe episode occurred over the 2008:Q1 – 2009:Q3 recession period. Here, a 23% positive real oil price shock in the second quarter of 2008 likely worsened the downturn.

We also compare alternative models with and without oil to highlight the importance of endogenous oil price and quantity dynamics, as well as the model's relative forecast performance. To the best of our knowledge, this is the first article to develop a SOE-NKDSGE model for South Africa with an explicit role for oil (energy) usage. In the process, we add to the fast-growing international literature on DSGE models that incorporate oil shocks (Kilian 2014) and particularly to the small number of articles that exist on oil shocks in DSGE models for small open oil-importing countries (see, for example, Alba, Chia, and Su 2013; An and Kang 2011; Beidas-Strom and Poghosyan 2011; Medina and Soto 2005).

The remainder of the article is organized as follows: First we develop the SOE-NKDSGE model wherein oil forms part of the representative household's consumption basket and enters as a factor input in firm production. This follows with a discussion on the data and calibration of the model as well as the Bayesian estimation results. Thereafter we present the main results for two alternative models: a SOE-NKDSGE model with oil versus one without. First we show both the historical and variance decomposition of output, inflation, and the nominal interest rate to investigate the importance

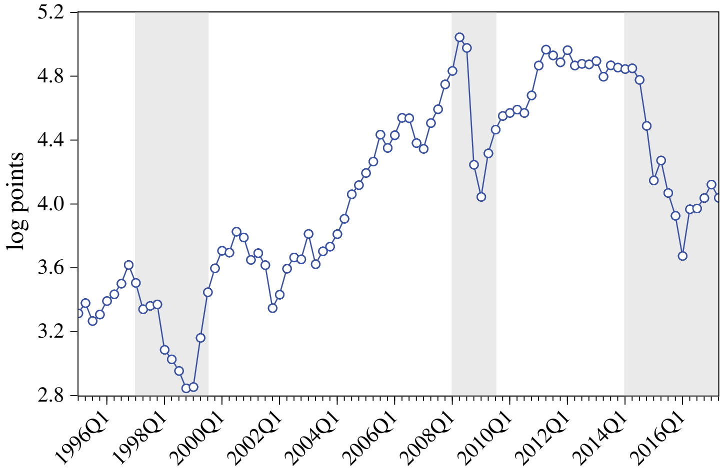

Figure 1. Log of the foreign real price of oil (shaded areas indicate downward phases of the South African business cycle).

of oil price shocks. Second we compare impulse response functions on key macroeconomic variables. To provide some additional insight on the merits of the model with oil, we conclude our comparison analysis with out-of-sample forecasts for output, inflation, and the nominal interest rate.

The Model

Domestic Households

The domestic economy is populated by a continuum of infinitely lived households, indexed by $j \in [0, 1]$. Each household j's consumption bundle is given by:

$$C_{j,t} = \left[(1-\gamma_o)^{\frac{1}{\eta_o}}(Z_{j,t})^{\frac{\eta_o-1}{\eta_o}} + \gamma_o^{\frac{1}{\eta_o}}(O^c_{j,t})^{\frac{\eta_o-1}{\eta_o}}\right]^{\frac{\eta_o}{\eta_o-1}}, \tag{1}$$

where the composite consumption index is a constant elasticity of substitution (CES) function consisting of fuel (oil) consumption $O^c_{j,t}$ and non-fuel (goods) consumption $(Z_{j,t})$. In addition, households consume both domestic and foreign (imported) consumption goods, given by:

$$Z_{j,t} = \left[(1-\gamma_c)^{\frac{1}{\eta_c}}(C^h_{j,t})^{\frac{\eta_c-1}{\eta_c}} + \gamma_c^{\frac{1}{\eta_c}}(C^f_{j,t})^{\frac{\eta_c-1}{\eta_c}}\right]^{\frac{\eta_c}{\eta_c-1}}, \tag{2}$$

where $C^h_{j,t}$ and $C^f_{j,t}$ represent consumption of domestic and foreign goods. $0 \leq \gamma_c, \gamma_o < 1$ capture the import shares of foreign goods and oil. η_c and η_o measure the respective intratemporal elasticities of substitution. Each household j chooses her desired combination of oil and core consumption and domestic and foreign consumption. Minimizing the total cost of each consumption basket subject to Eqs. 1 and 2 gives the demand functions for $Z_{j,t}$, $O^c_{j,t}$, $C^h_{j,t}$, and $C^f_{j,t}$[1]:

$$Z_{j,t} = (1-\gamma_o)\left(\frac{P^z_t}{P_t}\right)^{-\eta_o} C_{j,t}, O^c_{j,t} = \gamma_o\left(\frac{P^o_t}{P_t}\right)^{-\eta_o} C_{j,t} \tag{3}$$

$$C^h_{j,t} = (1-\gamma_c)\left(\frac{P^h_t}{P^z_t}\right)^{-\eta_c} Z_{j,t}, C^f_{j,t} = \gamma_c\left(\frac{P^f_t}{P^z_t}\right)^{-\eta_c} Z_{j,t}, \tag{4}$$

where P^h_t and P^f_t are the price indices for domestic and foreign goods and P^z_t and P^o_t are the price of core consumption goods and the price of oil given by:

$$P_t \equiv [(1-\gamma_o)(P^z_t)^{1-\eta_o} + \gamma_o(P^o_t)^{1-\eta_o}]^{\frac{1}{1-\eta_o}} \tag{5}$$

$$P^z_t \equiv [(1-\gamma_c)(P^h_t)^{1-\eta_c} + \gamma_c(P^f_t)^{1-\eta_c}]^{\frac{1}{1-\eta_c}}. \tag{6}$$

Household preferences are separable in consumption, labor, and real money balances, such that each household j maximizes their discounted lifetime utility function:

$$E_0\sum_{t=0}^{\infty}\beta^t[\frac{(C_{j,t}-\phi C_{t-1})^{1-\sigma_c}}{1-\sigma_c} - \frac{(N_{j,t})^{1+\sigma_n}}{1+\sigma_n} + \frac{a}{\sigma_m}(\frac{\mathrm{M}_{j,t}}{P_t})^{\sigma_m}], \tag{7}$$

where β^t is the subjective discount factor. The coefficient of relative risk aversion σ_c measures the curvature of the household's utility function with respect to its argument $C_{j,t} - \phi C_{t-1}$, where $C_{j,t}$ is real consumption at time t, and external habit formation is parameterized by ϕ. σ_n is the elasticity of labor supply $(N_{j,t})$ measured as hours worked. Households derive direct value from the liquidity services of real money holdings ($\mathrm{M}_{j,t}/P_t$), where σ_m is the interest elasticity of money demand.

Households have access to three types of assets: money domestic currency bonds ($B_{j,t}$), and foreign currency bonds ($B^*_{j,t}$). Domestic bonds pay a gross nominal rate of return I^b_t in domestic currency, whereas foreign bonds pay an exchange rate adjusted, ε_t, gross nominal rate of return I^{b*}_t. While capital mobility is flexible (i.e. no portfolio adjustment costs), domestic households face a risk premium μ^{b*}_t when borrowing in foreign currency. Similarly, the stochastic disturbance term μ^b_t represents the domestic risk premium (spread) over the monetary policy rate for domestic currency asset holdings.[2] The representative household's budget constraint is as follows:

$$\begin{aligned} &P^o_t O^c_{j,t} + P^h_t C^h_{j,t} + P^f_t C^f_{j,t} + \tfrac{B_{j,t}}{I^b_t\mu^b_t} + \tfrac{\varepsilon_t B^*_{j,t}}{I^{b*}_t\mu^{b*}_t} + \mathrm{M}_{j,t} \\ &= B_{j,t-1} + \varepsilon_t B^*_{j,t-1} + \mathrm{M}_{j,t-1} + W_t N_{j,t} + \Pi_{j,t} + T_{j,t}, \end{aligned} \tag{8}$$

where W_t is the nominal wage set by labor unions, $\Pi_{j,t}$ are dividends received from domestic firms, and $T_{j,t}$ represents lump-sum net transfers from government. Given the pricing functions Eqs. 5 and 6, we can re-write the budget constraint as:

$$\begin{aligned} &P_t C_{j,t} + \tfrac{B_{j,t}}{I^b_t\mu^b_t} + \tfrac{\varepsilon_t B^*_{j,t}}{I^{b*}_t\mu^{b*}_t} + \mathrm{M}_{j,t} \\ &= B_{j,t-1} + \varepsilon_t B^*_{j,t-1} + \mathrm{M}_{j,t-1} + W_t N_{j,t} + \Pi_{j,t} + T_{j,t}, \end{aligned} \tag{9}$$

where

$$P^z_t Z_{j,t} \equiv P^h_t C^h_{j,t} + P^f_t C^f_{j,t}\ , \tag{10}$$

$$P_t C_{j,t} \equiv P_t^o O_{j,t}^c + P_t^z Z_{j,t} \ . \tag{11}$$

Households optimize their consumption-savings decision by maximizing Eq. 7 subject to Eq. 9. The aggregated first-order conditions for domestic and foreign bonds give the standard Euler equations:

$$1 = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \frac{P_t}{P_{t+1}} I_t^b \mu_t^b \right], \tag{12}$$

$$1 = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \frac{P_t}{P_{t+1}} I_t^{b*} \frac{\varepsilon_{t+1}}{\varepsilon_t} \mu_t^{b*} \right] \ , \tag{13}$$

where Λ_t is the marginal utility of consumption and the Lagrangian multiplier of the budget constraint.

Similar to Medina and Soto (2005) and Steinbach, Mathuloe, and Smit (2009), complete international asset markets imply complete international consumption risk sharing. Eqs. 12 and 13 together give the standard UIP condition:

$$(1 + i_t^b) = (1 + i_t^{b*}) \frac{\varepsilon_{t+1}}{\varepsilon_t} \Phi_t \ , \tag{14}$$

where $I_t^b = (1 + i_t^b)$, $I_t^{b*} = (1 + i_t^{b*})$, and $\Phi_t = (\mu_t^{b*}/\mu_t^b)$ are the prevailing stochastic risk premiums. A positive shock to Φ_t, equivalent to a negative demand shock, raises the return on domestic currency bonds relative to foreign currency bonds and reduces current consumption (Smets and Wouters 2007; Steinbach, Mathuloe, and Smit 2009).

Labor Supply Decisions and the Wage-Setting Equation

Monopolistically competitive unions set the optimal wage at the prevailing labor demand equilibrium (see, e.g. Gali, Lopez-Salido, and Valles 2007). There is a continuum of unions, and each union represents workers of a certain type τ. The labor demand schedule that each household type τ faces is determined by:

$$N_t^\tau = \left(\frac{W_t^\tau}{W_t} \right)^{-\xi^w} N_t \ , \tag{15}$$

where ξ^w is the wage elasticity of substitution across different types of households.

Following Calvo-type price-setting, only a random fraction $(1 - \theta_w)$ of unions has the opportunity to reset their wages ($\tilde{W}_t$) each period. However, those unions that cannot reset their wages simply index to the lagged wage rate (Christiano, Eichenbaum, and Evans 2005; Smets and Wouters 2007).[3] Therefore, the aggregate wage index is given by:

$$W_t^{1-\xi^w} = \theta_w (\left(\frac{P_{t-1}}{P_{t-2}} \right)^{\gamma_w} W_{t-1})^{1-\xi^w} + (1 - \theta_w)(\tilde{W}_t)^{1-\xi^w} \tag{16}$$

where γ_w is the degree of wage indexation. The re-optimizing union's problem is to therefore choose $\tilde{W}_t$ to maximize the consumption-weighted wage income:

$$\max_{\tilde{W}_t} E_t \sum_{i=0}^{\infty} (\theta_w \beta)^i \left[\frac{\Gamma_{t+i} \tilde{W}_t N^{\tau}_{t+i}}{P_{t+i} \bar{C}^{\sigma_c}_{t+i}} - \frac{(N^{\tau}_{t+i})^{1+\sigma_n}}{1+\sigma_n} \right] \tag{17}$$

subject to the labor demand schedule Eq. 15.[4]

The first-order condition for the optimal reset wage $\tilde{W}_t$ is:

$$E_t \sum_{i=0}^{\infty} (\theta_w \beta)^i \left[\Gamma_{t+i} \frac{\tilde{W}_t}{P_{t+i}} \left(\frac{1}{MRS_{t+i}} \right) \right] = E_t \sum_{i=0}^{\infty} (\theta_w \beta)^i \left[\mu^w \left(\frac{\tilde{W}_t}{W_{t+i}} \right)^{-\xi^w \sigma_n} \right] \tag{18}$$

where $MRS_{t+i} = -\Lambda_{N,t}/\Lambda_t = \bar{C}^{\sigma_c}_{t+i} N^{\sigma_n}_{t+i}$ is the marginal rate of substitution between consumption and leisure for households and $[\mu^w = \xi^w/(\xi^w - 1)]$ is the steady-state wage markup. Log-linearizing Eq. 18 and combining it with the log-linearized wage index Eq. 16 give the forward-looking nominal wage inflation equation, as in the literature (see, Section S.1, Eq. S.8, available online).

Investment and Capital Goods

The capital goods-producing firm chooses a path for investment (V_t) that maximizes the present value of its profits:

$$\max_{K_{t+1}, V_t} E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left[\frac{R^k_{t+i} P^h_{t+i} K_{t+i} - P^V_{t+i} V_{t+i}}{P^h_{t+i}} - \phi \left(\frac{V_{t+i}}{K_{t+i}} \right) K_{t+i} \right] , \tag{19}$$

subject to the capital accumulation equation given by:

$$K_{t+1} = (1-\delta) K_t + V_t , \tag{20}$$

where δ measures the depreciation rate of capital and K_t represents the physical capital stock at the beginning of period t. R^k_t is the gross (real) return on rented capital holdings and $\phi(\cdot)$ captures the adjustment cost of capital installation.[5] As in Adolfson et al. (2007), we assume that the prices of domestically produced consumption goods and investment goods coincide ($P^h_t = P^V_t$).[6] $\Lambda_{t,t+i}$ denotes the stochastic discount factor for real profits, i-periods ahead given by:

$$\Lambda_{t,t+i} \equiv \beta^i \left(\frac{\bar{C}_{t+i}}{\bar{C}_t} \right)^{-\sigma_c} . \tag{21}$$

The first-order conditions for the capital goods producer problem are:

$$Q_t = E_t \left\{ \Lambda_{t,t+1} \left[R^k_{t+1} + Q_{t+1}(1-\delta) + \phi^v_{t+1} V_{t+1} - \phi_{t+1} \right] \right\} \tag{22}$$

$$Q_t = \frac{P^V_t}{P^h_t} + \phi^v_t K_t , \tag{23}$$

where $\phi^v_t = (\kappa_v/\delta)(V_t/K_t - \delta)(1/K_t)$ and Q_t are the marginal values of an additional unit of capital. That is, Q_t is the "shadow value" of the capital accumulation constraint (23) and equals the present discounted value of the marginal profits of an additional unit of capital (22).[7]

Domestic Production

The domestic goods-producing sector is made up of a continuum of infinitely lived firms indexed by $j \in [0,1]$. Each of these domestic firms combines labor, capital, and oil to produce intermediate goods for final good production. Notably, we emphasize the substitutability between capital and oil in the production process (e.g. Kim and Loungani 1992; Rotemberg and Woodford 1996; Backus and Crucini 2000; Frondel and Schmidt 2002, 2004) rather than between labor and oil as in Medina and Soto (2005) and Blanchard and Riggi (2013). Capital and oil therefore enter as a CES function within a Cobb–Douglas production function: $Y_{j,t} = A_t(N_{j,t})^{\alpha}[\vartheta(K_{j,t})^{1-v} + (1-\vartheta)(O^h_{j,t})^{1-v}]^{(1-\alpha)/(1-v)}$, where $1/v$ captures the elasticity of substitution between physical capital and oil. A_t represents the domestic technology shock.

The decision problem can be characterized by two stages. First, firm j minimizes the total cost of production subject to the production constraint. Second, each firm j maximizes its profit function subject to both foreign and domestic demands. Following Calvo (1983), all firms face a probability θ_h of not being able to optimally adjust prices. In this market, final goods producers are monopolistically competitive.

Demand for Inputs and Marginal Cost

Each intermediate goods-producing firm j therefore chooses its factor inputs—labor $N_{j,t}$, capital $K_{j,t}$, and oil $O^h_{j,t}$—to minimize the total cost of production, taking prices as given:

$$\min_{\{N_{j,t},K_{j,t},O^h_{j,t}\}} TC_{j,t} + \lambda_t(Y^h_{j,t} - A_t(N_{j,t})^{\alpha}[\vartheta(K_{j,t})^{1-v} + (1-\vartheta)(O^h_{j,t})^{1-v}]^{\frac{1-\alpha}{1-v}}) , \tag{24}$$

where $TC_{j,t} = \frac{W_t}{P^h_t}N_{j,t} + R^k_t K_{j,t} + \frac{P^o_t}{P^h_t}O^h_{j,t}$ is the total real cost of production.[8] The first-order efficiency conditions for labor, capital, and oil are:

$$\frac{W_t}{P^h_t} = \lambda_t \frac{\partial Y^h_{j,t}}{\partial N_{j,t}} = \alpha\lambda_t \frac{Y^h_{j,t}}{N_{j,t}} \tag{25}$$

$$R^k_t = \lambda_t \frac{\partial Y^h_{j,t}}{\partial K_{j,t}} = (1-\alpha)\vartheta\lambda_t \frac{Y^h_{j,t}}{(K_{j,t})^{v}[\vartheta(K_{j,t})^{1-v} + (1-\vartheta)(O^h_{j,t})^{1-v}]} \tag{26}$$

$$\frac{P^o_t}{P^h_t} = \lambda_t \frac{\partial Y^h_{j,t}}{\partial O^h_{j,t}} = (1-\alpha)(1-\vartheta)\lambda_t \frac{Y^h_{j,t}}{(O^h_{j,t})^{v}[\vartheta(K_{j,t})^{1-v} + (1-\vartheta)(O^h_{j,t})^{1-v}]} , \tag{27}$$

where λ_t is the real marginal cost of domestic production and the Lagrangian multiplier of the production function.

Price Setting

Each firm j is monopolistically competitive in its intermediate good $Y^h_{j,t}$. The firm is able to brand and sell its good at a markup P^h_t over marginal cost, taking into account their individual demand curves from domestic and foreign consumers. Here, we assume that both foreign and domestic consumers have identical elasticities with respect to domestic goods. Following Calvo (1983), we assume that only a random fraction $(1-\theta_h)$ of firms can adjust their retail price in each period. Therefore, each firm j faces the following decision problem:

$$\max_{\{\tilde{P}_t^h\}} E_t \sum_{i=0}^{\infty} \theta_h^i \Lambda_{t,t+i} \left[\left(\frac{\Pi_{t+i-1}^{\gamma_p} \tilde{P}_{j,t}^h}{P_{t+i}^h} - \lambda_{t+i} \right) Y_{j,t+i}^h \right] \tag{28}$$

subject to the consumer demand schedule for goods

$$Y_{j,t+i}^h = \left(\frac{\tilde{P}_{j,t}^h}{P_{t+i}^h} \right)^{-\xi_t^p} Y_{t+i}^h, \tag{29}$$

where $\Lambda_{t,t+i} = \beta^i (\Lambda_{t+i}/\Lambda_t)$ is the consumption-based relevant discount factor and ξ_t^p is the stochastic price-elasticity of demand for intermediate good Y_t^h.[9] $\tilde{P}_t^h$ denotes the optimal price set by firms who are able to adjust the price in period t and λ_t is the real marginal cost of production.

The aggregate price level is determined by

$$(P_t^h)^{1-\xi_t^p} = \theta_h (\left(\frac{P_{t-1}^h}{P_{t-2}^h} \right)^{\gamma_p} P_{t-1}^h)^{1-\xi_t^p} + (1-\theta_h)(\tilde{P}_t^h)^{1-\xi_t^p}, \tag{30}$$

where γ_p determines the degree of price indexation for non-optimizing retailers. Solving and linearizing the optimization problem and combining it with Eq. 30 gives the forward-looking New-Keynesian Phillips curve, as in the literature.

Domestic Importing Retailers and Incomplete Pass-Through

Extensive empirical evidence indicates the tendency for a high degree of pass-through to import prices, whereas the pass-through to domestic prices is more dampened (see Burstein and Gopinath 2014). For local importing retailers, we therefore introduce incomplete pass-through of exchange rate movements in the short-run (Calvo-type price setting). Specifically, they are import price takers (given the exchange rate) but face a downward sloping domestic demand curve. The law of one price (l.o.p) gap, Eq. 31, therefore measures deviations from the l.o.p. (Monacelli 2005):

$$\Psi_t^f \equiv \frac{\varepsilon_t P_t^{f*}}{P_t^f}, \tag{31}$$

where P_t^f is the price of foreign goods in the domestic currency (or the domestic currency price of imports).

The domestic demand schedule for foreign good j is given by:

$$C_{j,t}^f = \left(\frac{P_{j,t}^f}{P_t^f} \right)^{-\xi^f} C_t^f, \tag{32}$$

where, similar to domestic firms, import firms operate in a Calvo-type sticky price environment. Specifically, prices are adjusted with probability $1-\theta_f$ in each period. The aggregate import price index is therefore determined by:

$$(P_t^f)^{1-\xi^f} = \theta_f\left(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_f} P_{t-1}^f\right)^{1-\xi^f} + (1-\theta_f)(\tilde{P}_t^f)^{1-\xi^f}, \tag{33}$$

where ξ^f and $\tilde{P}_t^f$ denote the price elasticity of demand for foreign goods and the optimal price set by local importing retailers, respectively. If $\Psi_t^f \equiv 1$, then the l.o.p holds with the foreign price of foreign produced goods (imports) traded with the domestic country P_t^{f*}, adjusted for the spot nominal exchange rate ε_t (i.e. the price of one unit of foreign currency in terms of the domestic currency). For simplicity, we set γ_f to zero, which implies that import prices are not indexed to headline inflation. As such, the Calvo price-setting parameter θ_f governs the degree of import price pass-through of foreign goods.

Terms of Trade and the Real Exchange Rate

The foreign demand for domestic goods is captured by the following demand schedule:

$$C_t^{h*} = \gamma_c^* \left(\frac{P_t^{h*}}{P_t^{f*}}\right)^{-\xi^{f*}} C_t^* \ . \tag{34}$$

where ξ^{f*} is the foreign price elasticity of demand for domestic goods. A higher elasticity implies larger changes in foreign demand for domestic goods, given the foreign price of domestic goods relative to foreign goods.

The terms of trade of an economy (excl. oil imports) is defined as the price of imports relative to the price of domestically produced goods:

$$S_t = \frac{P_t^f}{P_t^h} \tag{35}$$

This implicitly assumes that domestic firms cannot price discriminate across markets and that the l.o.p holds for domestic export prices, $\varepsilon_t P_t^{h*} = P_t^h$. Medina and Soto (2005) also note that this assumes that the foreign consumption bundle excludes oil and that the share of domestic goods γ_c^* in C_t^* is negligible.

The definition of the real exchange rate can be written as:

$$RER_t \equiv \frac{\varepsilon_t P_t^{f*}}{P_t} \ , \tag{36}$$

which is the price of foreign headline consumer price index (CPI) denominated in domestic currency relative to domestic headline CPI. Given that the l.o.p for oil may not hold ($\Psi_t^o \equiv \varepsilon_t P_t^{o*}/P_t^o$), we have the following expression for the domestic real price of oil:

$$\frac{P_t^o}{P_t} = RER_t \frac{P_t^{o*}}{P_t^{f*}} \frac{1}{\Psi_t^o} \ , \tag{37}$$

where P_t^{o*} is the foreign currency price of oil in the rest of the world. P_t^{o*}/P_t^{f*} follows an exogenous stochastic AR(1) processes. In Table 5, we compare three alternative model estimates for specifications of the l.o.p gap for oil: $\Psi_t^o \equiv 1$; Ψ_t^o is an AR(1) process; and Ψ_t^o is endogenous and negatively correlated with (P_t^{o*}/P_t^{f*}).

International Risk Sharing and the UIP

We can combine the definition of the real exchange rate in Eq. 36 with the UIP condition of Eq. 14 to describe the equation of motion for the relative purchasing power parity condition (i.e. the real exchange rate):

$$E_t[RER_{t+1}] = RER_t \frac{(1+i_t^b)}{(1+i_t^{b*})} E_t\left[\frac{\Pi_{t+1}^{f*}}{\Pi_{t+1}}\right] \frac{1}{\Phi_t} \ . \tag{38}$$

Note that this condition holds only under complete asset markets (i.e. international risk sharing in consumption (see also, Steinbach, Mathuloe, and Smit 2009, p. 214)). The evolution of the real exchange rate—a measure of trade competitiveness—is rising in the domestic real interest rate (I_t^b/Π_{t+1}) and falling in the foreign real interest rate (I_t^{b*}/Π_{t+1}^{f*}). A positive shock to the prevailing stochastic risk premium (Φ_t) reduces the real exchange rate of the domestic economy. The domestic short-term nominal interest rate is determined by the following Taylor-type monetary policy reaction function:

$$I_t^b = (I_{t-1}^b)^{\rho_i} \left(\frac{\Pi_t}{\Pi^{target}}\right)^{\kappa_\pi(1-\rho_i)} \left(\frac{Y_t}{Y_{t-1}}\right)^{\kappa_y(1-\rho_i)} e^{\epsilon_t^i} \ , \tag{39}$$

$$P_t^h Y_t^h = P_t^h C_t^h + \varepsilon_t P_t^{h*} C_t^{h*}$$

$$Y_t^h = C_t^h + C_t^{h*}. \tag{40}$$

where ρ_i captures the degree of interest rate smoothing, κ_π is the weight on inflation, and κ_y is the weight on output growth. ϵ_t^i is the i.i.d monetary policy shock.

Aggregate Equilibrium and the Foreign Sector

In a symmetric equilibrium, all households and firms make identical decisions, so that $C_{j,t} = C_t$, $O_{j,t}^c = O_t^c$, $B_{j,t} = B_t$, $B_{j,t}^* = B_t^*$, $Y_{j,t}^h = Y_t^h$, $N_{j,t} = N_t$, $K_{j,t} = K_t$, $O_{j,t}^h = O_t^h$, $P_{j,t}^h = P_t^h$, $P_{j,t}^f = P_t^f$ for j $\in$ [0,1] and $t = 0, 1, 2 \ldots$. Equilibrium in the domestic goods-producing sector therefore requires that The total values of exports and imports are given by:

$$\frac{P_t^X}{P_t} X_t = \frac{\varepsilon_t P_t^{h*}}{P_t} C_t^{h*}$$

$$= \frac{P_t^h}{P_t} C_t^{h*} \ . \tag{41}$$

$$\frac{P_t^M}{P_t} M_t = \frac{\varepsilon_t P_t^{f*}}{P_t} C_t^f + \frac{\varepsilon_t P_t^{o*}}{P_t} O_t$$

$$= RER_t C_t^f + \frac{\Psi_t^o P_t^o}{P_t} O_t \ , \tag{42}$$

where $O_t = O_t^c + O_t^h$ is total oil imports used in consumption and production. The aggregate resource constraint then follows as $Y_t = C_t + V_t + X_t - M_t$.

We deviate from the Medina and Soto (2005) model, where foreign economy dynamics are captured and characterized by exogenous processes and rather follow Steinbach, Mathuloe, and Smit (2009, pp. 216–7) and assume a large open economy for the foreign market. This allows us to specify the foreign rate I_t^{b*}, foreign inflation $\Pi_{t+1}^* = \Pi_{t+1}^{f*}$, and foreign consumption $Y_t^* = C_t^*$ according to the standard three-equation New-Keynesian model, namely: an IS curve, a Phillips curve, and a Taylor-type policy rate rule. Foreign oil price shocks are assumed to not have a direct effect on the foreign economy.[10]

Exogenous Shocks

We include eight exogenous shocks in the model, where each stochastic variable in the linearized model is described as, e.g. $\hat{a}_t \equiv log(A_t)$. The foreign real price of oil follows $\hat{pr}_t^{o*} = \rho_{o*}\hat{pr}_{t-1}^{o*} + \epsilon_t^{o*}$, where the domestic deviations from l.o.p shock, $\hat{\psi}_t^o$, is assumed to be constant.[11] For the domestic economy, the monetary policy shock (ϵ_t^i), as given in Eq. 39, is i.i.d, whereas the domestic technology shock $(\hat{a}_t)$ and domestic price markup shock $(\hat{\xi}_t^p)$ follow AR(1) processes. Finally, we include a risk premium shock over the policy rate for domestic-currency assets: $\hat{\mu}_t^b = \rho_b \hat{\mu}_{t-1}^b + \epsilon_t^b$. The foreign economy follows with an i.i.d monetary policy shock (ϵ_t^{i*}) and an AR(1) process for the foreign supply shock $(\hat{a}_t^*)$. In addition, the risk premium shock for foreign-currency assets, equivalent to a foreign demand shock, is $\hat{\mu}_t^{b*} = \rho_b \hat{\mu}_{t-1}^{b*} + \epsilon_t^{b*}$.

Model Estimation

Data and Calibration

We estimate the model over the sample period 1995:Q1 – 2017:Q2. The data set contains seven observable variables.[12] For the domestic economy, South Africa, we have gross domestic product (GDP) per capita, the total consumer price index, and the 3-month treasury bill rate. The foreign economy macroeconomic data are calculated using a trade-weighted average for the USA, UK, Euro area, and Japan.[13] Combined, we have the foreign GDP per capita, the foreign total consumer price index, and the foreign 3-month treasury bill (government securities) rate. Finally, we include the foreign relative (real) price of oil: international price of Brent oil deflated by the foreign consumer price index. All data are log-differenced, except interest rates—which are in quarterly terms.

Table 1 presents the calibrated parameters. Table S.1, available online, shows the corresponding implied steady-state values from the model setup. For households, the share of imported goods in the non-fuel (core) consumption basket is set to 0.27, whereas the import share of oil in consumption is 0.07. Both values correspond to the aggregate South African trade statistics and the implied steady-state values from the model. Following the small open economy models of Faia and Monacelli (2008) and Steinbach, Mathuloe, and Smit (2009), we calibrate the external habit formation parameter ϕ to be 0.7 and the elasticity of labor supply parameter σ_n to be 3. Similarly, the discount factor β equals 0.99. For firms, the share of labor in production is 0.7, whereas the relative share of capital to oil in production is 0.9 (Alba, Chia, and Su 2013). To ensure a steady-state return on capital of 4%, the rate of physical capital depreciation is set to 0.03. Following Bernanke, Gertler, and Gilchrist (1999), we fix the elasticity of the price of capital with respect to the investment-capital ratio (κ_v) to 0.25. We assume wage contracts are reset, on average, every four quarters $(\theta_w = 0.75)$ with a moderate degree

Table 1. Calibrated parameters.

Parameter	Description	Value
Households		
γ_c	Import share of foreign goods in non-fuel goods consumption	0.27
γ_o	Import share of oil in consumption	0.07
β	Discount factor	0.99
ϕ	Habit formation	0.70
σ_n	Elasticity of labor supply	3.00
Firms		
α	Share of labor in firm production	0.70
ϑ	Relative share of capital to oil in production	0.90
δ	Rate of depreciation	0.03
κ_v	Physical capital adjustment costs	0.25
Unions		
θ_w	Sticky wage adjustment	0.75
γ_w	Wage indexation	0.50
ξ_w	Wage elasticity of substitution	5.00
Foreign economy		
ϕ^*	Habit formation	0.00
σ_n^*	Elasticity of labor supply	3.00
γ_p^*	Price indexation	0.00
Aggregate ratios		
V/Y	Investment-output	0.20
X/Y	Export-output	0.28
M/Y	Import-output	0.27
O/M	Import share of fuel to total merchandise imports	0.16
O^c/O	Household's consumption share of fuel imports	0.75

of price indexation ($\gamma_w = 0.5$). A wage elasticity of substitution of 5 implies a steady-state markup of 25% ($\xi^w/(\xi^w - 1)$). The remaining domestic economy steady-state parameters are calibrated directly from the aggregate data and implied model values.

Prior and Posterior Parameters

Tables 2 and 3 present the prior and posterior statistics for the estimated parameters. For the eight stochastic shocks, we set the prior means of the autoregressive coefficients to 0.75, each with a standard deviation of 0.1. The variances of the shocks follow inverse gamma distributions with a prior mean of 0.01, the exception being the foreign real price of oil shock (ϵ_{o*}), which is set to 0.1 (see, e.g. Medina and Soto 2005).

In line with the literature, we assume that the substitutability of oil in household consumption and firm production is low (see, e.g. Backus and Crucini 2000). The inverse elasticity of substitution between capital and oil (ν) is set to 2 with a standard deviation of 0.25, close to the values of 1.43 and 1.54 given in Kim and Loungani (1992) and Alba, Chia, and Su (2013). Following Medina-Soto (2005), we set the elasticity of substitution between oil and consumption (η_o) to 0.2 with a standard deviation of 0.05. A foreign demand elasticity (ξ^{f*}) of 2 falls within the range of estimates (from 1.36 to 4.59) in Adolfson et al. (2007, pp. 500–502). Given this wide range, we choose a standard deviation of 0.5 for ξ^{f*}. The prior distributions for domestic prices and the monetary policy rule conform closely to other estimates for the South Africa economy and open economy models in general (see, e.g. Adolfson et al. 2007; Steinbach, Mathuloe, and Smit 2009).

Table 2. Structural parameters.

	Parameter	Prior distribution			Posterior distribution			
		Type	Mean	Std.dev	Mean	Median	90% HPD int.	
Preferences								
η_c	Domestic–foreign substitution elasticity	Gamma	0.60	0.05	0.559	0.558	0.482	0.628
η_o	Oil-core consumption subst. elasticity	Gamma	0.20	0.05	0.200	0.196	0.120	0.281
σ_c	Domestic relative risk aversion	Inv.Gamma	1.00	0.20	3.637	3.474	2.613	5.102
σ_c^*	Foreign relative risk aversion	Inv.Gamma	1.00	0.20	0.798	0.786	0.602	0.989
v	Oil-capital subst. elasticity (inverse)	Gamma	2.00	0.25	2.109	2.098	1.696	2.514
ξ^{f*}	Foreign demand elasticity	Gamma	2.00	0.50	0.306	0.292	0.224	0.392
Prices								
θ_h	Domestic price stickiness	Beta	0.60	0.05	0.470	0.469	0.389	0.557
γ_p	Domestic price indexation	Beta	0.60	0.05	0.537	0.539	0.453	0.620
θ_f	Import price stickiness	Beta	0.80	0.05	0.734	0.737	0.628	0.843
θ^*	Foreign price stickiness	Beta	0.75	0.10	0.448	0.450	0.380	0.515
Monetary policy rule								
κ_π	Coefficient on inflation	Gamma	1.50	0.20	1.405	1.398	1.137	1.641
κ_y	Coefficient on output change	Beta	0.50	0.20	0.727	0.742	0.512	0.934
κ_π^*	Coefficient on foreign inflation	Gamma	1.50	0.20	2.129	2.121	1.806	2.432
κ_y^*	Coefficient on foreign output change	Beta	0.50	0.20	0.768	0.785	0.589	0.959

Table 3. Exogenous processes.

	Parameter	Prior distribution			Posterior distribution			
		Type	Mean	Std.dev	Mean	Median	90% HPD int.	
AR coefficients								
ρ_{o*}	Foreign oil price shock	Beta	0.75	0.1	0.985	0.987	0.973	0.998
ρ_a	Technology	Beta	0.75	0.1	0.868	0.870	0.809	0.924
ρ_p	Price markup	Beta	0.75	0.1	0.712	0.723	0.529	0.902
ρ_i	Monetary policy	Beta	0.75	0.1	0.849	0.850	0.819	0.877
ρ_{a*}	Foreign supply	Beta	0.75	0.1	0.890	0.933	0.710	0.989
ρ_{i*}	Foreign monetary policy	Beta	0.75	0.1	0.853	0.855	0.821	0.886
ρ_{b*}	Foreign risk premium	Beta	0.75	0.1	0.870	0.871	0.836	0.902
ρ_b	Domestic risk premium	Beta	0.75	0.1	0.860	0.863	0.810	0.914
Standard deviations								
ϵ_{o*}	Foreign oil price shock	Inv.Gamma	0.1	inf	0.151	0.150	0.133	0.169
ϵ_a	Technology	Inv.Gamma	0.01	inf	0.025	0.025	0.016	0.033
ϵ_p	Price markup	Inv.Gamma	0.01	inf	0.009	0.007	0.003	0.016
ϵ_i	Monetary policy	Inv.Gamma	0.01	inf	0.002	0.002	0.002	0.002
ϵ_{a*}	Foreign supply	Inv.Gamma	0.01	inf	0.004	0.004	0.003	0.004
ϵ_{i*}	Foreign monetary policy	Inv.Gamma	0.01	inf	0.002	0.002	0.001	0.002
ϵ_{b*}	Foreign risk premium	Inv.Gamma	0.01	inf	0.001	0.001	0.001	0.002
ϵ_b	Domestic risk premium	Inv.Gamma	0.01	inf	0.004	0.004	0.003	0.005

The pass-through of import prices into domestic retail prices tends to be low (Burstein and Gopinath 2014; Monacelli 2005). Import prices therefore exhibit higher price stickiness, to which we set θ_f a prior mean of 0.8 and standard deviation of 0.05. As a result, the price adjustment mechanism required to bring real relative prices into equilibrium falls more heavily on the nominal exchange rate. That is, consistent with small open economies, low pass-through is associated with higher exchange rate variability.

For the foreign economy, we restrict the standard three-equation New-Keynesian model with zero habit formation and no price indexation. Structural persistence in consumption is therefore governed by the foreign risk aversion coefficient σ_c^*, to which we set the prior mean to 1 with a standard deviation of 0.2. Similarly, Calvo foreign prices control the degree of price stickiness. The prior mean for θ^* is set to 0.75 with a standard deviation of 0.1.

The posterior parameter estimates in Tables 2 and 3 are based on standard Bayesian techniques (e.g. Adolfson et al. 2007). Most of the prior distributions are shown to be robust to the data. Notably, domestic households exhibit a relatively higher degree of risk aversion (3.6) and therefore respond more smoothly to interest rates. A difference of 0.36 between the posterior means of η_c and η_o implies that households raise their consumption of domestic goods in response to real exchange rate increases (i.e. an improved competitiveness) and reduce their consumption of domestic goods when relative domestic prices increase (see Eq. S.1). The reverse holds for the consumption of foreign goods (see Eq. S.2). The data also predict a foreign demand elasticity close to 0.3, which is lower than the estimates identified in Adolfson et al. (2007) for the euro area as well as Medina and Soto (2005) for the Chilean economy. In both Adolfson et al. (2007, p.488) and Medina and Soto (2005, p.9–10), however, the foreign economy is identified exogenously by autoregressive processes. In our model, the foreign sector contains endogenous frictions which may reduce the need for a high degree of foreign demand elasticity. Import price stickiness remains high (0.73) relative to domestic and foreign Calvo prices (0.47 and 0.45). These results follow closely to that of Steinbach, Mathuloe, and Smit (2009, p. 219) for the South African economy. Similarly, we find that the South African monetary authorities have a consistent anti-inflation bias (κ_π>1) and a relatively large weight on output—indicating greater exploitation of the Phillips curve's output-inflation trade-off (see also Ortiz and Sturzenegger 2007, p. 667–671). Finally, the autoregressive coefficients for the eight estimated shocks are all persistent with posterior means at 0.7 or higher. The contribution of the various shocks to the model is studied in more detail in the next section.

In order to highlight the role of oil in a small open oil-importing economy, we estimate the model excluding oil as a factor of production and as a commodity for consumption. The baseline model without oil (*no oil* hereafter) is obtained by setting the shares of oil in consumption and production to zero ($\gamma_o = 0; \vartheta = 1$). Table 5 compares the posterior parameter estimates for the *no oil* model to that of the model with oil (*oil* hereafter). Section 4.3 discusses these results in more detail.[14]

Results

Historical and Variance Decomposition

Table 4 reports the variance decompositions for the three main variables of interest: output, total (headline) inflation, and the nominal interest rate. The results are shown for 1-quarter, 1-year, 2-year, and 5-year horizons.[15] Columns 2–5 report the results for the model with oil (*oil* hereafter). Columns 6–9 report the results for the baseline model without oil (*no oil* hereafter). Figure 2 shows the results for the historical decompositions of the same three variables over the sample period 1995:Q1 – 2017: Q2. The purpose of this section is to provide a formal assessment of the contribution of each structural shock to fluctuations in the endogenous variables, firstly, at different horizons, and secondly, at each observation of the actual data. We find that oil price shocks have a significant effect on all three macro variables.

The effect of a foreign real oil price shock (ϵ_{o*}) on output is strong and persistent across all horizons (between 9.6% and 26.7%). Given the model setup, a decline in the oil price has an important direct real effect on domestic production and consumption activities. Traditional supply and demand dynamics intuitively describe the long-run versus short-run effect of domestic demand and supply shocks. In the short-run, the domestic risk premium shock (ϵ_b) contributes 31.0% after 1 quarter and

Table 4. Forecast error variance decomposition of output, total inflation, and nominal interest rate.

	***Oil* model: time horizons**				***No oil* model: time horizons**			
Shocks	**1 quarter**	**1 year**	**2 years**	**5 years**	**1 quarter**	**1 year**	**2 years**	**5 years**
Variance decomposition of output								
ϵ_{o*}	9.62	15.61	18.93	26.70				
ϵ_{a*}	0.97	0.88	1.08	1.29	1.79	2.29	3.20	4.35
ϵ_{i*}	0.11	0.02	0.02	0.01	0.25	0.09	0.07	0.08
ϵ_{a}	44.93	66.2	68.76	63.47	22.77	48.69	59.40	63.73
ϵ_{p}	4.27	3.03	2.07	1.54	13.06	12.89	9.51	7.68
ϵ_{i}	9.02	3.22	2.09	1.61	16.72	9.74	7.60	6.70
ϵ_{b*}	0.1	0.02	0.01	0.01	0.23	0.08	0.07	0.07
ϵ_{b}	30.98	11.01	7.05	5.36	45.17	26.23	20.15	17.39
Variance decomposition of total inflation								
ϵ_{o*}	44.92	31.11	30.18	30.00				
ϵ_{a*}	0.09	0.10	0.10	0.12	0.17	0.16	0.18	0.23
ϵ_{i*}	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ϵ_{a}	40.11	51.31	51.41	51.59	53.26	52.28	50.38	50.35
ϵ_{p}	3.66	3.62	3.89	3.88	34.67	26.29	26.90	26.78
ϵ_{i}	2.40	2.81	2.85	2.83	2.83	4.68	4.76	4.73
ϵ_{b*}	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ϵ_{b}	8.80	11.03	11.55	11.58	9.06	16.58	17.78	17.91
Variance decomposition of nominal interest rate								
ϵ_{o*}	34.22	16.44	12.91	12.78				
ϵ_{a*}	0.01	0.02	0.03	0.05	0.03	0.05	0.10	0.20
ϵ_{i*}	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01
ϵ_{a}	17.18	37.09	35.71	34.51	16.95	32.81	30.75	29.61
ϵ_{p}	1.58	2.11	1.60	1.42	10.92	12.87	9.26	8.10
ϵ_{i}	21.06	7.81	5.70	5.16	52.55	18.87	13.27	11.88
ϵ_{b*}	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01
ϵ_{b}	25.94	36.53	44.04	46.08	19.52	35.39	46.61	50.20

11.0% after 1 year. The impact of this domestic demand shock declines quickly, contributing 7.1% and 5.4% in the medium- and long-run, respectively. In addition, the domestic monetary policy shock shows a similar pattern, but at approximately one-third the magnitude. In contrast, the domestic technology shock contributes 44.9% in the first quarter to almost two-thirds the variance of output after 5 years. Notably, other than the oil price, foreign economy shocks have a negligible impact on the domestic real economy. This result is in line with similar SOE-NKDSGE models estimated for South Africa (e.g. Alpanda, Kotzé, and Woglom 2010; Steinbach, Mathuloe, and Smit 2009).[16] Compared to the *no oil* model, we find that the technology and risk premium shock are reduced by approximately 20 and 10 percentage points across all horizons, whereas the monetary policy shock increases in the short run by about 5 percentage points.

The contribution of the foreign real oil price shock has a significant impact on total headline inflation across all horizons: from 44.9% after the first quarter to 30.0% after 5 years. Compared to the *no oil* model, the impact of the technology shock is dampened in the first quarter horizon only and still contributes half of the forecast error variance of headline inflation. That said, it is clear that the impact of the price markup shock is significantly reduced after introducing the *oil* cost channel. In contrast to Steinbach, Mathuloe, and Smit (2009) and Alpanda, Kotzé, and Woglom (2010), monetary policy surprises and price markup shocks are the least important domestic shocks in both models, whereas the impact of foreign economy shocks are again negligible.[17]

Table 5. Alternative model parameter estimates.

	Posterior distribution means					Posterior distribution means			
	Baseline (*No oil*)	mod.1 (*Oil*)	mod.2	mod.3		Baseline (*No oil*)	mod.1 (*Oil*)	mod.2	mod.3
Marginal density	**2203.6**	**2182.4**	**2175.1**	**2201.1**					
Structural parameters					Shock parameters				
η_c	0.210	0.559	0.553	0.580	ρ_{o*}		0.985	0.983	0.973
η_o		0.200	0.194	0.215	ρ_{ψ}			0.483	0.852
σ_c	3.915	3.637	3.881	3.414	$\rho_{\psi*}$			0.057	
σ_c^*	0.781	0.798	0.800	0.804	ρ_a	0.862	0.868	0.869	0.894
v		2.109	2.146	1.953	ρ_p	0.628	0.712	0.685	0.754
ξ_{f*}	0.335	0.306	0.301	0.387	ρ_i	0.847	0.849	0.850	0.848
					ρ_{a*}	0.858	0.890	0.843	0.913
θ_h	0.498	0.470	0.466	0.629	ρ_{i*}	0.836	0.853	0.853	0.854
γ_p	0.549	0.537	0.535	0.596	ρ_{b*}	0.862	0.870	0.869	0.869
θ_f	0.759	0.734	0.735	0.762	ρ_b	0.867	0.860	0.863	0.862
θ^*	0.453	0.448	0.448	0.449					
					ϵ_{o*}		0.151	0.151	0.151
κ_π	1.472	1.405	1.400	1.545	ϵ_ψ				0.123
κ_y	0.608	0.727	0.716	0.796	ϵ_a	0.014	0.025	0.024	0.014
κ_π^*	1.739	2.129	2.114	2.125	ϵ_p	0.015	0.009	0.010	0.006
κ_y^*	0.623	0.768	0.758	0.751	ϵ_i	0.002	0.002	0.002	0.002
					ϵ_{a*}	0.004	0.004	0.004	0.004
					ϵ_{i*}	0.002	0.002	0.002	0.002
					ϵ_{b*}	0.001	0.001	0.001	0.001
					ϵ_b	0.003	0.004	0.004	0.003

Notes: We exclude parameter descriptions, prior means, and standard deviations (see Tables 2 and 3) and statistic confidence intervals in the table due to the limited space. Eq. 37 and ft. 11 provide details of the alternative specifications for $\hat{\psi}_t^o$. Model 2 (mod.2) is the model with an endogenous l.o.p gap. Model 3 (mod.3) gives the estimates for the model with both the foreign real oil price shock and the deviations from l.o.p for oil shock.

In the *no oil* model, nominal interest rate is mainly driven by the monetary policy shock in the short-run and the domestic risk premium and technology shocks in the medium- to long-run (see also Steinbach, Mathuloe, and Smit 2009, p. 222). Introducing *oil* significantly reduces the contributions of the price markup shock and the monetary policy shock. A sizeable first-quarter contribution of the foreign real oil price to the variance of the short-term nominal interest rate suggests a strong initial policy response to oil price shocks, which also partly accounts for the strong first-quarter reaction of the monetary authorities in the *no oil* model.[18] Over the medium- to long-run, the effect of foreign real oil price shocks is smaller but noticeable. In summary, it is clear that oil price shocks are a key driver of output, inflation, and interest rates in a small open economy. This is further substantiated by the minimal explanatory power of real and nominal foreign economy shocks in describing the domestic business cycle.

The historical decompositions of the same three variables over the sample period 1995:Q1–2017:Q2 are shown in Figure 2. Intuitively, positive oil price shocks should feed through into higher headline inflation and lower output and *vice versa*. This effect can be clearly seen over the whole sample period: most notably around the periods of large declines in the foreign real price of oil in 1997/1998, 2001, 2008/2009, and 2014/2015.[19] Also, foreign oil price shocks tend to offset

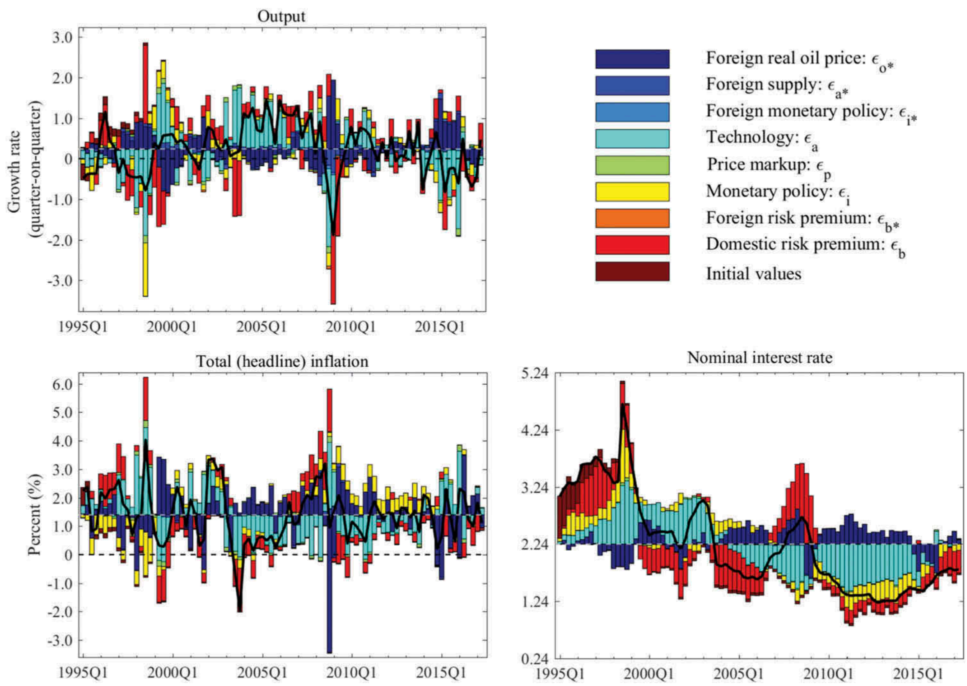

Figure 2. Historical decomposition: output (top-left); total inflation (bottom-left); and nominal interest rate (bottom-right).

technology and risk premium shocks. The recent Great Recession is a case in point, whereby the decline in oil prices dampened the negative impact of technology and risk premium shocks on output and inflation. Turning to the short-term nominal interest rate in the bottom-right of Figure 2, we find a similar relationship between oil price shocks and domestic shocks. Here, oil prices influence interest rates through inflation and real wealth effects on household consumption. Overall, episodes of positive (negative) oil price shocks tend to put upward (downward) pressure on the nominal interest rate, which suggests that oil's effect on inflation is greater than on household consumption. In particular, the 23% positive real oil price rise in 2008:Q2 contributed to inflation concerns and a tighter policy stance going into the Great Recession period, which likely worsened the downturn.

Impulse Response Function Analysis: Oil Versus No Oil

Figure 3(a,b) shows the impulse response function results to a domestic technology shock (column 1), a domestic monetary policy shock (column 2), a domestic price markup shock (column 3), and a foreign real oil price shock (column 4). To highlight the role of oil, we compare the responses of the *oil* model to that of the *no oil* model. The *no oil* model is obtained by setting the shares of oil in consumption and production to zero ($\gamma_o = 0; \vartheta = 1$). In the Supplementary Material for the article, available online, we present the impulse responses for the various shocks for the model with and without oil along with the confidence bands, which in turn, highlights the significance, in general, of the effects of the various shocks.

A positive 15% shock to the foreign real price of oil raises oil inflation in the domestic economy by 14 percentage points (pp) (row 4, column 4 in Figure 2). Total inflation rises 1 pp which implies a pass-through of 7%, wherein the second-round effect on domestic inflation accounts for one-fifth of total inflation. The higher real price of oil therefore induces households to reduce their consumption of both oil (by 2.5%) and domestic goods. Similarly, the demand for oil in domestic production declines 6.7% in response to the oil price shock. In aggregate, domestic oil usage falls 4% (row 4 in Figure 3(b)). Given that foreign goods and physical capital are imperfect substitutes for oil, domestic output declines from the first quarter to its peak in the fourth quarter an accumulated 2.32%. In response to declining output and rising inflation, the monetary authorities raise the short-term nominal interest rate 68 basis points (annualized). Oil price shocks therefore generate a trade-off between output and inflation stabilization when the substitutability of oil in consumption and production is low (Montoro 2012; Natal 2012). In our estimated model of the South African economy, the endogenous tightening of monetary policy slows the recovery of the real economy. Compared to the estimated model of Medina and Soto (2005) for the Chilean economy, the responses of inflation, output, and the real exchange rate are closely comparable.[20] Although the responses of the policy rate are qualitatively similar, including a risk premium on domestic-currency assets (μ_t^b) in our model reduces the emphasis on endogenous tightening of monetary policy (see Table 4).

Under the monetary policy shock (column 2), the difference between the *oil* model and *no oil* model is small. A 0.5 pp (annualized) rise in the policy rate reduces output and total inflation by 0.37% and 0.22 pp compared to 0.33% and 0.12 pp in the *no oil* model.

Conversely, the model with oil significantly reduces the effect of a domestic price markup shock (column 3) and increases the effect of a domestic technology shock (column 1), confirming the variance decomposition results in Table 4. Comparing columns 3 and 4 in Figure 3(a) and (b) show that both the domestic price markup shock and the oil price shock have qualitatively analogous impacts on nominal and real variables in the domestic economy. As a result, including oil in the

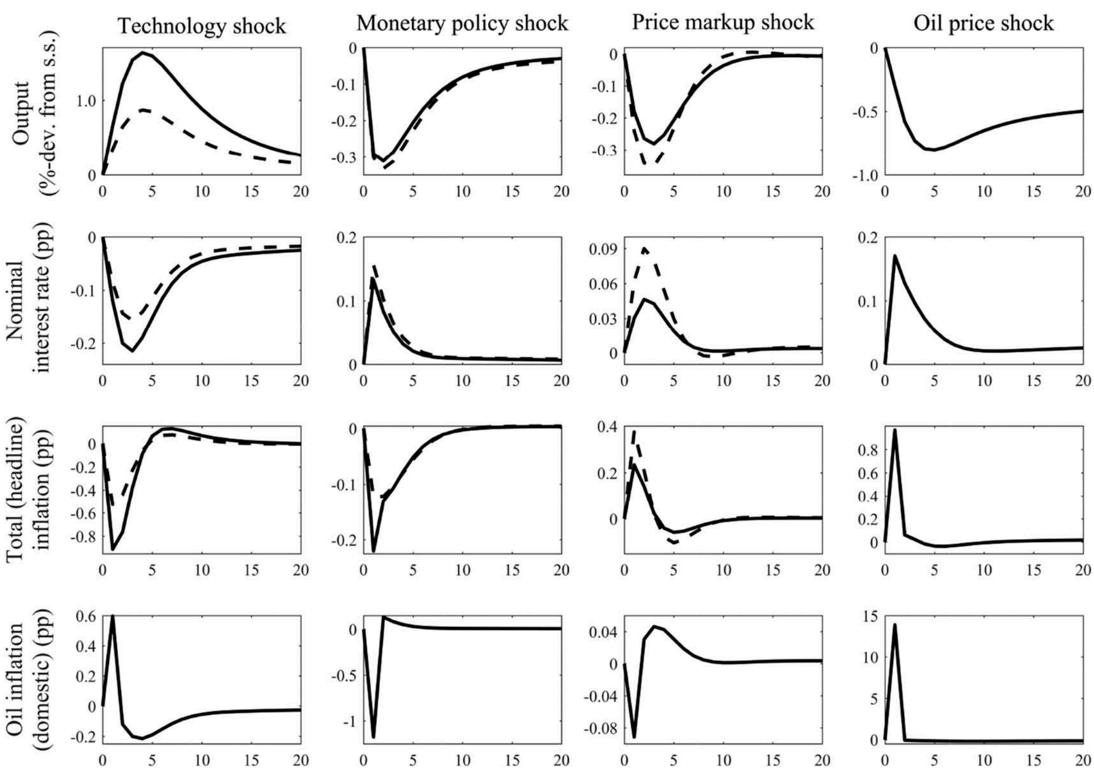

Figure 3. Impulse responses (solid line: oil model; dashed line: no oil model). (a): Top panel. (b): Bottom panel. Inflation and interest rates are measured in percentage points. All other variables are measured as %-deviations from steady state.

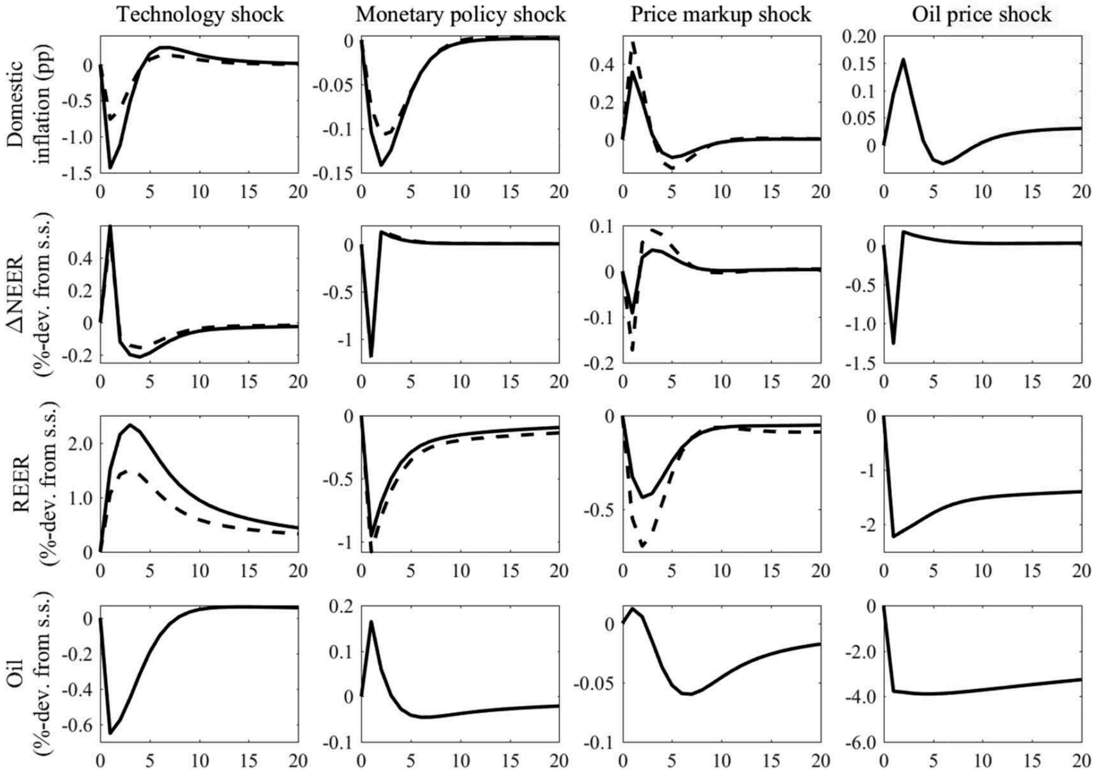

Figure 3. (Continued).

model framework highlights the relative importance of oil price shocks in distorting relative prices. It also clearly explains the dampened effect of price markup shocks in the *oil* model.

A positive technology shock (column 1) raises output by 0.84% and reduces domestic inflation by 0.51 pp in the *no oil* model. In response, the policy rate is cut 0.60 pp (annualized). The *oil* model introduces imperfect substitutability with capital goods for production and domestic goods for consumption. Due to the tendency of the real oil price to rise and fall with the business cycle (Figure 1), domestic technology shocks are underestimated when oil is excluded from the model.[21] That is, imperfect substitution implies that output is more persistent in response to total factor productivity (technology) shocks. Specifically, in response to improved competitiveness (*REER*) and lower oil imports, exports rise and imports fall which improves the trade balance and therefore total output (see Eqs. S.35 and S.36). Initially, the domestic real price of oil ($\hat{pr}_t^o$) rises in response to higher household consumption and firm production, dampening downward pressure on total inflation from the domestic economy (see Eq. S.17). As a result, the magnitude of the monetary policy response, although larger than that of the *no oil* model, is dampened by the endogenous presence of oil.

For the open economy variables in Figure 2, the competitiveness of the home country improves through a rise (depreciation) in the real effective exchange rate (*REER*). For example, a positive technology shock that reduces unit costs of production leads to domestic goods being relatively cheaper than foreign goods. As a result, the real exchange rate depreciates. In the model economy, international risk sharing in consumption implies that rising domestic consumption relative to foreign consumption must be accompanied by a rising real exchange rate (see Eq. S.5). As such, the results confirm strong co-movement between the real exchange rate and domestic output (e.g. Steinbach, Mathuloe, and Smit 2009). We can also think of nominal effective exchange rate changes (*ΔNEER*) as the price adjustment mechanism that maintains equilibrium between foreign and domestic goods markets; in relative purchasing power parity (PPP) terms, a change in the real effective exchange rate must equate with changes in *NEER* plus the foreign–domestic inflation differential (Eq. S.23): $\Delta REER = \Delta NEER \ + \ (\pi^* - \pi)$. Row 2 shows the well-known phenomenon of nominal exchange rate overshooting, in that initial changes in *NEER* tend to be greater than foreign–domestic inflation differentials before returning to relative PPP with $\Delta REER \approx 0$. Specifically, arbitrage in international asset markets requires that the UIP condition holds (Eq. 14), after which the goods market takes time to clear. Corresponding to an extensive literature, in all four shocks, we see strong initial co-movement between real and nominal exchange rates (e.g., Burstein and Gopinath 2014; Finn 1999). The foreign oil price shock mimics that of a domestic price markup shock: a rise in headline inflation relative to the foreign economy leads to an appreciation in the real exchange rate. Similarly, a rise in the nominal interest rate relative to the foreign interest rate induces an initial appreciation in $\Delta NEER$ due to capital inflows. Subsequently, this leads to an expected depreciation in the nominal exchange rate, which satisfies the UIP condition.

Given the impulse response results, it is clear that the model with oil is robust to the baseline small open economy model and that oil in production and consumption are both important determinants of nominal and real variables in the South African economy.

Comparing the Fits of the DSGE Model with and without Oil

In this subsection, we compare both the in-sample and out-of-sample performances of the DSGE model with and without oil. To assess in-sample fit, as well as robustness, Table 5 compares the posterior parameter estimates for the *no oil* model to that of the *oil* models (see Eq. 37 and ft. 11 for details of the three specifications corresponding to *oil* models 1–3).[22] Notably, the change in parameter values for η_c and σ_c seems to be key for the structural dynamics of the *oil* model: that is, while the majority of structural parameters are robust (stable) to the alternative model estimations, excluding oil from the model reduces η_c, the intratemporal elasticity of substitution between domestic goods and foreign goods, from 0.56 to 0.21, and raises the risk aversion coefficient σ_c from 3.64 to 3.92. As a result, the effect of relative price movements on the consumption of foreign and domestic goods is dampened, as well as the response of aggregate consumption to the real interest rate. Both the *intra*-temporal and *inter*-temporal consumption ($1/\sigma_c$) decisions of households are therefore more muted in the *no oil* model.

Next, we turn our attention to a more robust comparison between the models by looking at one- to eight-quarter-ahead out of sample forecasts for output, inflation, and interest rate. For our purpose, we use an out-of-sample period of 2008:Q2–2017:Q2 and 2008:Q2–2011:Q2 over which the DSGE model is estimated recursively to produce the forecasts at various horizons. The choice of the out-of-sample periods corresponds to the start in the recent decline of oil prices and also when the South African economy was on the verge of its largest post-1994 recession. The shorter out-of-sample period focuses on the recession and initial recovery only. Table S.3.2, available online, presents the ratio of root mean square errors from the model with oil (*oil*) relative to the same model without oil (*no oil*). Understandably, if the ratio is less than 1, the model with oil outperforms the model without it. As can be seen from the table, the *oil* model outperforms the *no oil* model for output at horizons 1–3. The same holds for horizon 3 for inflation, whereas, for the interest rate, the model with oil does not outperform the DSGE model without it at any horizons. When we look at the shorter out-of-sample period, the model with oil continues to outperform the model without it for inflation at the third-quarter-ahead forecast and now for the interest rate at one-quarter-ahead. For output, the *oil* model now outperforms the one without it consistently over horizons 1–6. Based on McCracken (2007) MSE-F statistic suitable for nested models, we find that the forecasts for output from the *oil* model are significantly better than those from the *no oil* version at least at the 5% level of significance for horizons 1 and 2 for output and at horizon 3 for inflation under the longer out-of-sample period. However, in case of the shorter out-of-sample period, significance is observed for horizons 1–3 for output, 3 for inflation, and 1 for the interest rate. The fact that introducing a role for oil does not appear to improve inflation (and interest rate) forecasts can be explained by South Africa's relatively successful inflation-targeting performance, especially since 2000 (see, e.g. Ortiz and Sturzenegger 2007).[23] More broadly, this echoes Blanchard and Galí (2010) and Blanchard and Riggi (2013) who find that "better monetary policy" since 2000 (in the USA and for other advanced economies) has played an important role in dampening the pass-through of oil price movements to inflation. What the results for the recession and recovery period in Table S.3.2 do suggest is a strong one-step-ahead interest rate response during episodes of large oil price fluctuations: in fact, the 23% increase in the real price of oil in 2008:Q2 preceded a 50 basis points increase in the short-term nominal interest rate to its peak (11.3%) in 2008:Q3. At the same time, total headline inflation rose 1.2 percentage points to its peak of 11.2% before the economy headed into its 2009 recession.

Concluding Remarks

Just like most economies around the world, there is also a large literature on the role of oil prices in affecting the macroeconomy (and financial market) of South Africa—an oil-importing and inflation-targeting country. While these studies generally conclude that the impact of positive oil shocks is inflationary for the South African economy, the evidence is mixed for output, interest rates, and exchange rates. This we believe is possibly due to the fact that the South African literature on the effects of oil price is based on atheoretical models and hence is not robust to choice of variables, models, and sample sizes. Given this, in this study, we aim to develop a SOE-NKDSGE model to provide definitive answers to the impacts of oil shocks on the macroeconomic variables of South Africa as obtained from the theoretical framework.

Upon estimating the SOE-NKDSGE model using quarterly data over the period of 1995:Q1–2017:Q2, we can draw the following conclusions. Foreign real oil price shocks have a strong and persistent effect on domestic production and consumption activities and, hence, are a fundamental driver of output, inflation, and interest rates in both the short- and long-run. Oil price shocks also generate a trade-off between output and inflation stabilization. As a result, episodes of endogenous tightening of monetary policy slow the recovery of South Africa's real economy.[24] Accounting for oil (energy) demand in firm production and household consumption is therefore crucial for policymakers in oil-importing small open economies. In fact, the historical decomposition results show a clear pattern for oil price shocks on output and inflation, most notably around the periods of large declines in the foreign real price of oil in 1998:Q1, 2001:Q4, 2008:Q4, and 2015:Q1: lower (higher) oil prices feed through into lower (higher) headline inflation and improved (deteriorated) output conditions. For example, declining oil prices in the recent 2008/2009 recession benefited the economy by offsetting adverse demand (risk premium) and supply (technology) shocks. As a result, oil prices influence interest rates through inflation, real wealth effects on household consumption, and production capacity. Overall, episodes of positive (negative) oil price shocks tend to put upward (downward) pressure on the nominal interest rate. We also find that the SOE-NKDSGE model with oil significantly improves the out-of-sample forecast for output over the period 2008:Q2 – 2017:Q2, i.e. during and after the recession that followed the 2008 global financial crisis.

As Kilian (2009) points out, not all oil price fluctuations have the same macroeconomic impacts. For instance, if oil demand and oil prices rise because of strong foreign aggregate demand, worldwide activity expands rather than contracts—as in the case of price increases resulting from foreign oil supply disruptions. Given this, the international dimension of oil trade matters and the structure of the oil market in DSGE models must be rich enough to identify different kinds of oil demand and supply shocks. While some attempts have been made to enrich the oil-based DSGE models for the US economy (see, for example, Bodenstein and Guerrieri 2011; Peersman and Stevens 2010), it would be interesting to incorporate such a structure of the oil market in a small open economy model for South Africa as part of future research.

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Supplementary materials

Supplementary material can be accessed here.

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Notes

1. The household's decision problem can be characterized by three stages. (1) Each household j minimizes the total cost of its consumption basket, $P_t^z Z_{j,t} + P_t^o O_{j,t}^c$ subject to Eq. 1, where P_t^z and P_t^o are the price of core consumption goods (i.e. the core consumption deflator) and the price of oil; (2) similarly, we minimize the core consumption basket, $P_t^h C_{j,t}^h + P_t^f C_{j,t}^f$ subject to Eq. 2; and (3) we maximize utility subject to the budget constraint.
2. With the assumption of complete markets (i.e. a complete set of contingent claims), the decision problem is identical for all households. This feature allows for a well-defined steady state for the small open economy (see, e.g. Schmitt-Grohé, and Uribe (2003) and Steinbach, Mathuloe, and Smit (2009).
3. i.e. when wages cannot be reset: $W_t^\tau = \Gamma_t W_{t-1}$, where $\Gamma_t = \Pi_{t-1}^{\gamma_w} = (P_{t-1}/P_{t-2})^{\gamma_w}$.
4. $\bar{C}_{t+i} = (C_{t+i} - \phi C_{t-1+i})$.
5. $\phi' > 0$, $\phi'' < 0$, $\phi'(\delta) = 0$, $\phi(\delta) = 0$. Specifically, $\phi(V_t/K_t)K_t = (\kappa_v/2\delta)(V_t/K_t - \delta)^2 K_t$.
6. In Adolfson et al. (2007) and Medina and Soto (2007, 2014), there are monopolistically competitive firms in the import and export markets for both investment and consumption goods. When nominal rigidities (as in Smets and Wouters 2002) are zero, exchange rate pass-through to import and export prices is complete.
7. In order to ensure κ_v captures realistic adjustment costs in the investment schedule, we assume that the firm ignores external habit formation of households ($\phi = 0$) in its stochastic discount factor. Preliminary estimations of the model led to either implausibly high estimates (of between 20 and 30) for the capital adjustment cost parameter (κ_v) or a fairly sizeable loss of model in-sample fit with κ_v fixed. One likely reason is due to output, inflation, and the interest rate being the only observable variables used for the domestic economy, which restricts including additional shocks (e.g. investment specific) or the identification of parameters that control for monopolistic competition of investment goods in an open economy (see, e.g. Adolfson et al. (2007) and Medina and Soto (2007, 2014)).
8. Notice that while households consider total (headline) price adjustments (ΔP_t), firms operate in the domestic goods sector only. That is, they consider the price of domestic goods (P_t^h) only and therefore only indirectly internalize oil and foreign price shocks. Therefore, when derivation is complete, the system of equilibrium conditions (specifically the real price of domestic goods in production) must account for the relative price differences conditioned in each sector. In other words, the real price in the domestic economy is in terms of P_t, and therefore the domestic sector must account for the relative price difference P_t^h/P_t.
9. Note that the above assumption concerning domestic and foreign elasticities implies that ξ_t^p incorporates both domestic and foreign elasticities of demand with $Y_t^h = C_t^h + C_t^*$, where C_t^* is foreign consumption of domestic goods. However, as we will see below, the foreign demand for domestic goods in the foreign economy has its own demand curve. As such, it serves as an exogenous foreign demand shock with uncertainty (i.e. foreign demand shocks are not substitutable and have complete pass-through to the real economy).
10. See Section S.1, available online, for the full linearized system of equilibrium conditions.
11. In Table 5, we compare three alternative model estimates for specifications of the l.o.p gap for oil: (1) a constant ($\hat{\psi}_t^o \equiv 0$); (2) an exogenous AR(1) process ($\hat{\psi}_t^o = \rho_\psi \hat{\psi}_{t-1}^o + \epsilon_t^\psi$); and (3) an endogenous process negatively correlated with pr_t^{o*} ($\hat{\psi}_t^o = \rho_\psi \hat{\psi}_{t-1}^o - \rho_{\psi*} \hat{pr}_{t-1}^{o*}$). We find that a constant l.o.p gap for oil provides the best interpretable results without loss of generality.
12. See the Supplementary Material for data and sources (Section S.2), available online.

13. The USA, UK, Euro area, and Japan make up 67% of total trade over the sample period. From 1994 to 2002, the average was 77.65%; from 2003 to 2009, the average was 70.53%; and from 2010 to 2012, the average was 54.83%. The recent drop is due to China's current 20% share of trade with South Africa (SARB Quarterly Bulletin, December 2008 and June 2014).

14. Figure S.3.2, available online, plots the prior and posterior distributions of the estimated parameters. The parameters that exhibit very similar prior and posterior means and distributions are: $\left\{\eta_c, \eta_o, \nu, \rho_p, \epsilon_p\right\}$. An identification analysis (following Ratto (2008) and Ratto and Iskrev (2011)) shows that all parameters are identified in the model at the posterior mean. The parameter of most concern (i.e. that shows the weakest identifiable patterns) is ν. Based on collinearity patterns, the identification analysis suggests that adjusting the prior distribution of ν will likely be offset by changes in θ_f and/or η_o. Table 5 supports this conclusion: excluding oil (*no oil* model) results in slightly more import price stickiness (θ_f) and significantly lower domestic–foreign consumption elasticity of substitution (η_c). The full set of results on the prior and posterior distributions, the posterior densities, Markov chain Monte Carlo (MCMC) diagnostics, and identification tests of the corresponding parameters are available on request.

15. 1–4 quarters captures the short-run, 8 quarters the medium-run, and 20 quarters the long-run.

16. Alpanda, Kotzé, and Woglom (2010) compare Steinbach, Mathuloe, and Smit's (2009) model to a model with an independent country risk premium shock in the UIP condition. For both models, they find that the combined contributions of foreign shocks to inflation, output, and nominal interest rate are less than 1% across all horizons. Adolfson et al. (2007, p. 506) find a similar result in an estimated model for the Euro area.

17. From Eq. S.21, available online: $\hat{pr}_t^o - \hat{pr}_t^{o*} = \hat{rer}_t + \hat{\psi}_t^o$, we can see that when deviations from the l.o.p for oil are zero ($\hat{\psi}_t^o = 0$), the difference between the domestic and foreign real price of oil is fully absorbed by the real exchange rate ($\hat{rer}_t$). Given the contribution of l.o.p deviations for oil, the net effect of the foreign oil price shock is not significantly affected (see, e.g. Figure S.3.1). A comparison of historical decomposition results from the alternative specifications in Table 5 is available upon request.

18. This result also provides some impetus for the significant improvement in the first-quarter forecast of the nominal interest rate during 2008:Q2 − 2011:Q2 (see Table S.3.2).

19. The largest quarter declines for each episode were: −25% (1998:Q1); −24% (2001:Q4); −52% (2008:Q4); and −29% (2015:Q1).

20. Just like South Africa, Chile too is a small open economy with an inflation targeting monetary policy and a floating exchange rate regime. Both countries are also net importers of oil.

21. The real oil price has a correlation coefficient with real GDP of 0.37 for growth rates and 0.82 for levels.

22. We find that all three specifications for oil provide very similar posterior results and impulse response functions (Figure S.3.1). Importantly, mod.1 ($\Psi_t^o \equiv 1$) provides the best interpretable results for the variance and historical decompositions, which comes at the expense of some reduction in in-sample fit compared to adding Ψ_t^o as an additional exogenous shock (2182.4 versus 2201.1). That is, following the approach of Medina and Soto (2005) does improve the in-sample model fit, but misspecification of the net effect of foreign oil price shocks on the domestic economy remains small (see also Rondina (2017) on the irrelevance of oil price endogeneity in structural models). The *oil* mod.1 specification we adopt follows Sánchez (2011), Natal (2012), and Vásconez et al. (2015).

23. Ortiz and Sturzenegger (2007, pp. 667–672) find, in comparison to emerging and advanced economies, a consistently strong anti-inflation bias and a stable monetary policy reaction function for the South African Reserve Bank from 1984:Q4 to 2006:Q4. South Africa explicitly adopted an inflation targeting regime in February 2000.

24. In particular, the 23% positive real oil price rise in 2008:Q2 contributed to inflation concerns and a tighter policy stance going into the Great Recession period, which likely worsened the downturn. Negative oil price shocks, on the other hand, will tend to lead to an accommodative monetary policy response, a widening output gap and likely excessive asset price imbalances.

References

Adolfson, M., S. Laséen, J. Lindé, and M. Villani. 2007. Bayesian estimation of an open economy DSGE model with incomplete pass-through. *Journal of International Economics* 72:481–511. doi:10.1016/j.jinteco.2007.01.003.

Ajmi, A., R. Gupta, V. Babalos, and R. Hefer. 2015. Oil price and consumer price nexus in South Africa revisited: A novel asymmetric causality approach. Energy *Exploration and Exploitation* 33 (1):63–74. doi:10.1260/0144-5987.33.1.63.

Alba, J. D., W.-M. Chia, and Z. Su. 2013. Oil shocks and monetary policy rules in emerging economies. *Applied Economics* 45 (35):4971–84. doi:10.1080/00036846.2013.808312.

Alpanda, S., K. Kotzé, and G. Woglom. 2010. The role of the exchange rate in a New Keynesian DSGE model for the South African economy. *South African Journal of Economics* 78 (2):170–91. doi:10.1111/j.1813-6982.2010.01239.x.

An, S., and H. Kang. 2011. Oil shocks in a DSGE model for the Korean economy. *Commodity Prices and Markets, East Asia Seminar on Economics* 20:295–321.

Aye, G., V. Dadam, R. Gupta, and B. Mamba. 2014. Oil price uncertainty and manufacturing production. *Energy Economics* 43:41–47. doi:10.1016/j.eneco.2014.02.004.

Aye, G., O. Gadinabokao, and R. Gupta. 2017. Does the South African Reserve Bank (SARB) respond to oil price movements? Historical evidence from the frequency domain. *Energy Sources* 12 (1):40–46. doi:10.1080/15567249.2014.966927.

Backus, D. K., and M. J. Crucini. 2000. Oil prices and the terms of trade. *Journal of International Economics* 50:185–213. doi:10.1016/S0022-1996(98)00064-6.

Balcilar, M., J. Uwilingiye, and R. Gupta. 2018. Dynamic relationship between oil price and inflation in South Africa. *Journal of Developing Areas* 52 (2):73–95. doi:10.1353/jda.2018.0023.

Balcilar, M., R. van Eyden, J. Uwilingiye, and R. Gupta. 2017. The impact of oil price on South African GDP growth: A Bayesian Markov Switching-VAR analysis. *African Development Review* 29 (2):319–36. doi:10.1111/1467-8268.12259.

Baumeister, C., G. Peersman, and I. Van Robays. 2010. The economic consequences of oil shocks: Differences across countries and time. In *Inflation in an era of relative price shocks*, Eds. R. Fry, C. Jones, and C. Kent, 91–128. Sydney: Reserve Bank of Australia.

Beidas-Strom, S., and T. Poghosyan, February 2011. An estimated dynamic stochastic general equilibrium model of the Jordanian economy. IMF Working Paper No. WP/11/28

Bellamy, D., 2006. The macroeconomic effects of the crude oil price on the South African economy. Unpublished Masters Dissertation. University of Cape Town.

Bernanke, B., M. Gertler, and S. Gilchrist.1999.The financial accelerator in a quantitative business cycle framework. In *Handbook of macroeconomics*. J. B. Taylor, and M. Woodford. Eds., 1st. Vol. 1. Elsevier Science B.V, Amsterdam: Ch. 21 1341–93.

Blanchard, O. J., and J. Galí, 2010. The macroeconomic effects of oil price shocks: Why are the 2000s so different from the 1970s? University of Chicago Press, pp. 373–421.

Blanchard, O. J., and M. Riggi. October 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):1032–52. doi: 10.1111/jeea.12029.

Bodenstein, M., and L. Guerrieri, 2011. Oil efficiency, demand, and prices: A tale of ups and downs. Board of Governors of the Federal Reserve System, International Finance Discussion Papers, Number 1031.

Burstein, A., and G. Gopinath. 2014. International prices and exchange rates. In *Handbook of international economics*, Eds. G. Gopinath, E. Helpman, and K. Rogoff, Vol. 4. , Ch. 7. Amsterdam, North Holland: Elsevier.

Calvo, G. 1983. Staggered prices in a utility-maximizing framework. *Journal of Monetary Economy* 12 (3):383–98. doi:10.1016/0304-3932(83)90060-0.

Chisadza, C., J. Dlamini, R. Gupta, and M. Modise. 2016. The impact of oil shocks on the South African economy. *Energy Sources* 11 (8):739–45. doi:10.1080/15567249.2013.781248.

Christiano, L. J., M. Eichenbaum, and C. L. Evans. 2005. Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy* 113 (1):1–45. doi:10.1086/426038.

Cologni, A., and M. Manera. 2008. Oil prices, inflation and interest rates in a structural cointegrated VAR model for the G-7 countries. *Energy Economics* 30 (3):856–88. doi:10.1016/j.eneco.2006.11.001.

Cologni, A., and M. Manera. 2009. The asymmetric effects of oil shocks on output growth: A Markov switching analysis for the G-7 countries. *Economic Modelling* 26 (1):1–29. doi:10.1016/j.econmod.2008.05.006.

Cunado, J., and F. Perez de Gracia. 2003. Do oil price shocks matter? Evidence for some European countries. *Energy Economics* 25 (2):137–54. doi:10.1016/S0140-9883(02)00099-3.

Cunado, J., and F. Perez de Gracia. 2005. Oil prices, economic activity and inflation: Evidence for some Asian countries. *The Quarterly Review of Economics and Finance* 45 (1):65–83. doi:10.1016/j.qref.2004.02.003.

Dagut, M. B. 1978. The economic effect of the oil crisis on South Africa. *South African Journal of Economics* 46 (1):23–35. doi:10.1111/j.1813-6982.1978.tb00543.x.

de Bruyn, R., R. Gupta, and R. van Eyden. 2015. Can we beat the random-walk model for the South African rand-U.S. dollar and South African rand–UK pound exchange rates? Evidence from dynamic model averaging. Emerging markets finance and trade. *Special Issue: Emerging Economies: Business Cycles, Growth, and Policy* 51 (3):502–24.

Faia, E., and T. Monacelli. June 2008. Optimal monetary policy in a small open economy with home bias. Journal of Money *Credit and Banking* 40(4):721–50. doi: 10.1111/j.1538-4616.2008.00133.x.

Finn, M. G. December 1999. An equilibrium theory of nominal and real exchange rate comovement. *Journal of Monetary Economics* 44(3):453–75.

Fofana, I., M. Chitiga, and R. Mabugu. 2009. Oil prices and the South African economy: A macromeso-micro analysis. *Energy Policy* 37 (12):5509–18.

Frondel, M., and C. M. Schmidt. 2002. The capital-energy controversy: An artifact of cost shares? *The Energy Journal* 23 (3):53–79.

Frondel, M., and C. M. Schmidt. 2004. Facing the truth about separability: Nothing works without energy. *Ecological Economics* 51:217–23.

Gali, J., J. D. Lopez-Salido, and J. Valles. 2007. Understanding the effects of government spending on consumption. *Journal of the European Economic Association* 5:227–70.

Gupta, R., and F. Hartley. 2013. The role of asset prices in forecasting inflation and output in South Africa. *Journal of Emerging Market Finance* 12 (3):239–91.

Gupta, R., and P. Kanda. 2015. Does the price of oil help predict inflation in South Africa? historical evidence using a frequency domain approach. *Economia Internazionale/International Economics LXVIII* 4:451–67.

Gupta, R., and K. Kotze. 2017. The role of oil prices in the forecasts of South African interest rates: A Bayesian approach. *Energy Economics* 61 (1):270–78.

Gupta, R., and X. Sun, 2016. Housing market spillovers in South Africa: Evidence from an estimated small open economy DSGE model. Department of Economics, University of Pretoria, Working Paper No. 201641.

Gupta, R., and M. Wohar. 2017. Forecasting oil and stock returns with a Qual VAR using over 150 years of data. *Energy Economics* 62 (1):181–86.

Hamilton, J. D. 1983. Oil and the macroeconomy since world war II. *Journal of Political Economy* 91:228–48.

Hickman, B., H. Huntington, and J. Sweeney. Eds., 1987. *Macroeconomic impacts of energy shocks*. North-Holland, Amsterdam.

Hou, K., D. Mountain, and C. Wu. 2016. Oil price shocks and their transmission mechanism in an oil-exporting economy: A VAR analysis informed by a DSGE model. *Journal of International Money and Finance* 68:21–49.

Jiménez-Rodríguez, R., and M. Sánchez. 2005. Oil price shocks and real GDP growth: Empirical evidence for some OECD countries. *Applied Economics* 37:201–28.

Kantor, B. S., and G. D. I. Barr. 1986. The impact of a change in the price of petrol on the South African rate of inflation. *Journal for Studies in Economics and Econometrics* 26:35–57.

Kilian, L. 2009. Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American Economic Review* 99 (3):1053–69.

Kilian, L. 2014. Oil price shocks: Causes and consequences. *The Annual Review of Resource Economics* 6:133–54.

Kim, I.-M., and P. Loungani. 1992. The role of energy in real business cycle models. *Journal of Monetary Economics* 29 (2):173–89. URL. http://www.sciencedirect.com/science/article/pii/030439329290011P.

Kin, S., and M. Courage. 2014. The impact of oil prices on the exchange rate in South Africa. *Journal of Economics* 5 (2):193–99.

Kohler, M. 2006. The economic impact of rising energy prices: A constraint on South Africa's growth and poverty reduction opportunities. Paper prepared for the TIPS/DPRU Forum, Johannesburg, 18-20 October 2006.

Lucas, R. E., Jr. 1976. Econometric policy evaluation: A critique. Carnegie-Rochester Conference Series on Public Policy 1, 19–46.

McCracken, M. W. 2007. Asymptotics for out-of-sample tests of granger causality. *Journal of Econometrics* 140:719–52.

McDonald, S., and M. van Schoor, February 2005. A computable general equilibrium analysis of the impact of an oil price increase in South Africa. PROVIDE Working Paper 2005:1, Elsenburg.

Medina, J. P., and C. Soto, December 2005. Oil shocks and monetary policy in an estimated DSGE model for a small open economy. Central Bank of Chile, Working Paper No. 353

Medina, J. P., and C. Soto, December 2007. Copper price, fiscal policy and business cycle in Chile. Central Bank of Chile Working Papers No. 458.

Medina, J. P., and C. Soto, February 2014. Commodity price shocks and imperfectly credible macroeconomic policies in commodity-exporting small open economies. IMF Working Paper, WP/14/33, IMF Institute for Capacity Development.

Monacelli, T. December 2005. Monetary policy in a low pass-through environment. *Journal of Money, Credit, and Banking* 37 (6):1047–66.

Montoro, C. 2012. Oil shocks and optimal monetary policy. *Macroeconomic Dynamics* 16:240–77.

Mork, K., and R. Hall. 1980. Energy prices, inflation and recession 197475. *Energy Journal* 1:31–63.

Natal, J.-M. February 2012. Monetary policy response to oil price shocks. Journal of Money *Credit and Banking* 44(1):53–101.

Nkomo, J. C. 2006. The impact of higher oil prices on Southern African countries. *Journal of Energy Research in Southern Africa* 17 (1):10–17.

Ortiz, A., and F. Sturzenegger. 2007. Estimating SARB's policy reaction rule. *South African Journal of Economics* 75 (4):659–80.

Paetz, M., and R. Gupta. 2016. Stock price dynamics and the business cycle in an estimated DSGE model for South Africa. *Journal of International Financial Markets, Institutions and Money* 44 (1):166–82.

Peersman, G., and A. Stevens. 2010. *Oil demand and supply shocks: An analysis in an estimated DSGE-model*. Ghent, Belgium: Ghent University, Mimeo.

Rasche, R., and J. Tatom. 1977. The effect of the new energy regime on economic capacity, production and prices. *Economic Review* 52:2–12.

Ratto, M. 2008. Analysing DSGE models with global sensitivity analysis. *Computational Economics* 31:115–39.

Ratto, M., and N. Iskrev, 2011. Identification analysis of DSGE models with DYNARE. mimeo. URL https://www.ifk-cfs.de/fileadmin/downloads/events/conferences/monfispol2011/RATTO_IdentifFinal.pdf

Rondina, F., 2017. The impact of oil price changes in a New Keynesian model of the U.S. economy. Working Papers 1709E, University of Ottawa, Department of Economics.

Rotemberg, J. J., and M. Woodford. November 1996. Imperfect competition and the effects of energy price increases on economic activity. *Journal of Money, Credit, and Banking* 28(4):549–77.

Sánchez, M. September 2011. Oil shocks and endogenous markups: Results from an estimated euro area DSGE model. *International Economics and Economic Policy* 8(3):247–73.

Schmitt-Grohé, S., and M. Uribe. 2003. Closing small open economy models. *Journal of International Economics* 61:163–85.

Smets, F., and R. Wouters. 2002. Openness, imperfect exchange rate pass-through and monetary policy. *Journal of Monetary Economics* 49 (5):913–40.

Smets, F., and R. Wouters. 2007. Shocks and frictions in US business cycles: A Bayesian approach. *American Economic Review* 97 (3):586–606.

Steinbach, M., P. Mathuloe, and B. Smit. 2009. An open economy New Keynesian DSGE model of the South African economy. *South African Journal of Economics* 77 (2):207–27.

Swanepoel, J. A. 2006. Do international economic developments affect the South African economy? *South African Journal of Economic and Management Sciences* 9 (1):128–48.

Tshepo, M. 2015. *Analysing the pass-through effects of oil prices on inflation in South Africa: Granger-causality approach*. Cape Town, South Africa: Biennial Economic Society of South Africa Conference.

Vásconez, V. A., G. Giraud, F. McIsaac, and N.-S. Pham. 2015. The effects of oil price shocks in a New-Keynesian framework with capital accumulation. *Energy Policy* 86:844–54.

Wakeford, J. 2006. *The impact of oil price shocks on the South African macroeconomy: History and prospects*, 95–115. Johannesburg, South Africa: South African Reserve Bank Conference.

Wakeford, J., 2012. Implications of global oil depletion for South Africa: vulnerabilities, impacts and transition to sustainability. Ph.D. thesis, Stellenbosch University, South Africa