World Oil and Inventory Study: A Global VAR Analysis

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Key Points

The global oil market has many moving parts, including, but not limited to, oil production, inventories, price and business cycles. Its analysis requires a model that is dynamic and sufficiently sophisticated to be able to capture a broad range of interrelationships between macroeconomic variables.

KAPSARC has developed an analytic framework to analyze country-specific and global shocks to world oil and inventory markets.

While a vector autoregression (VAR) model can be used to capture the linear interdependencies across multiple time series in a given country or region, this study develops a multisector global vector autoregression (GVAR) model to simulate various types of shocks to oil markets. The GVAR model can be used to capture the co-movements of variables in and across countries.

GVAR highlights the value of data-driven modeling. Its structure allows countries with different institutional legacies (e.g., a free market, or a command economy) to interact with each other without imposing any assumptions.

Summary

Despite numerous journal articles, forecasting studies, and books, very little is known about the actual quantitative value, or economic cost, of shocks to world oil markets. The potential consequences of a given political or economic disturbance are unclear, and appear to depend on market conditions at the time of forecast and the idiosyncratic nature of the shock (see Figure 1). This study develops a new analytical framework to analyze shocks to world oil markets. We build upon the global vector autoregression (GVAR) model developed in 2016 by Mohaddes and Pesaran to include a new variable, OECD oil inventories, creating the GVAR Oil and Inventory Model — GOVAR. We also expand its geographic coverage by adding two new countries, Russia and Venezuela.

Two characteristics make a GVAR-based approach particularly well suited to this research. First, it is designed to account for the interactions between many countries, each with its own political and legislative system. This is crucial, as the effects of severe shocks and global imbalances cannot be contained to one country or region. Second, GVAR can model world oil supplies and inventories jointly with key macroeconomic variables, including short- and long-term interest rates, inflation, equity prices and real gross domestic product (GDP). The framework therefore facilitates investigation of the effects of country- and region-specific oil shocks on GDP, inflation, interest rates, inventories, exchange rates and equity prices around the world.

Figure 1. 150 years of oil price shocks.

Source: Durden (2014).

Introduction

This study develops an analytical framework to analyze shocks to world oil and inventory markets. The model can facilitate an investigation of the economic implications of country- and region-specific oil and inventory disruptions, such as economic sanctions, war, financial crises, natural disasters and monetary and fiscal policy changes.

The model proposed for this study expands the global vector autoregression (GVAR) model proposed by Dees et al. (2007) and further developed for the oil industry by Mohaddes and Pesaran (2016).

This study proposes two key modifications to existing GVAR models:

- It includes a new variable, Organisation for Economic Co-operation and Development (OECD) oil inventories.

- It expands geographic coverage to 36 countries (adding Russia and Venezuela) and extends the timeframe to 1979 Q1 to 2018 Q3.

The result of these changes is the GVAR Oil and Inventory Model (GOVAR), a theoretical framework that examines factor interdependencies and the international co-movements of crude oil production, inventories and business cycles.

The paper is organized as follows. Section 2 gives a description of GOVAR, including a brief discussion of the GVAR framework and its properties. Section 3 presents the empirical results of the modeling exercise, including the formulation of country-specific models for the base case, and examines the dynamic properties of the system-wide model, including persistence profiles. Section 4 provides the derivation of impulse response functions and an analysis of the country-specific shocks to oil

inventories and global shocks to oil prices. Section 5 concludes the paper and offers suggestions for future research. Appendix A details the data sources. Additional information, such as the statistical properties of the country-specific models, and further details of the estimates (including tests for the weak exogeneity of country-specific variables and the ability of the model to account for interdependencies and international co-movements across variables), is available from the authors upon request.

With the creation of GOVAR, this study provides an analytical tool that utilizes state-of-the-art forecasting methods and data sources to investigate the potential impacts of a variety of market disturbances and policy prescriptions. In the future, GOVAR can be expanded with the creation of a unique real-time database that combines information from a variety of sources (some of which are subject to frequent revision), such as United States (U.S.) petroleum inventories, real-time crude oil prices, shipping activity, geospacial and remote sensing data, and news.

The GVAR Oil and Inventory Model

Understanding the basic VAR framework

The complex relationships between crude oil supplies, oil inventories, world oil prices, and business cycles have been well documented. Numerous models have been used to analyze and interpret these interactions for the purpose of economic analysis and forecasting. These include, but are not limited to, maximum likelihood and Bayesian estimation, vector autoregression (VAR), general equilibrium models (GEM), dynamic stochastic general equilibrium (DSGE) models, and dynamic panel models (Hashimzade and Thornton 2013; Bournstein and Kellogg 2012; Economou, Agnolucci, and De Lipsis 2017; Oberholzer 2017; Board of Governors of the Federal Reserve System 2020; Bragoli and Modugno 2016; Joëts and Razafindrabe 2015).

The impacts of geopolitical shocks, such as U.S. and European Union (EU) sanctions against oil and gas producing countries, on world oil prices and business cycles have been examined in considerable depth in the context of detailed GEMs. Gharibnavaz, Reza and Waschik (2018) use a computable multi-region GEM to evaluate the implications of international sanctions on Iran. They show that the restrictions significantly reduced aggregate welfare in the country, and that these costs were unevenly distributed, hurting the poorest households (both rural and urban) much more than the highest income households, whose welfare actually increased by 2-3%.

Of the models listed above, VAR often delivers the best results. Simple forecasting methods can outperform complex ones, and VAR models have been shown to deliver more accurate results than futures and random walk forecasts for horizons of up to two years (Green and Armstrong 2015; Beckers

and Beidas-Strom 2015). VAR models can capture the linear interdependencies across multiple time series for a given country or region. Kilian (2009) investigates the dynamic effects of demand shocks on world oil prices and various economic indicators. He finds that higher oil prices significantly affect gross domestic product (GDP) and inflation in the U.S., but the exact impact depends on the particular circumstances of the related shock (Kilian 2008). In fact, the source of the market disturbance and the state of the market can significantly shape the forecasted consequences of an oil price shock. An oil supply shock arising from a change in flow demand or flow supply will have different implications for the market than a speculative demand shock affecting above-ground oil inventories arising from forward-looking factors (Kilian and Murphy 2014).

Economou, Agnolucci, and De Lipsis (2017) show that forecasting models that distinguish between exogenous and endogenous supply shocks (such as structural VAR models) can be more accurate than those that restrict the analysis to flow supply shocks. Acquah-Andoh and Olasojiand (2016) use ordinary least squares (OLS) multiple regression, cointegration, vector error correction model, and ex-post forecast techniques to evaluate the short-run implication of U.S. crude oil inventory levels on West Texas Intermediate (WTI) crude prices. Contrary to established theory, they find an absence of any short-term relationship between crude oil inventories and WTI prices for the 1993-2013 period.

While a basic VAR model can capture linear interdependencies across multiple time series for a given country (or region), a multi-country, cointegrating GVAR structure also allows for cointegration of the variables within and between countries. Country-specific models can thus be combined to create a system that treats all variables as endogenous and quantifies complex interactions between economies.

The GVAR methodology has been criticized for its inability to interpret system-wide disruptions as supply or demand shocks in an economic sense. However, it makes up for this perceived shortfall with its flexibility to handle many shocks while simultaneously accommodating multiple economies of different sizes. While competing frameworks, such as DSGE, have the capacity to model shocks that can be given a simple economic interpretation, their expansion to a multi-economy system is extremely complex. Large-scale open-economy DSGE models tend to be restricted to two regions of comparable size, where one region, such as the rest of the world, is given exogenously (Dees et al. 2014). The Oxford Global Economic Model uses a macroeconomic error correction method — essentially a hybrid of VAR and DSGE — to estimate the speed at which the dependent variables return to equilibrium after a shock (Oxford Economics 2020).

The intricate interrelationships and co-movements between variables such as crude oil production, GDP, equity prices, inflation, and interest rates have evolved significantly since the late 1990s due to changes in trade agreements and the broader financial and economic integration of the global economy. In the cases of business cycles and financial systems, these movements have been investigated in detail by a number of international and multivariable studies, such as research by Dees et al. (2007) that examines the international linkages of the Euro area. In the energy field, Mohaddes and Pesaran (2016) analyze the effect of country-specific shocks to crude oil supplies on the global economy. In another study, the same authors (2016b) use a GVAR model to investigate the effects of sudden crude oil price shocks on the U.S. and global economies. Ratti and Vespignani (2016) examine the relationships between oil prices, global industrial production, central bank policies and interest rates with a global factor-augmented error correction model.

The GOVAR model proposed for the World Oil and Inventory Study builds upon the GVAR methodology developed by Mohaddes and Pesaran (2016). The GOVAR methodology is a slight variation from the traditional GVAR models, as the global oil markets are modeled separately, by means of a single price equation that accounts for global supply and demand conditions. As a result, global oil supplies are included in each country-specific model reflecting global oil supplies for all major oil-producing countries. The combined system-wide model can estimate the impact of country-specific oil shocks on the global economy and the related implications for global financial markets, equity prices, interest rates and oil prices. Appendix A details the data series utilized in the model and the corresponding sources.

The model for the oil price

The dynamics of the global oil market can be described by the following equation for the aggregate demand for oil:

$$Qd_t^0 = a_d + \varepsilon_y a_y(L) y_t - \varepsilon_p a_p(L) p_t^0 + \varepsilon_i a_i(L) I_t^0 + \varepsilon_{dt} \quad (1)$$

Where:

- $Qd_t^0 \equiv$ Logged value of oil demand
- $Y_t \equiv$ Logged value of real seasonally adjusted GDP
- $P_t \equiv$ Logged value of the real price of oil
- $I_t^0 \equiv$ Logged value of oil inventories
- $a_y(L), a_p(L), a_i(L) \equiv$ Polynomials in the lag operator, L , whose coefficients add to 1

$$\begin{aligned} a_y(L) &= a_{y0} + a_{y1}L + a_{y2}L^2 + \dots \\ a_p(L) &= a_{p0} + a_{p1}L + a_{p2}L^2 + \dots \\ a_i(L) &= a_{i0} + a_{i1}L + a_{i2}L^2 + \dots \\ a_y(1) &= a_p(1) = a_i(1) = 1 \end{aligned} \quad (2)$$

The GVAR Oil and Inventory Model

In this specification of the world oil market, ε_y , ε_p , and ε_I are the long-run income, price, and inventory elasticities of the demand for oil, respectively.

We assume oil prices adjust to the difference between the demand and supply of oil to rebalance world oil markets.

$$\Delta p_t^0 = a_s + \lambda(Qd_t^0 - Qs_t^0) + \varepsilon_{st} \quad (3)$$

- $\lambda \equiv$ The speed of adjustment
- $a_s \equiv$ A fixed constant representing the scarcity of oil
- $\varepsilon_{st} \equiv$ Speculative oil price changes unrelated to fundamental factors
- $Qs_t^0 \equiv$ Logged value of oil supply

Substituting equation 1 into equation 2 and solving for Δp_t^0 yields:

$$\Delta p_t^0 = a_p + \lambda \left(\varepsilon_y a_y(L) y_t - \varepsilon_p a_p(L) p_t^0 + \varepsilon_I a_I(L) I_t^0 - Qs_t^0 \right) + \varepsilon_{pt} \quad (4)$$

Where:

$$a_p \equiv a_s + \lambda a_d$$

$$\varepsilon_{pt} \equiv \varepsilon_s + \lambda \varepsilon_{dt}$$

Solving for p_t^0 yields a standard autoregressive distributed lag model (ARDL) for oil prices, income, inventory, and world oil production.

$$\begin{aligned} p_t^0 = & \left(\frac{1}{1 + \lambda \varepsilon_{po} a_{po}} \right) a_p + \left(\frac{1 - \lambda \varepsilon_{po} a_{po}}{1 + \lambda \varepsilon_{po} a_{po}} \right) p_{t-1}^0 \\ & - \left(\frac{\lambda \varepsilon_{po}}{1 + \lambda \varepsilon_{po} a_{po}} \right) \sum_{l=2}^{\infty} a_{pl} p_{t-l}^0 + \\ & \left(\frac{\lambda \varepsilon_y}{1 + \lambda \varepsilon_{po} a_{po}} \right) a_y(L) y_t + \left(\frac{\lambda \varepsilon_I}{1 + \lambda \varepsilon_{po} a_{po}} \right) a_I(L) I_t \\ & + \left(\frac{\lambda}{1 + \lambda \varepsilon_{po} a_{po}} \right) Qs_t^0 + \left(\frac{1}{1 + \lambda \varepsilon_{po} a_{po}} \right) \varepsilon_{pt} \end{aligned} \quad (5)$$

Following Mohaddes and Pesaran (2016), we formulate the ARDL model shown in equation 5. We avoid endogeneity problems by using lagged values of y_t and Qs_t^0 .

$$\begin{aligned} p_t^0 = & c_p + \sum_{l=1}^{m_{p0}} a_l p_{t-l}^0 + \sum_{l=1}^{m_y} \beta_l y_{t-l} \\ & + \sum_{l=1}^{m_{qo}} \gamma_l Q_{t-l,s}^0 + \sum_{l=1}^{m_I} \delta_l I_{t-l} + v_t^0 \end{aligned} \quad (6)$$

Where m_{p0} , m_y , m_{qo} , and m_I are allowed to vary across the different variables and will be selected using the Akaike information criterion (AIC).

Thus the price, income and inventory elasticities of the world oil model are:

$$\begin{aligned} \varepsilon_{po} = & - \left(\sum_{l=1}^{m_{qo}} \gamma_l \right)^{-1} (1 - \sum_{l=1}^{m_{p0}} a_l) \\ \varepsilon_y = & - \left(\sum_{l=1}^{m_{qo}} \gamma_l \right)^{-1} \left(\sum_{l=1}^{m_{p0}} \beta_l \right) \\ \varepsilon_{Io} = & - \left(\sum_{l=1}^{m_{qo}} \gamma_l \right)^{-1} \left(\sum_{l=1}^{m_{p0}} \delta_l \right) \end{aligned} \quad (7)$$

Expanding the system: an international perspective of the GVAR model

While the estimation of each country is done on a country-by-country basis, GVAR will be solved for the world as a whole because all variables are endogenous to the worldwide system.

The GVAR system analysis proposed by Pesaran, Schuermann and Weiner (2004), and further developed by Dees et al. (2007), utilizes a single equation for each country-specific model:

$$\begin{aligned} x_{it} = & a_{io} + a_{io} t + \phi_{i1} x_{i,t-1} + \dots + \phi_{ip_i} x_{i,t-p_i} \\ & + A_{i1} x_{i,t-1}^* + \dots + A_{iq} x_{i,t-q_i}^* + u_{it} \end{aligned} \quad (8)$$

Where:

$x_{it} = k_i \times I$ vector of "country-specific" domestic variables

$x_{it}^* = k_i^* \times I$ vector of "country-specific" weekly exogenous star (foreign) variables

$\phi_i, \dots, \phi_{ip}, A_{io}, \dots, A_{iq} \equiv k_i \times 1$ vectors or matrices of fixed coefficients that vary across countries i

- 1) $x_{it} = (Qs_{it}^0, Y_{it}, P_t, I_{it}^0, r_{it}, rl_{it}, Dp_{it}, ep_{it}, eq_{it})$
- 2) $x_{it}^* = (Y_{it}^*, I_{it}^{0*}, r_{it}^*, rl_{it}^*, Dp_{it}^*, ep_{it}^*, eq_{it}^*)$
- 3) $Qs_{it}^0 \equiv$ Logged value of oil supply
- 4) $Y_{it} \equiv$ Logged value of real seasonally adjusted GDP
- 5) $P_t \equiv$ Logged value of the real price of oil
- 6) $I_{it}^0 \equiv$ Logged value of oil inventories
- 7) $r_{it} = 0.25 * \ln(1 + R_{it}/100)$
- 8) $R_{it} \equiv$ Nominal short-term interest rates
- 9) $rl_{it} = 0.25 * \ln(1 + Rl_{it}/100)$
- 10) $Rl_{it} \equiv$ Nominal long-term interest rates
- 11) $Dp_{it} \equiv$ Inflation first difference of the logged value of the consumer price index (CPI)
- 12) $ep_{it} \equiv$ Equity prices, logged value of nominal equity prices divided by CPI
- 13) $eq_{it} \equiv$ Exchange rates, logged value of nominal exchange rates divided by CPI

The variables $x_{it}^* = (Y_{it}^*, I_{it}^{0*}, r_{it}^*, rl_{it}^*, Dp_{it}^*, ep_{it}^*, eq_{it}^*)$ are country-specific star foreign variables constructed using country-specific trade shares, and defined by equation 8a. Note: The variable Qs_{it}^0 is excluded because it has already been included in the oil price model.

$$x_{it}^* = \sum_{j=1}^N w_{ij} x_{jt} \quad (8a)$$

Where w_{ij} , $i, j=1, 2, \dots, N$ are bilateral trade weights with $w_{ii}=0$, and $\sum_{j=1}^N w_{ij}=1$. We chose bilateral trade weights over other type of weights (such as financial) as these have been identified as important determinants of national business cycles (Baxter and Kouparitsas 2004).

We compute the trade weight, w_{ij} , as a three-year moving average in order to reduce the impact of annual movements (Mohaddes and Pesaran 2016). Specifically:

$$w_{ij} = \frac{T_{ij,2014} + T_{ij,2015} + T_{ij,2016}}{T_{i,2014} + T_{i,2015} + T_{i,2016}} \quad (8b)$$

Where T_{ijt} is the bilateral trade of country i with country j during a given year t , and is equal to the average of exports and imports of country i with country j , and $T_{it} = \sum_{j=1}^N T_{ijt}$ (the total trade of country i) for $t=2014, 2015, 2016$, and $j=1, 2, \dots, N$.

The variable P_t is a global or dominant variable that applies to the world as a whole and is included in all country-specific equations (Dees et al. 2007).

The model can be estimated as follows:

Let:

$$z_{it} = \begin{pmatrix} x_{it} \\ x_{it}^* \end{pmatrix} \quad (9)$$

The GVAR Oil and Inventory Model

Equation 8 can be written for each region as:

$$A_{io}z_{it} = a_{io} + a_{i1}t + A_{i1}z_{it-1} + \dots + A_{ip_i}z_{it-p_i} + u_{it} \quad (10)$$

Where:

$$A_{io} = (I_{k_i} - A_{io}), A_{ij} = (\theta\Phi_{ij}, A_{ij}) \text{ for } j = 1, \dots, p_i \quad (11)$$

Then the trading weights, or aggregation weights, can be defined so that:

$$z_{ioit} = W_i x_t \quad (12)$$

Where $x_t = (x'_{ot}, x'_{1t}, \dots, x'_{Nt})$ is the $k \times 1$ vector, which includes all of the endogenous variables of the system, and W_i is a $(k_i \times k_i^*) \times k$ matrix.

$$A_{io}W_i x_t = a_{io} + a_{i1}t + A_{i1}W_i x_{t-1} + \dots + A_{ip_i}W_i x_{t-p_i} + u_{it} \quad (13)$$

for $i = 0, 1, 2, \dots, N$

The individual models can be stacked to give the model for x_t

$$G_0 x_t = a_{io} + a_{i1}t + G_{i1}x_{t-1} + \dots + G_p x_{t-p} + u_{it} \quad (14)$$

Where:

$$G_0 = \begin{bmatrix} A_{00}W_0 \\ A_{10}W_1 \\ \vdots \\ A_{N0}W_N \end{bmatrix}, G_j = \begin{bmatrix} A_{00}W_0 \\ A_{10}W_1 \\ \vdots \\ A_{N0}W_N \end{bmatrix} \text{ for } j = 1, 2, \dots, p \quad (15)$$

$$a_o = \begin{bmatrix} a_{00} \\ a_{10} \\ \vdots \\ a_{N0} \end{bmatrix}, a_i = \begin{bmatrix} a_{01} \\ a_{11} \\ \vdots \\ a_{N1} \end{bmatrix}, u_t = \begin{bmatrix} u_{0t} \\ u_{1t} \\ \vdots \\ u_{Nt} \end{bmatrix}$$

Where G_0 is a known non-singular matrix that depends on trade weights and parameter estimates.

The GVAR(p) model is obtained by pre-multiplying equation 14 by G_0^{-1} .

$$x_t = b_0 + b_1 t + F_1 x_{t-1} + \dots + F_p x_{t-p} + \varepsilon_t \quad (16)$$

Where:

$$b_0 = G_0^{-1}a_0, b_{10} = G_1^{-1}a_1, F_j = G_j^{-1}G_j, \quad j = 1, 2, 3, \dots, p, \varepsilon_t = G_{j0}^{-1}u_t \quad (17)$$

Equation 15 can be solved recursively and, if desired, sign restrictions may be imposed on the impulse response functions of the model ε_t . For the purpose of this study, the model is estimated without imposing any such sign restrictions.

Including the dominant variable: the oil price

Following Chudik and Pesaran (2013), we extend the model to allow common variables, such as the oil price, to be added to the system — to the conditional country models — as global or dominant variables. Adding a global variable for the oil price results in the following augmentation to equation 8:

$$x_{it} = a_{io} + a_{io}t + \phi_{i1}x_{i,t-1} + \dots + \phi_{ip_i}x_{i,t-p_i} + A_{io}x_{i,t}^* + \dots + A_{iq}x_{i,t-q_i} + \Psi_{i0}\omega_{i,t} + \dots + \Psi_{iq_i}\omega_{i,t-q_i} + u_{it} \quad (18)$$

In this revised model, ω_t is a vector of global or dominant variables:

$$\omega_t = \mu_0 + \mu_1 t + \phi_1 \mu_{t-1} + \dots + \phi_p \mu_{t-p_\omega} + \eta_t \quad (19)$$

Where p_ω can be selected by the AIC or Schwarz information criterion (SBC) methodologies.

The dominant variables, ω_t , can be treated as a foreign variable for the purposes of modeling and shares the same lag order (q). However, this specification allows for different lag orders for the dominant and foreign variables (Chudik and Pesaran 2013). Therefore, the world oil price is the dominant variable in the GOVAR and is specified by equation (19):

$$p_t^0 = c_p + \sum_{l=1}^{m_{p^0}} a_l p_{t-l}^0 + \sum_{l=1}^{m_y} \beta_l y_{t-l} + \sum_{l=1}^{m_{q^0}} \gamma_l Q_{t-l,s}^0 + \sum_{l=1}^{m_I} \delta_l I_{t-l} + v_t^0 \quad (20)$$

Where m_{p^0} , m_y , m_{q^0} , and m_I are allowed to vary across the different variables and will be selected using the AIC.

The combined GOVAR model (equations 15-20) permits a two-way link between real GDP, oil supplies, oil inventories, and the world oil price. Changes in GDP, inventories, and oil supplies are affected by the world oil price with a lag. At the same time, country-specific changes to inventories, GDP and oil production affect oil prices with a lag. The fact that world GDP and global oil production is excluded from the world oil price equation allows us to identify and evaluate country-specific shocks to inventories, income and oil supplies (Mohaddes and Pesaran 2016).

Technical terms employed in GVAR analysis

Cointegration: The time series X_{1t} and X_{2t} are cointegrated if they never get too far from one another as they progress through time. That is to say, a linear combination $aX_{1t} + bX_{2t}$ has a constant mean and standard deviation, and can be said to be stationary.

Impulse response function: An impulse response function shows the response of a variable to an impulse in another variable.

Persistence profiles: A persistence profile measures the reaction time of the system to a system-wide shock in units of variance. After the initial disruption, the impacts on the variables gradually become smaller and eventually disappear (Lassiter 2007).

Bootstrapping: The practice of estimating a population parameter through repeated sampling, with replacement, of a fixed number of observations. It is based on the law of large numbers, which suggests that drawing samples over and over will approximate the true population of data.

Source: KAPSARC (2020).

Properties of the GVAR model structure

Persistence profiles

Equation (15) defines the properties of the GVAR. These include the persistence profiles, impulse response functions, and variance decompositions. This study performs all bootstrapping according to u_t innovations.

We determine the persistence profiles as follows:

Let an infinite moving average of the GVAR be given by:

$$x_t = d_t + \sum_{s=0}^{\infty} B_s \varepsilon_{t-s} \quad (21)$$

Where d_t represents the deterministic component of x_t , $\varepsilon_t = G_{j0}^{-1} u_t$ and

$$B_s = F_1 B_{s-1} + F_2 B_{s-2} + \dots + F_p B_{s-p} \quad (22)$$

The cointegrating relationships of the country-specific models are given by the matrix of cointegrating vectors $z_{it} \cdot \beta_i$, where:

$$z_{it} = (x'_{it}, x'^*_{it}, w'_t) \text{ and } \beta_i = (\beta'_{im}, \beta'^*_{im}, \beta'_{iw}) \quad (23)$$

The relationship, or mapping, between the GVAR variables x and z is given by $z_{it} = W_{il} y_t$, where:

$$W_i = \begin{bmatrix} W_i & 0 \\ 0 & I_m \end{bmatrix} \quad (24)$$

$$z_{it} = W_i d_t + W_i B_0 \varepsilon_t + \sum_{s=1}^{\infty} W_i B_0 \varepsilon_{t-s} \quad (25)$$

The persistence profiles for a system-wide shock are given by:

$$PP(\beta'_{ji} w_t \cdot \varepsilon_t, n) = \frac{\beta'_{ji} W B_n \Sigma B'_n W' B_{ji}}{\beta'_{ji} W B_{n0} \Sigma_e B'_{n0} W' B_{ji}}, n = 0, 1, 2, \dots \quad (26)$$

Where $\beta'_{ji} z_{it}$ is the j th cointegrating relation in the i th country, n is the horizon, and Σ_e is the $(k \times m) \times (k \times m)$ covariance matrix of ε_t (Smith and Galesi 2014).

Generalized impulse response functions for country-specific models

Given a one standard deviation shock to the system v_t , the generalized impulse response function is:

$$GIRF(h, x_t, v_t) = E(y x_{t+h} | v_t = \sqrt{b' \theta_y b} I_{t-1}) - E\{x_{t+h} | I_{t-1}\} \quad (27)$$

Where b is a $(k+m) \times 1$ vector of purchasing power parity (PPP) GDP weights with zero values everywhere except the variables to be shocked for the countries involved, scaled to sum to 1, and I_{t-1} is the information set at time $t-1$. The vector b can consider country-specific shocks, regional shocks, and shocks to global variables (Smith and Galesi 2014).

Empirical Results: Formulation Of The Oil Price Equation And Base Case Country-Specific Models

This study utilizes a stylized representation of the global economy developed by KAPSARC, representing a maximum of 36 countries, seven regions or subregions, and eight country-specific variables (see Table 1). The model uses quarterly

data from 1979Q1 to 2018Q3 from a variety of sources, including the U.S. Energy Information Agency (EIA), World Bank, International Monetary Fund (IMF), and Bloomberg. Appendix A details the data sources used in the study.

Table 1. Countries utilized in the World Oil Inventory Model.

Argentina	Indonesia	Russia
Australia	Iran	Saudi Arabia
Austria	Italy	South Africa
Belgium	Japan	Singapore
Brazil	Korea	Spain
Canada	Malaysia	Sweden
Chile	Mexico	Switzerland
China	Netherlands	Thailand
Finland	New Zealand	Turkey
France	Norway	United Kingdom
Germany	Peru	U.S.
India	Philippines	Venezuela
Regions and subregions accounted for in the World Oil Inventory Model		
Euro area	Net oil exporters	Asia Pacific
Europe	Net oil importers	Latin America
	Rest of world	
Global variables in the World Oil Inventory Model		
World oil price		
Country-specific variables in the World Oil Inventory Model		
Real GDP	Oil inventories	Real exchange rates
Inflation	Crude oil production	Short-term interest rates
Real equity prices		Long-term interest rates

Source: KAPSARC.

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We selected the 36 countries for the GOVAR analysis to represent the global oil market, taking data availability into account. Collectively they represent over 87% of global GDP and eight of the world's top 15 oil exporting nations.

The countries include 12 major oil producers that collectively account for 66% of global crude oil output and hold approximately 65% of proven oil reserves (see Table 2). The U.S., Saudi Arabia, Russia, Canada, and China — five of the world's top six producers — represent nearly 40% of global oil production (unfortunately, the dataset excludes Iraq, the world's number five oil producer, due to insufficient data). Saudi Arabia plays a key role in the global oil market as the world's largest crude oil exporter, with ample spare capacity and reserves for future production. Eight of the 12 are net oil exporters (Canada, Indonesia, Iran, Mexico, Russia, Norway, Saudi Arabia and Venezuela) while the remaining four are net oil importers (Brazil, China, the United Kingdom [U.K.] and the U.S.). Note: the U.S. is a net exporter for some timeframes but was a net importer in the third quarter of 2018.

The model includes the world's top 10 crude oil importing countries: China, the U.S., India, Japan, Korea, the Netherlands, Germany, Spain, Italy, and France. Together these account for over 68% of global crude oil imports. Austria, Belgium, Finland, France, Germany, Italy, the Netherlands, and Spain comprise the 'Euro' block of countries in the model and account for over 20% of global imports. We calculate the corresponding time series using the weighted average of these eight Eurozone countries based on PPP-GDP weights for the year 2017 (see Table 3).

To accommodate global economic developments, the model includes estimates of worldwide real GDP, oil supply, and oil inventories, calculated as simple weighted averages of the country-specific logs of seasonally adjusted real GDP, oil prices, and value of inventories, respectively:

$$Y_t = \sum_{j=1}^N w_j^{PPP} Y_{jt} \quad (28)$$

$$Qs_t^0 = \sum_{j=1}^N w_j^q Qs_{jt}^0$$

$$I_t^0 = \sum_{j=1}^N w_j^I I_{jt}^0$$

Where $j=1,2,3,\dots,N$ are the individual countries represented in the GOVAR model $\sum_{j=1}^N w_j^{PPP} = 1$, $\sum_{j=1}^N w_j^q = 1$, and $\sum_{j=1}^N w_j^I = 1$.

Following Mohaddes and Pesaran (2016), we model world oil prices as a global or dominant variable, and include them as weakly exogenous in all of the individual country models. This departs from traditional GVAR models, which tend to view oil prices as endogenous variables, thereby restricting the ability of countries (other than the U.S.) to affect oil prices. For the purposes of this study, it is important to allow the effects of production to affect oil prices, and, indeed, all of the macroeconomic variables in GOVAR.

Figure 2. Crude oil production and reserves, 2017.

Country	Oil production	Oil reserves
	Thousand barrels daily	Billion barrels
Net exporters		
Canada	4,830.63	168.92
Indonesia	948.89	3.17
Iran	4,981.68	157.20
Mexico	2,224.15	7.22
Norway	1,968.87	7.92
Russia	11,257.26	106.19
Saudi Arabia	11,950.84	266.21
Venezuela	2,110.20	303.18
Net importers		
Brazil	2,733.99	12.79
China	3,845.94	25.66
United Kingdom	999.13	2.31
United States	13,056.99	49.97
Total	60,908.59	1,110.74
Rest of world	31,740.05	585.86
World total	92,648.63	1,696.60
Model producers as a percentage of the world total	0.66	0.65

Source: BP Statistical Review of World Energy, 2019.

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Table 3. Aggregation weights utilized in the GOVAR model.

Country weights for real GDP, production and inventories			
Country	GDP-PPP	Production	Inventories
Argentina	0.0087	0.0000	0.0000
Australia	0.0113	0.0000	0.0000
Brazil	0.0308	0.0000	0.0000
Canada	0.0163	0.0946	0.1186
Chile	0.0042	0.0000	0.0000
China	0.2213	0.0932	0.0000
Euro	0.1270	0.0000	0.3509
India	0.0898	0.0000	0.0000
Indonesia	0.0308	0.0753	0.0000
Iran	0.0161	0.0949	0.0000
Japan	0.0521	0.0000	0.1424
Korea	0.0187	0.0000	0.1195
Malaysia	0.0088	0.0000	0.0000
Mexico	0.0224	0.0853	0.0000
New Zealand	0.0019	0.0000	0.0000
Norway	0.0031	0.0826	0.0000
Peru	0.0041	0.0000	0.0000
Philippines	0.0083	0.0000	0.0000
Russia	0.0363	0.1053	0.0000
Saudi Arabia	0.0168	0.1049	0.0000
Singapore	0.0050	0.0000	0.0000
South Africa	0.0073	0.0000	0.0000
Sweden	0.0048	0.0000	0.0000
Switzerland	0.0052	0.0000	0.0000
Thailand	0.0117	0.0000	0.0000
Turkey	0.0203	0.0000	0.0000
U.K.	0.0271	0.0766	0.0988
U.S.	0.1842	0.1057	0.1698
Venezuela	0.0055	0.0815	0.0000

Sources: EIA; World Bank Development Indicator database; KAPSARC calculations.

Estimation of the oil price equation

The oil price equation uses logged values of Brent nominal crude oil prices from 1979Q2 to 2018Q3. Following Mohaddes and Pesaran (2016), we chose nominal oil prices for their ability to reflect political and economic factors and disruptions more effectively than real oil prices. This is a critical consideration when evaluating shocks attributed to war and economic sanctions in countries such as Iran, Russia and Venezuela.

Given world oil prices, real GDP and inventories, we estimate the oil price equation (equation 6) using an ARDL approach, with lags selected according to AIC and SBC subject to a maximum lag order

$m_{p^0}^{MAX} = m_y^{MAX} = m_{q^0}^{MAX} = m_I^{MAX} = 4$. Both AIC and SBC selected a lag order of (4,1,1,1), resulting in the following equation for the oil price model.

$$p_t^0 = c_p + \sum_{l=1}^4 a_l p_{t-l}^0 + \beta_1 y_{t-l} + \gamma_l Q_{t-l}^0 + \delta_l I_{t-l} + v_t^0 \quad (29)$$

Where:

$$\begin{aligned} \varepsilon_{p^0} &= -(\gamma_l)^{-1}(1 - \sum_{l=1}^4 a_l) \\ \varepsilon_y &= -(\gamma_l)^{-1}(\beta_l) \\ \varepsilon_{I_0} &= -(\gamma_l)^{-1}(\delta_l) \end{aligned} \quad (30)$$

Table 4 displays the results of the ARDL estimation. All of the estimated coefficients have the correct signs and are statistically significant. The F-statistic for the joint hypothesis indicates that we can reject the null hypothesis that all of the estimated coefficients equal zero. The estimates for the long-term price and income elasticities are -0.10 and

0.089, respectively. The price elasticity falls within the range indicated by a U.S. Federal Reserve Bank analysis of oil elasticities across 30 studies, which ranged from -0.03 to -0.92, with a median value of -0.13 (Caldara, Cavallo, and Iacoviello 2016). The income elasticity of 0.089 is extremely low compared to most estimates, which place income elasticities in the range of 0.5 to 0.9 (Mohaddes and Pesaran 2016). However, it is more in line with recent estimates for developing nations, such as those obtained for India and Pakistan of 0.07 to 0.09, and for China of 0.1 (Ashraf et al. 2018). Finally, the inventory elasticity of approximately 0.47 predicts a positive relationship between oil prices and inventories and generally agrees with established storage theory (Fama and French 1987).

Specification of country-specific vector autoregression models

We derive the trade weights used to calculate the country-specific star foreign variables from the IMF Direction of Trade Statistics database (see Appendix A) by averaging trade flow data for every country and region for the years 2014 to 2016. The resulting weights matrix allows us to calculate the foreign specific star variables, find the solution to the GOVAR model, including the W (or link) matrices (see equation 21), and conduct the necessary bootstrapping. Table 5 shows the country-weight matrix.

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Table 4. Crude oil price model: equation estimates.

$$p_t^0 = c_p + \sum_{l=1}^4 a_l p_{t-l}^0 + \beta_1 y_{t-l} + \gamma_l Q_{t-1}^0 + \delta_l I_{t-1} + v_t^0$$

Variable	Coefficient	Std. error	t-Statistic	Prob.
c_p	3.7360***	(1.9366)	1.9291	0.0557
p_{t-l}^0	1.1684*	(0.0817)	14.3001	0.0000
p_{t-2}^0	-0.4732**	(0.1234)	-3.8357	0.0002
p_{t-3}^0	0.36131**	(0.1228)	2.9419	0.0038
p_{t-4}^0	-0.1684**	(0.0816)	-2.0639	0.0408
y_{t-l}	0.1003***	(0.0511)	1.9622	0.0516
I_{t-1}	0.5295**	(0.2369)	2.2343	0.0270
Q_{t-1}^0	-1.1225*	(0.4080)	-2.7513	0.0067
R-squared	0.95954	Mean dependent var	3.53077	
Adjusted R-squared	0.95760	S.D. dependent var	0.66806	
S.E. of regression	0.13757	Akaike info criterion	-1.07881	
Sum squared resid	2.76316	Schwarz criterion	-0.92104	
Log likelihood	91.06805	Hannan-Quinn criter.	-1.01472	
F-statistic	494.57520	Durbin-Watson stat	2.00498	
Prob(F-statistic)	0			
Elasticities				
ε_{po}	-0.100			
ε_y	0.089			
ε_{Io}	0.472			

Note: Standard errors are presented below the corresponding coefficients in brackets. Symbols *, ** and *** denote significance at the 1%, 5% and 10% respectively.

Source: KAPSARC calculations 2019; GVAR (Smith and Galesi 2014).

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Table 5. Trade and aggregation weights utilized in the GVAR model.

Country	Argentina	Australia	Brazil	Canada	China	Chile	Euro	India	Indonesia	Iran	Japan	Korea	Malaysia	Mexico
Argentina	0	0	0.08	0	0.01	0.01	0.01	0	0	0	0	0	0	0
Australia	0.01	0	0	0	0.03	0.01	0.02	0.02	0.03	0	0.03	0.02	0.04	0.01
Brazil	0.24	0.01	0	0.01	0.02	0.06	0.02	0.03	0.01	0	0.01	0.02	0.01	0.01
Canada	0.03	0.01	0.02	0	0.03	0.02	0.02	0.02	0.01	0	0.02	0.02	0.01	0.07
Chile	0.05	0	0.03	0	0.01	0	0.01	0	0	0	0	0	0	0.01
China	0.11	0.39	0.26	0.05	0	0.31	0.12	0.08	0.14	0.42	0.26	0.4	0.22	0.03
Euro	0.14	0.04	0.16	0.04	0.16	0.12	0	0.18	0.09	0.05	0.09	0.05	0.07	0.05
India	0.05	0.05	0.02	0.01	0.04	0.04	0.02	0	0.09	0.18	0.02	0.03	0.04	0.01
Indonesia	0.03	0.03	0.01	0	0.02	0	0.01	0.02	0	0	0.02	0.02	0.04	0
Iran	0	0	0	0	0.01	0	0	0.01	0	0	0	0.01	0	0
Japan	0.02	0.19	0.04	0.02	0.1	0.1	0.04	0.03	0.14	0.09	0	0.06	0.1	0.01
Korea	0.01	0.09	0.02	0.01	0.05	0.07	0.03	0.03	0.06	0.08	0.08	0	0.04	0.01
Malaysia	0.02	0.02	0.01	0	0.02	0	0.01	0.02	0.05	0	0.03	0.02	0	0
Mexico	0.02	0	0.03	0.03	0.04	0.02	0.02	0.03	0.01	0	0.03	0.03	0.03	0
New Zealand	0	0.02	0	0	0	0	0	0	0	0	0	0	0.01	0
Norway	0	0	0.01	0	0	0	0.02	0	0	0	0	0	0	0
Peru	0.02	0	0.01	0	0.01	0.02	0	0.01	0	0	0	0	0	0
Philippines	0.01	0	0	0	0.01	0	0	0.01	0.02	0	0.01	0.01	0.01	0
Russia	0.02	0	0.02	0	0.02	0.01	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0
Saudi Arabia	0.02	0.01	0.02	0	0.01	0	0.02	0.03	0.01	0	0.02	0.02	0.01	0
Singapore	0	0.02	0.01	0	0.03	0	0.02	0.04	0.1	0	0.03	0.04	0.15	0.01
South Africa	0.01	0.01	0.01	0	0.01	0	0.01	0.03	0.01	0	0.01	0	0	0
Sweden	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0
Switzerland	0.02	0	0.01	0	0.01	0.01	0.08	0.01	0.01	0	0.01	0	0	0
Thailand	0.01	0.02	0.01	0	0.02	0.01	0.01	0.02	0.04	0	0.06	0.02	0.05	0
Turkey	0.01	0	0.01	0	0.02	0	0.04	0.04	0.01	0.15	0.01	0.02	0.01	0
U.K.	0.02	0.02	0.02	0.03	0.04	0.01	0.18	0.05	0.01	0	0.02	0.01	0.02	0.01
U.S.	0.09	0.05	0.16	0.76	0.28	0.14	0.19	0.27	0.13	0	0.23	0.16	0.14	0.76
Venezuela	0.03	0	0.02	0	0	0.01	0	0	0	0	0	0	0	0

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Table 5. Trade and aggregation weights utilized in the GVAR model.

Country	Norway	New Zealand	Peru	Philippines	Russia	South Africa	Saudi Arabia	Singapore	Sweden	Switzerland	Thailand	Turkey	U.K.	U.S.	Venezuela
Argentina	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0
Australia	0	0.2	0.01	0.01	0	0.01	0	0.05	0.01	0.01	0.06	0.01	0.02	0.02	0
Brazil	0.01	0	0.04	0	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Canada	0.01	0.02	0.07	0.02	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.2	0
Chile	0	0	0.04	0	0	0	0	0	0	0	0	0	0	0.01	0
China	0.04	0.24	0.26	0.29	0.14	0.34	0.17	0.17	0.05	0.12	0.2	0.03	0.06	0.12	0.18
Euro	0.46	0.07	0.15	0.09	0.43	0.19	0.11	0.1	0.5	0.41	0.08	0.48	0.46	0.15	0.05
India	0.01	0.02	0.02	0.01	0.02	0.07	0.12	0.04	0.01	0.08	0.03	0.01	0.01	0.02	0.19
Indonesia	0	0.02	0	0.01	0	0	0.02	0.12	0.01	0	0.05	0.01	0	0.01	0
Iran	0	0	0	0	0.01	0	0	0	0	0.01	0	0.04	0	0	0
Japan	0.02	0.08	0.04	0.14	0.07	0.06	0.15	0.05	0.02	0.03	0.11	0.01	0.02	0.06	0
Korea	0.02	0.04	0.04	0.05	0.05	0.02	0.12	0.05	0.01	0.01	0.03	0.01	0.02	0.04	0
Malaysia	0	0.02	0	0.02	0	0.01	0.01	0.13	0	0.01	0.06	0	0.01	0.01	0.01
Mexico	0	0.01	0.02	0.03	0.01	0	0	0.01	0.01	0.01	0.03	0.01	0.01	0.16	0
New Zealand	0	0	0	0	0	0	0	0.01	0	0	0.01	0	0	0	0
Norway	0	0	0.01	0	0.01	0	0	0	0.08	0	0	0.01	0.01	0	0
Peru	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0
Philippines	0	0.01	0	0	0	0	0.01	0.03	0	0	0.03	0	0	0.01	0
Russia	0.01	0.01	0	0	0	0.01	0	0	0.02	0.01	0.01	0.05	0.01	0.01	0
Saudi Arabia	0	0.02	0	0	0	0.01	0	0.01	0.01	0.02	0.02	0.03	0.01	0.02	0
Singapore	0.01	0.02	0	0.07	0.02	0.01	0.05	0	0.01	0.02	0.04	0.01	0.02	0.03	0.05
South Africa	0	0.01	0	0	0	0	0.02	0.01	0.01	0	0.01	0.01	0.01	0.01	0
Sweden	0.11	0	0	0	0.02	0	0	0	0	0	0	0.01	0.02	0	0.01
Switzerland	0	0	0.08	0.01	0.01	0.02	0	0.01	0.01	0	0.02	0.05	0.08	0.02	0.03
Thailand	0	0.02	0	0.04	0.01	0.01	0.03	0.04	0.01	0.02	0	0	0.01	0.01	0
Turkey	0.01	0	0	0	0.08	0.01	0.01	0	0.01	0.01	0.01	0	0.02	0.01	0
U.K.	0.21	0.04	0.01	0.01	0.03	0.1	0.01	0.01	0.09	0.07	0.02	0.12	0	0.05	0.01
U.S.	0.05	0.13	0.17	0.16	0.07	0.09	0.14	0.11	0.08	0.13	0.15	0.08	0.16	0	0.43
Venezuela	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0.01	0

Sources: KAPSARC calculations 2019; GVAR (Smith and Galesi 2014).

Note: The modeling exercise assumes that the country-specific foreign variables are weakly exogenous $I(1)$ and the parameters are stable over time. Unit root tests performed on the variables utilized by the GOVAR analysis confirm that they are integrated of order one, $I(1)$. The unit root tests, weak exogeneity and structural stability test results are available from the authors upon request.

List of variables included in the country-specific VARX models

As mentioned above, the KAPSARC stylization of the global economy can represent 36 countries, seven regions and subregions, and eight country-specific variables (see Table 1). The dataset employed in this study includes quarterly data from 1979Q1 to

2018Q3. We calculate the fixed GVAR weights as three-year moving averages over the 2014-2016 period. Table 6 displays the variables specified by the country-specific VARX models.

The model includes the log of real U.S. dollar (US\$) exchange rates as an endogenous variable for all countries except the U.S. This reflects the importance of the U.S. financial system in the world

Table 6. Variables included in the country-specific VARX model reference case.

Models	Domestic variables								Foreign variables								Global variables
	Y_{it}	DP_{it}	eq_{it}	ep_{it}	r_{it}	rl_{it}	I_{it}^o	QS_{it}^o	Y_{it}	DP_{it}	eq_{it}	ep_{it}	r_{it}	rl_{it}	I_{it}^o	P_{it}^o	
Argentina	1	1	1	1	1				1	1	1	0	0	1	1	1	
Australia	1	1	1	1	1	1			1	1	1	0	1	1	1	1	
Brazil	1	1		1	1				1	0	1	0	1	1	0	1	
Canada	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	1	
Chile	1	1	1	1	1				1	1	1	0	1	1	1	1	
China	1	1		1	1			1	1	1	1	0	1	1	1	1	
Euro	1	1	1	1	1	1	1		1	1	1	0	1	1	1	1	
India	1	1	1	1	1	1			1	1	0	0	1	1	1	1	
Indonesia	1	1		1	1			1	1	1	1	0	1	1	0	1	
Iran	1	1		1	1	1		1	1	1	1	0	0	1	1	0	
Japan	1	1	1	1	1	1	1		0	1	1	0	1	1	1	1	
Korea	1	1	1	1	1	1	1		1	1	1	0	0	1	1	1	
Malaysia	1	1	1	1	1				0	0	1	0	1	1	1	1	
Mexico	1	1		1	1			1	1	1	1	0	1	1	0	1	
New Zealand	1	1	1	1	1	1			0	1	1	0	1	1	1	1	
Norway	1	1	1	1	1	1		1	1	1	1	0	1	1	1	1	
Peru	1	1		1	1				0	1	1	0	1	1	1	1	
Philippines	1	1	1	1	1				1	1	1	0	1	1	0	1	
Russia	1	1		1				1	1	1	1	0	1	1	1	0	
Saudi Arabia	1	1	1	1	1	1			1	1	1	0	1	1	1	1	
Singapore	1	1	1	1	1				1	1	1	0	1	1	1	1	
South Africa	1	1	1	1	1	1			1	1	1	0	1	1	1	1	
Sweden	1	1	1	1	1	1			1	1	1	0	1	1	1	1	
Switzerland	1	1	1	1	1	1			1	1	1	0	1	1	1	1	
Thailand	1	1	1	1	1				1	1	1	0	1	1	1	1	
Turkey	1	1		1	1				1	1	1	0	1	1	1	1	
U.K.	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	
U.S.	1	1	1	0	1	1	1	1	1	0	0	1	0	0	1	1	
Venezuela	1	1		1	1			1	1	1	1	0	1	0	1	1	

Source: KAPSARC calculations.

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economy and is supported by empirical evidence that U.S. monetary policy serves as the primary driver for global financial cycles in capital flows, asset prices and credit growth (Mohaddes and Pesaran 2016). As mentioned above, the model treats global crude oil supplies as weakly exogenous for all countries through the dominant variable, the oil price, which transmits production shocks. That is to say, we model world oil prices as a global or dominant variable, and include these as weakly exogenous in all of the individual country models. Accordingly, changes in global GDP, inventories and oil supplies affect oil prices with a lag, and oil prices in turn impact country-specific oil production, GDP, interest rates, equity prices, and exchange rates (Mohaddes and Pesaran 2016). Domestic oil production, meanwhile, responds to changes in world oil prices, feeding back to affect global prices with a lag, as specified in equation 29.

We model oil prices as a weakly exogenous dominant variable for all countries, except Iran and Russia, reflecting the effects of sanctions imposed on both countries for a large part of the forecast period. The U.S. first imposed sanctions on Iran in November 1979 with Executive Order 12170, following the Iranian hostage crisis. Although President Obama lifted them on January 16, 2016, as a result of the provisional agreement for limits on Iran's nuclear programs, President Trump reinstated them on May 8, 2018, when the U.S. withdrew from the nuclear deal (Landler 2018). In the case of Russia, we take into account the events of the Cold War from 1947 to December 3, 1989 (BBC 1989), NATO, and the general deterioration of relations leading to the imposition of sanctions, and the Ukraine Freedom Support Act of 2014 (Baker 2014). All of these factors tend to isolate, or 'dislocate' the countries from the implications of changing oil prices, primarily because trade is constrained and/or the country does not receive the 'full' world oil price for exports.

Estimating the contemporaneous effects of foreign variables on their domestic counterparts

Tables 7a and 7b show the impact of elasticities of foreign variables on their domestic counterparts for the countries included in this analysis. These reflect the international linkages between domestic and foreign variables included in the GVAR analysis and represent how a country will be affected by foreign (i.e., external) changes in real GDP, inflation, short- and long-term interest rates, and equity prices.

The majority of the estimated coefficients for real GDP, inflation, short- and long-term interest rates, and equity prices have the correct sign and are statistically significant. The real income elasticity for the Euro area of 0.57% suggests that a 1% increase in foreign (non-Euro) GDP results in a 0.57% change in real GDP for the bloc. Most of the developed countries have similar or greater real income elasticities, including the U.S. (0.57%), Sweden (1.24%), and Switzerland (0.54%). Among the developing nations, quite a few, including Argentina (0.62%), China (0.75%) and Turkey (1.37%), are sensitive to changes in foreign GDP.

The elasticities for short-term interest rates are quite low, and often negative, for all countries except Brazil (2.0%), Peru (-4.7%) and Turkey (2.08%). This illustrates a weak relationship between short-term rates and monetary policy reactions across countries. The elasticities for long-term rates are considerably higher, indicating a stronger international relationship between long-term rates and monetary policy reactions. Interest rate data were not available for Saudi Arabia, Russia or Argentina.

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Table 7a. The contemporaneous effects of foreign variables on their domestic counterparts.

		Y_{it}	DP_{it}	eq_{it}	r_{it}	rI_{it}	I_{it}^0
Argentina	Coefficient	0.62120	0.43730	1.60000			
	White's adjusted SE	0.40740	0.50330	0.34910			
	Newey-West's adjusted SE	0.49350	0.46970	0.40470			
Australia	Coefficient	0.23000	0.34590	0.67390	0.44810	0.83130	
	White's adjusted SE	0.09310	0.12000	0.11480	0.13640	0.17360	
	Newey-West's adjusted SE	0.06620	0.11380	0.11970	0.16850	0.16440	
Brazil	Coefficient	0.51450			2.06690		
	White's adjusted SE	0.17680			2.87320		
	Newey-West's adjusted SE	0.18600			2.53270		
Canada	Coefficient	0.34150		0.92000	0.55990	1.00210	
	White's adjusted SE	0.08750		0.04040	0.14580	0.07360	
	Newey-West's adjusted SE	0.08480		0.03470	0.16130	0.09340	
Chile	Coefficient	0.49040	-0.10520	0.83240	0.44110		
	White's adjusted SE	0.21890	0.15580	0.14950	0.12580		
	Newey-West's adjusted SE	0.21180	0.16310	0.14360	0.15380		
China	Coefficient	0.75040	0.17910		-0.02160		
	White's adjusted SE	0.25160	0.19060		0.03840		
	Newey-West's adjusted SE	0.18300	0.17520		0.04380		
Euro	Coefficient	0.56620	0.15780	1.08740	0.03540	0.67320	0.49710
	White's adjusted SE	0.08300	0.04960	0.04620	0.02190	0.07380	0.07540
	Newey-West's adjusted SE	0.09230	0.05380	0.05880	0.02090	0.08870	0.09670
India	Coefficient	0.49370	-0.03330		-0.00530	-0.08640	
	White's adjusted SE	0.35730	0.24510		0.04060	0.12820	
	Newey-West's adjusted SE	0.38250	0.25890		0.03180	0.12870	
Indonesia	Coefficient	0.57150	0.93990		0.05230		
	White's adjusted SE	0.32750	0.41360		0.29580		
	Newey-West's adjusted SE	0.33710	0.39830		0.29230		
Iran	Coefficient	0.28190	0.23850			0.39080	
	White's adjusted SE	0.29580	0.21050			0.20440	
	Newey-West's adjusted SE	0.29870	0.22050			0.21130	
Japan	Coefficient		-0.00820	0.79460	-0.03070	0.47850	0.43300
	White's adjusted SE		0.08540	0.09310	0.03750	0.09080	0.08290
	Newey-West's adjusted SE		0.07750	0.09570	0.04330	0.08380	0.07970
Korea	Coefficient	0.07910	0.17730	1.06190		0.05850	0.57610
	White's adjusted SE	0.15330	0.14490	0.17210		0.19640	0.70340
	Newey-West's adjusted SE	0.16020	0.16490	0.15120		0.19410	0.77290
Malaysia	Coefficient			1.23620	-0.10930		
	White's adjusted SE			0.18870	0.05540		
	Newey-West's adjusted SE			0.21300	0.05660		
Mexico	Coefficient	0.27150	-0.38200		0.18220		
	White's adjusted SE	0.19720	0.34360		0.56230		
	Newey-West's adjusted SE	0.17840	0.30450		0.32210		
New Zealand	Coefficient		0.50160	0.72460	0.46050	0.55920	
	White's adjusted SE		0.21800	0.10860	0.23690	0.18250	
	Newey-West's adjusted SE		0.25960	0.08920	0.23220	0.18020	

Note: The European nations are included in Euro.

Sources: KAPSARC calculations (2019); GVAR (Smith and Galesi 2014).

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Table 7b. The contemporaneous effects of foreign variables on their domestic counterparts.

		Y_{it}	DP_{it}	eq_{it}	r_{it}	rl_{it}	I_{it}^o
Norway	Coefficient	0.33540	0.49830	1.05470	0.12950	0.92180	
	White's adjusted SE	0.23300	0.23540	0.08550	0.18840	0.14490	
	Newey-West's adjusted SE	0.22020	0.24510	0.09250	0.17840	0.14400	
Peru	Coefficient		2.83240		-4.78190		
	White's adjusted SE		2.78230		2.13500		
	Newey-West's adjusted SE		1.94840		3.09100		
Philippines	Coefficient	-0.13600	-0.01310	1.16660	0.64440		
	White's adjusted SE	0.26610	0.38250	0.15000	0.40180		
	Newey-West's adjusted SE	0.27710	0.39630	0.17220	0.39210		
Russia	Coefficient	0.02980	-1.46830				
	White's adjusted SE	0.27090	1.37450				
	Newey-West's adjusted SE	0.25490	1.29750				
Saudi Arabia	Coefficient	0.23920					
	White's adjusted SE	0.20910					
	Newey-West's adjusted SE	0.24730					
Singapore	Coefficient	0.51880	0.14160	1.22580	0.15680		
	White's adjusted SE	0.26290	0.10770	0.09280	0.10050		
	Newey-West's adjusted SE	0.33700	0.11060	0.10260	0.11250		
South Africa	Coefficient	0.40700	0.55980	0.87270	0.22350	0.65120	
	White's adjusted SE	0.21360	0.14690	0.12760	0.09060	0.22010	
	Newey-West's adjusted SE	0.20120	0.15900	0.13320	0.08640	0.20640	
Sweden	Coefficient	1.23970	0.57210	1.13820	0.16690	0.96470	
	White's adjusted SE	0.21710	0.15940	0.06100	0.07970	0.11150	
	Newey-West's adjusted SE	0.20100	0.13900	0.06820	0.07360	0.11450	
Switzerland	Coefficient	0.54400	0.28190	0.89900	0.12650	0.58230	
	White's adjusted SE	0.11990	0.11440	0.06350	0.05780	0.07180	
	Newey-West's adjusted SE	0.09510	0.11620	0.06690	0.06160	0.07340	
Thailand	Coefficient	0.47030	0.26220	1.09460	0.01780		
	White's adjusted SE	0.30250	0.16950	0.12570	0.17270		
	Newey-West's adjusted SE	0.29450	0.19350	0.12570	0.19420		
Turkey	Coefficient	1.37620	-0.76740		2.07840		
	White's adjusted SE	0.43020	0.88480		1.25950		
	Newey-West's adjusted SE	0.47010	0.73660		1.44060		
U.K.	Coefficient	0.21840	0.56060	0.79670	0.10340	0.83520	0.79090
	White's adjusted SE	0.10810	0.15110	0.04630	0.07950	0.11040	0.11680
	Newey-West's adjusted SE	0.10700	0.12490	0.05700	0.08170	0.10450	0.12810
U.S.	Coefficient	0.57270					0.52940
	White's adjusted SE	0.11310					0.08870
	Newey-West's adjusted SE	0.11690					0.13710
Venezuela	Coefficient	0.47060	0.74170		0.67110		
	White's adjusted SE	0.22810	0.63260		0.54150		
	Newey-West's adjusted SE	0.22540	0.61190		0.51790		

Sources: KAPSARC calculations (2019); GVAR (Smith and Galesi 2014).

The elasticities for oil inventories are high, and statistically significant at the 1% level for all regions included in the GOVAR model. Notably, a 1% increase in global inventories results in a 0.5% increase in inventories in the Euro area, 0.79% in the U.K. and 0.57% in Korea.

For the Russian Federation, the elasticities of the two included variables, GDP and inflation, are very low, and in the case of GDP statistically insignificant, indicating minimal sensitivity to foreign GDP. Inflation elasticity is high but also statistically insignificant. Iran and Venezuela show similar results, suggesting economic isolation due to sanctions, and high sensitivity to foreign inflation rates.

Pairwise cross-section correlations

The GVAR approach assumes that any idiosyncratic shock to a country-specific model will be only weakly correlated across countries, or that $cov(x_{ij}^*, u_{it}) \rightarrow 0$, as $N \rightarrow \infty$. More precisely, in the GVAR framework the country-specific models are conditioned on weakly exogenous foreign variables, which serve as proxies for all common global factors affecting the system. All remaining shocks across countries should be modest and reflect only residual impacts, such as the spillover effects of monetary and fiscal policy and trade movements (Dees et al. 2014).

Following the procedure utilized by Dees et al. (2007), we test the proposition that the foreign variables have successfully captured common global factors, thereby reducing the cross-section correlation of the variables in the model, by computing average pairwise correlations for the levels and first differences of all endogenous variables and associated residuals for the sample period, 1979 to 2016.

Tables 8a-c report the results of these calculations. The tests find residuals all well below 15%, except for the oil inventory variable for Korea (-0.17). As expected, the pairwise cross-section correlations are high for the levels of the endogenous variables and fall when first differences and residuals are considered. Real GDP shows the highest levels of cross-section correlations, which range between 0.85 and 0.91 for all countries except Russia (0.29) and Venezuela (-0.25).

Equity prices have the second-highest average cross-sectional correlations, ranging from 0.31 to 0.81 for all the countries for which the time series was available. These are followed closely by exchange rates (0.34 to 0.63) for all countries except Venezuela (0.12) and Iran (-0.24). For exchange rates, the cross-sectional correlation for Russia is estimated at 0.66, in line with those of the other major oil producing countries: Saudi Arabia (0.62), the U.K. (0.72), Canada (0.75), Norway (0.75), Mexico (0.67) and Indonesia (0.89).

The tests show significant and consistent cross-sectional correlations for long- and short-term interest rates across all countries for which data were available. Long-term interest rate cross-sectional correlations range from 0.63 to 0.75 for all countries except Iran, whose correlation of -0.75 reflects years of harsh economic sanctions and war. Short-term interest rate cross-sectional correlations were significantly lower, ranging from 0.38 in Sweden to 0.63 in Turkey and Argentina. Both Venezuela (-0.11) and Iran (-0.62) had negative correlations, once again reflecting years of economic isolation.

In the oil sector, results show significant pairwise cross-sectional correlations for the level of oil inventories, ranging from -0.57 for the U.K. to 0.3 for Japan, with an average of 0.13. The effects

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taper off for the first differences, falling to 0.06 to 0.36. The oil production variable exhibits less pronounced correlations, from 0.21 for Norway to -0.34 for Russia. As expected, the OPEC member

countries — Saudi Arabia (0.10), Iran (0.17) and Venezuela (0.16) — have similar cross-sectional correlations for the oil production variable.

Table 8a. Average pairwise cross-section correlations of all variables and associated model's residuals.

	Y_{it}			DP_{it}			eq_{it}		
	Levels	First differences	VECMX* residuals	Levels	First differences	VECMX* residuals	Levels	First differences	VECMX* residuals
Argentina	0.8690	0.0428	-0.0068	0.2381	0.0406	0.0484	0.3141	0.2315	-0.0188
Australia	0.9103	0.1145	0.0241	0.2989	0.0670	0.0224	0.7896	0.5312	0.0345
Brazil	0.9028	0.1293	0.0142	0.2584	0.0092	-0.0207			
Canada	0.9060	0.1708	-0.0074	0.2482	0.0515	0.0289	0.7433	0.5463	0.0364
Chile	0.9013	0.1148	0.0039	0.3557	0.0449	0.0270	0.7800	0.3286	0.0168
China	0.9118	0.0882	-0.0342	0.1639	0.0484	-0.0026			
Euro	0.8980	0.2121	-0.0370	0.3984	0.1242	0.0405	0.7650	0.5566	-0.0850
India	0.9086	0.0745	-0.0008	0.1347	0.0220	0.0267	0.7715	0.3244	-0.0093
Indonesia	0.8997	0.0788	0.0071	0.0505	0.0456	0.0161			
Iran	0.8952	-0.0561	-0.0391	0.1131	0.0428	0.0270			
Japan	0.8365	0.1476	0.0170	0.2945	0.0520	0.0004	0.3099	0.4318	-0.0877
Korea	0.8916	0.1258	0.0235	0.3172	0.0332	0.0289	0.7250	0.3738	-0.0462
Malaysia	0.9026	0.1804	0.0348	0.2255	0.0921	0.0171	0.6421	0.3919	-0.0053
Mexico	0.9045	0.1459	0.0136	0.2261	0.0091	0.0245			
New Zealand	0.9036	0.1165	0.0535	0.2823	0.0508	0.0111	0.4034	0.3542	0.0145
Norway	0.8968	0.0814	-0.0079	0.3116	0.0751	0.0398	0.8050	0.4945	0.0326
Peru	0.8518	0.0678	0.0249	0.2368	-0.0385	-0.0242			
Philippines	0.8875	0.0425	0.0094	0.1969	0.0096	-0.0073	0.7332	0.3616	-0.0049
Russia	0.2889	0.0597	-0.0025	0.0422	0.0102	-0.0001			
Saudi Arabia	0.8686	0.0363	0.0046	-0.0172	-0.0146	0.0294			
Singapore	0.9045	0.1734	-0.0046	0.2102	0.0489	0.0105	0.7357	0.5344	-0.0150
South Africa	0.8963	0.1725	0.0515	0.3322	0.0709	0.0186	0.7690	0.4559	0.0688
Sweden	0.9073	0.1741	0.0165	0.3982	0.0815	0.0422	0.7764	0.5018	-0.0257
Switzerland	0.9084	0.1822	0.0043	0.3624	0.0816	0.0325	0.7873	0.5314	-0.0141
Thailand	0.8840	0.1120	0.0003	0.2675	0.0620	0.0248	0.6732	0.3953	-0.0160
Turkey	0.9089	0.1127	0.0016	0.1980	-0.0097	0.0261			
U.K.	0.8995	0.1553	-0.0103	0.3941	0.0851	0.0342	0.7632	0.5522	0.0124
U.S.	0.9004	0.1772	-0.0412	0.2475	0.1292	0.0526	0.7762	0.5360	-0.0086
Venezuela	-0.2485	0.0843	0.0294	-0.0547	-0.0317	0.0013			

Sources: KAPSARC calculations (2019); GVAR (Smith and Galesi 2014).

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For the oil sector, and indeed the GVAR results as a whole, the residuals have very small correlations that do not appear to depend on the country or variable under consideration. This indicates that

the model has successfully accounted for the macroeconomic factors behind the country-specific variables, with only a single exception (the oil inventory variable for Korea, estimated at -0.17).

Table 8b. Average pairwise cross-section correlations of all variables and the associated model's residuals.

	eq_{it}			r_{it}			rl_{it}		
	Levels	First differences	VECMX* residuals	Levels	First differences	VECMX* residuals	Levels	First differences	VECMX* residuals
Argentina	0.3480	0.0775	0.0387	0.3875	0.0318	0.0182			
Australia	0.7785	0.3415	0.1880	0.5631	0.1230	0.0445	0.7314	0.3403	0.0541
Brazil	0.7371	0.2045	0.1128	0.4069	0.0156	-0.0499			
Canada	0.7594	0.2936	0.1635	0.6038	0.1745	0.0879	0.7430	0.3329	0.0005
Chile	0.7104	0.2596	0.1496	0.5738	0.0265	-0.0308			
China	0.5491	0.0806	0.0251	0.5298	0.0487	-0.0041			
Euro	0.7311	0.3189	0.2392	0.6180	0.1563	0.0597	0.7400	0.4038	-0.0476
India	0.5842	0.2321	0.1574	0.2875	0.0782	0.0312	0.4005	0.0769	-0.0185
Indonesia	0.3747	0.1902	0.0844	0.2919	0.0755	0.0172			
Iran	-0.2435	0.0338	0.0414	-0.6223	-0.0294	-0.0319	-0.7538	0.0536	-0.0051
Japan	0.6537	0.1568	0.1100	0.5537	0.0318	0.0135	0.6977	0.2309	-0.0254
Korea	0.7517	0.2691	0.1437	0.5888	0.0531	0.0456	0.7046	0.0409	-0.0505
Malaysia	0.6916	0.2905	0.1559	0.4823	0.0621	0.0379			
Mexico	0.6703	0.1058	-0.0075	0.4716	0.0170	0.0114			
New Zealand	0.7740	0.3327	0.1990	0.5343	0.0527	0.0039	0.6793	0.1748	0.0133
Norway	0.7523	0.3548	0.2518	0.5709	0.0370	0.0328	0.7260	0.2770	-0.0086
Peru	0.7117	0.0583	0.0476	0.4064	0.0334	0.0264			
Philippines	0.7562	0.1764	0.1189	0.5925	0.0897	0.0268			
Russia	0.6623	-0.0361	-0.0100						
Saudi Arabia	0.6214	0.0595	0.0609						
Singapore	0.7710	0.3519	0.2297	0.5499	0.0771	0.0252			
South Africa	0.6462	0.2779	0.1840	0.5146	0.1029	0.0237	0.6315	0.1881	-0.0063
Sweden	0.7042	0.3198	0.2188	0.6317	0.0786	-0.0019	0.7587	0.3568	0.0267
Switzerland	0.7640	0.2831	0.2472	0.5319	0.0798	0.0138	0.7081	0.3429	0.0209
Thailand	0.7597	0.2723	0.1636	0.5719	0.1090	0.0326			
Turkey	0.7598	0.1972	0.1222	0.3755	0.0545	0.0108			
U.K.	0.7213	0.2856	0.1696	0.6242	0.1340	0.0213	0.7466	0.3727	-0.0010
U.S.				0.5630	0.1186	0.0417	0.7180	0.3710	-0.0168
Venezuela	0.1271	-0.0300	-0.0337	-0.1104	0.0457	0.0351			

Sources: KAPSARC calculations (2019); GVAR (Smith and Galesi 2014).

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Table 8c. Average pairwise cross-section correlations of all variables and the associated model's residuals.

	I_{it}^o			$Q_{it}^{s^o}$		
	Levels	First differences	VECMX* residuals	Levels	First differences	VECMX* residuals
Canada	0.2442	0.2175	0.0229	0.0786	0.0317	0.0052
China				0.137	-0.0187	-0.0196
Euro	0.1928	0.2542	-0.0744			
Indonesia				-0.1756	0.0131	0.0001
Iran				0.1743	-0.0118	0.0064
Japan	0.3634	0.3043	0.0463			
Korea	0.3557	0.0551	-0.1692			
Mexico				0.0745	0.038	0.0514
Norway				0.2066	0.017	0.0179
Russia				-0.3375	-0.0427	0.0052
Saudi Arabia				0.1002	0.0344	0.0264
South Africa						
U.K.	-0.5739	0.1168	-0.033	-0.1383	0.0526	0.0538
U.S.	0.23	0.3585	0.0067	-0.3097	-0.0008	0.0025
Venezuela				0.1634	0.0224	0.023

Sources: KAPSARC calculations (2019); GVAR (Smith and Galesi 2014).

In summary, we find clear evidence of cross-country correlations for all the variables in the GVAR model. Their extent depends on the variable and is noticeable for real GDP, equity prices, exchange rates, long- and short-term interest rates, inflation, and crude oil inventories. The effects taper off considerably for residuals, suggesting that the model has successfully captured the dependencies that exist across the macroeconomic variables considered.

The unit root tests for all the variables included in the GOVAR, the results of weak exogeneity tests for the foreign variables, and the issue of structural breaks in the time series are available on request.

The selection of lag orders, cointegrating relationships, and persistence profiles

This study selects the lag orders for the domestic and foreign variables using the AIC test statistic, which we apply to the underlying VARX (4,2) models, with maximum lag orders set to 4 for the domestic variables, and 2 for the foreign variables (Akaike 1981). Table 9 presents the results of the selection process. The analysis determines the cointegrating relationships, also shown in Table 9, using the MacKinnon trace test statistics and 95% critical values (MacKinnon 1990; Pesaran, Smith and Shin 1997). Based on these results, the GOVAR model has 53 cointegrating relationships, including two each in Russia and Venezuela, and one in Iran.

Table 9. Lag orders and cointegrating relationships of variables included in the country-specific VARX model reference case.

	Lag orders for domestic variables	Lag orders for foreign variables	Cointegrating relationships
Argentina	4	1	1
Australia	3	1	2
Brazil	1	1	2
Canada	1	2	2
Chile	4	1	2
China	1	1	2
Euro	2	1	2
India	2	1	1
Indonesia	4	1	2
Iran	1	1	1
Japan	2	2	2
Korea	3	1	2
Malaysia	4	2	2
Mexico	3	2	2
New Zealand	3	2	2
Norway	4	1	2
Peru	1	1	2
Philippines	1	1	2
Russia	1	1	2
Saudi Arabia	4	1	1
Singapore	1	1	2
South Africa	2	1	2
Sweden	3	1	2
Switzerland	1	1	2
Thailand	4	1	2
Turkey	2	1	1
U.K.	4	2	2
U.S.	2	1	2
Venezuela	1	1	2

Source: KAPSARC calculations (2019); GVAR (Smith and Galesi 2014).

The persistence profiles (PP) of a system-wide shock illustrate the dynamic properties of the model. As shown in Figure 2, the PPs are normalized to a starting value of 1 on the impact of the disruption. The rate at which they approach zero reflects

the speed at which the system tends to return to equilibrium after a shock. If the relationship underlying the model is cointegrated, the PPs can overshoot but will converge to zero in a finite time period (Esfahani, Mohaddes and Pesaran 2012).

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Figure 2. Persistence profiles of the effect of a system-wide shock to the cointegrating relations.

Sources: KAPSARC calculations (2019); GVAR (Smith and Galesi 2014).

None of the PPs in the reference case scenario had a tendency to overshoot, and convergence occurred relatively quickly in the majority of the countries, taking three to four years. Brazil, India, Peru, the Philippines and Venezuela required less than three years. This might be explained by the relatively underdeveloped nature of the capital markets in these countries (Mohaddes and Pesaran 2016). Conversely, Canada, Russia, the Euro zone, the U.S., Switzerland, Sweden, Norway, the U.K. and Korea — which have more mature capital markets — took longer than average.

Figure 3 shows the PPs for the net oil exporters and their 95% bootstrapped error bands. Most of these countries (Saudi Arabia, Canada, Norway, Mexico, and Indonesia) converge in just two to three years. The fastest, Iran and Venezuela, take less than

one year, while the slowest, Russia, needs over four years. This aligns with a study by Esfahani, Mohaddes and Pesaran (2012) that indicates slower speeds of convergence in Saudi Arabia and Norway could be attributed to the establishment of sovereign wealth funds in these countries that can absorb economic shocks, thereby dampening the response of the wider economy to system-wide disruptions. Similarly, the results obtained by Mohaddes and Pesaran (2016) suggest that the faster speeds of adjustment for Iran (and in the case of this study, Venezuela) might be due to the lack of developed capital markets in these countries. Russia's slow convergence could stem from the ability of its command economy to absorb shocks by keeping a steady flow of investment to the sector despite shocks to the financial system and world oil prices.

Figure 3. Persistence profiles for the net oil exporting countries.

Sources: KAPSARC calculations (2019); GVAR (Smith and Galesi 2014).

Empirical Results: Formulation Of The Oil Price Equation And Base Case Country-Specific Models

Figure 4 shows the PPs for the net oil importing countries and their 95% bootstrapped error bands. Notably, the speed of convergence for the net oil importers is slightly more compact, ranging from just over one year for Brazil to over four years for the U.K. Once again, the results agree with those obtained by Esfahani, Mohaddes and Pesaran

(2012), who suggest that the fully developed capital markets and hedging instruments found in developed countries result in slower speeds of convergence. The unit root, weak exogeneity, and structural stability tests are available from the authors upon request.

Figure 4. Persistence profiles for the net oil importing countries.

Sources: KAPSARC calculations (2019); GVAR (Smith and Galesi 2014).

Counterfactual Analysis Of System-Wide And Regional Supply Shocks

The GOVAR model has now been fully specified and can be utilized to access the time profile of the effects of shocks to the global system. To illustrate its dynamic properties, we examine a simple negative shock to world oil prices, represented as one standard error reduction in the world oil price.

Importantly, the model has been developed without any restrictions to the equations or estimated parameters. Restrictions on price, income and interest rate elasticities are beyond the scope of this analysis and offer a possible area for future research.

We analyze the shocks utilizing generalized impulse response functions (GIRFs), developed by Koop, Pesaran and Potter (1996). The GIRF methodology considers shocks to individual errors and integrates out the effects of other shocks by using the observed distribution of all of the shocks. Thus, the ordering of the variables in the model does not affect the outcome (Dees et al. 2014; Pesaran, Smith and Shin 1997). The analysis considers a time frame of 40 quarters (10 years) and displays the results in terms of sieve bootstrapped values with 90% confidence intervals.

Regarding the stability of the system, the reference case GOVAR model has 163 endogenous variables, with 53 cointegrating relationships, so that at least 110 ($163 - 53$) eigenvalues should lie on the unit circle for the system to be stable. In other words, when the GOVAR is stable, the global system will have at least 110 eigenvalues that lie on the unit circle. In fact, when fully specified, the system has exactly 110 eigenvalues that are equal to one. All of the remaining eigenvalues are less than one, suggesting the stability of the system as a whole. The large number of eigenvalues that are equal to one suggests that some shocks can be expected to have permanent effects on the endogenous variables of the GVAR reference case inventory model (Chudik and Pesaran 2016).

Conclusion And Suggestions For Future Research

This study develops the Global Vector Autoregression Oil and Inventory model (GOVAR) to examine the consequences of market disturbances across diverse sets of locations, economies, political systems, and market conditions. GOVAR disaggregates the global industry into country- and region-specific models. It determines crude oil supplies and inventories in country-specific models conditional on world oil prices, which it in turn estimates from aggregate global inventories, world oil supplies and income.

GOVAR covers 36 countries and seven regions or subregions, using quarterly data for 1979Q1 to 2018Q3 from a variety of industry sources, including the EIA, World Bank, IMF, and Bloomberg. We tested the model for weak exogeneity of the global and country-specific variables, and for the stability of the estimated parameters. At a 5% level of significance, only 14 of the 180 exogeneity tests are statistically significant. Overall, the calculations support the treatment of the foreign country-specific and world oil prices in GOVAR. While results show evidence of structural breaks, it would appear to indicate structural breaks in the error variances and not the parameter coefficients. We addressed these issues by employing a robust standard errors procedure when calculating the impacts of foreign variables, and using bootstrap measures with confidence intervals to estimate the impulse response functions.

Future research

We identify considerable scope to expand the GOVAR framework to include more countries, additional variables, and restrictions on price elasticities. Restrictions that have been utilized in simple VAR studies in the past include (Kilian 2009):

- Near vertical supply curve with a price elasticity of 0.025.

- Response of the real price of oil to a negative supply shock must be positive for at least 12 months.

- Response of real economic activity to a negative supply shock must be negative for at least 12 months.

- Dynamic sign restrictions imposed on GDP shocks.

These are all excellent candidates for future research. The list could be expanded to include restrictions on the dynamic sign restrictions imposed on shocks to long-term interest rates, specifically their effect on U.S. production, and shocks to equity prices.

On the geopolitical front, some of the many research questions that could be investigated using GOVAR include:

- Given an oil price shock, and the knowledge of its underlying transmission mechanisms, what are the appropriate fiscal and monetary policy responses and what is the appropriate use of strategic inventories?

- What are the consequences, intended and otherwise, of sanctions on major oil producing nations such as Iran?

- What are the appropriate policy tools and responses that might be used to address a supply shock crisis?

What are the roles of speculation, financial regulation, and alternative regulatory regimes in preventing and mitigating supply shocks?

What are the potential roles of the IEA, OPEC and strategic petroleum reserves, given contemporary and expected future market conditions?

To what extent has the shale boom in the U.S. disrupted energy markets, and what are the resulting policy choices faced by Saudi Arabia, OPEC and other oil producers?

How would the impact of a shock to short-term U.S. interest rates compare with a disruption to short-term global interest rates?

Finally, future expansions to the model framework might include:

The expansion of the data set to include a wider range of countries, especially Iraq and other OPEC nations not currently in the model, larger oil consumers, and rapidly developing producing nations in the rest of the world (ROW) and Asia.

Modifications to the key variables utilized in the model to improve estimates of global inventory forecasts and real economic activity. These variables can be augmented significantly with geospatial estimates (such as for aboveground storage, floating storage and vessel tracking), financial flow analysis, nowcasts and news forecasts (Bloomberg 2017).

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Appendix A: Data Sources

Table A1. Countries utilized in the world oil inventory model.

Argentina	Indonesia	Russian Federation
Australia	Iran	Saudi Arabia
Austria	Italy	Singapore
Belgium	Japan	South Africa
Brazil	Korea	Spain
Canada	Malaysia	Sweden
Chile	Mexico	Switzerland
China	Netherlands	Thailand
Finland	New Zealand	Turkey
France	Norway	United Kingdom
Germany	Peru	United States
India	Philippines	Venezuela

GOVAR includes data from 36 countries, including those in the Eurozone. The data set follows the standard GVAR framework used by Smith and Galesi (2014) in their GVAR toolbox. Table A1 lists the countries utilized by the model.

The primary data sources for the variables are as follow.

Global variables

- Crude oil production: U.S. Energy Information Administration (EIA).
- Oil price index: Brent crude price from Bloomberg (ticker: 01 Comdty). The quarterly series was constructed using the simple mathematical average of daily closing prices for trading days in each quarter.

Country-specific variables

- Petroleum stocks: EIA (2020)
- Crude oil production: EIA (2020).

Real gross domestic product (GDP), the consumer price index (CPI), equity price index, exchange rates, and short- and long-term interest rates, from 1979Q1 to 2013Q1 were obtained from Smith and Galesi (2014). The observations from 2013Q2 to 2016Q4 were obtained by revising and updating the existing GVAR dataset as described below.

Real GDP

Real GDP includes quarterly values for seasonally adjusted real GDP for all countries, indexed to the year 2005=100. The original data runs from 1979Q1 to 2013Q1 and divides the country-specific real GDP estimates into three groups:

1. Group I. International Financial Statistics (IFS) data for GDP (real index, quarterly, 2005=100) were used for Australia, Canada, France, Germany, Italy, Japan, Netherlands, New Zealand, South Africa, Spain, Switzerland, the United Kingdom (U.K.), and the United States (U.S.) (IMF 2013; Smith and Galesi 2014).
2. Group II. IFS data for GDP (real index, quarterly, 2005=100) were used for Austria, Belgium, Finland, India, Indonesia, Korea, Malaysia, Singapore, Sweden, Thailand, and Turkey. When IFS data were not available (India and Singapore), Bloomberg data were used. The series were seasonally adjusted using Eviews, applying the U.S. National Bureau of the Census' X-12 program (see note on seasonality below). The X-12 seasonal adjustment package was developed to comply with best practices in econometrics and statistics, and is used by most of the leading national statistics institutes across the world. For Saudi Arabia, annual IFS data for GDP were interpolated to obtain quarterly values for 2012 (Smith and Galesi 2014).
3. Group III. Inter-American Development Bank (IADB) data for GDP (real index, quarterly, 2005=100) were used for the Latin American countries (Argentina, Brazil, Chile, Mexico, Peru and Venezuela) (IADB 2017). For the Philippines, the quarterly rate of change of the seasonal adjusted real GDP index (Bloomberg) was used to extrapolate forward from 2011 to 2013. For Norway, continued seasonality — additional seasonality remaining in the time series post X-12 — was corrected by using Organisation for Economic Co-operation and Development (OECD) data (GPSA). The real seasonally-adjusted data for China were constructed using data from the country's National Bureau of Statistics (Smith and Galesi 2014).

The GDP time series includes quarterly values for seasonally adjusted GDP for all countries, indexed to the year 2010=100. Data for 1979Q2 to 2016Q4 are taken from Mohaddes, Kamilar and Raissi (2018), and for 2016Q4 to 2018Q2 from the IFS (IMF 2018). The 1979-2016 data set was extended to 2018 using the quarterly growth rates of both the adjusted and non-adjusted series from 2016Q4 to 2018Q2. For Venezuela and Argentina, IADB data for GDP (real index, quarterly) were used (IMF 2018).

For Venezuela, the time series was completed using an interpolated annual value from the World Bank, with data for 2018 from Focus Economics projections. (FocusEconomics 2018; Laya and Rosati 2018). For Iran, yearly data were obtained from the World Bank for 1979-1987, 2008 and 2009. For Russia, annual real GDP data were obtained from several sources: 1979-1989 from the CIA (2019), 1988-1990 from the Slavic Research Center (2020), and 1990-1994 from the Federal Reserve Bank of St Louis (FRED 2019); quarterly data for 1994Q1-2017Q4 were taken from the IFS (2018), and for 2018Q1-Q2 figures were calculated from real growth data from the CEIC (2019). When necessary, the data were spliced at 1988, 1990, 1994, and normalized.

When only yearly data were present, quarterly data were interpolated using the multiplicative cubic spline method and seasonally adjusted.

Consumer price index (CPI)

The CPI time series includes quarterly values for seasonally adjusted CPI for all countries, indexed to the year 2010=100. Data for 1979Q2 to 2016Q4 are taken from Mohaddes, Kamiar and Raissi (2018) and for 2016Q4 to 2018Q3 from the IFS (IMF 2018).

The 1979-2016 dataset was extended to 2018 using the quarterly growth rates of both the adjusted and non-adjusted series from 2016Q4 to 2018Q2. For Argentina, IADB data were used for GDP (real index, quarterly, 2005=100) (IADB 2017; IM 2018). For Canada, the Philippines, and the Netherlands, data from FRED were used to update the series by extrapolating forward using quarterly growth rates.

For Russia, the time series was interpolated from quarterly values using the multiplicative cubic spline method.

Venezuelan yearly CPI data (1979-1989) were taken from FRED, quarterly data thereafter (1990-2016) from the IFS. Because the IFS stopped reporting CPI for Venezuela in 2017Q1, 2017-2018 data were extrapolated. For Iran, annual data for 1979-2007 was obtained from FRED and quarterly data for 2008 onwards from the IFS. For Russia, annual data for 1979-1980 came from the U.S. Congress Report (1982); 1980-1991 from Shleifer, and Vishny (1991); 1991-1992 from Filatochev and Bradshaw (1992); quarterly data for 1993Q1 onward was taken from the IFS (2017). When only annual data were available, quarterly values were interpolated using the multiplicative cubic spline method.

Short-term interest rates

The short-term interest rate time series includes quarterly values for the deposit rate percentage (per annum). The data for 1979Q2 to 2016Q4 is taken from Mohaddes, Kamiar and Raissi (2018), and 2016Q4 to 2018Q2 from the IFS (IMF 2018). IFS data for interest rates and the deposit rate were collected for Argentina, Austria, Chile, China, Malaysia and Turkey for 1979-2016. For Peru, IFS data for interest rates and discount rate were used for 1979-2016. The IFS T-bill rate was used for Canada, Belgium, France, Germany, Italy, Mexico, Norway, Philippines, South Africa, Sweden, the U.K. and the U.S. The IFS money market rate was used for all years from 1979 to 2016 for Australia, Brazil, Finland, India, Indonesia, Japan, Korea, Saudi Arabia, Singapore, Spain, Switzerland, and Thailand.

For Germany, the three-month T-bill rate was used starting from 2010Q1, and for Singapore the overnight rate average was used from 2005Q3. In Australia, Belgium, France, Italy, Japan, and Norway, short-term interest rates from 2016Q1 onward were extrapolated forward using quarterly growth rates taken from the OECD short-term interest rate series, based on three-month money market rates (OECD 2018). The T-bill rate for Canada from 2017Q3 onward was taken from the Bank of Canada (2018). For Indonesia, because the money market rate used for the years through 2016 was no longer available, the series was

extrapolated forward using the change in quarterly deposit rates from IFS. For Malaysia, the series was unavailable from 2017Q1, and was extrapolated forward using the quarterly rate of change of the money market rate from IFS. For the U.K., the data were extrapolated forward using T-bill rates from FRED (2019).

For Venezuela, the time series includes quarterly values for the discount rate from IFS (IMF 2018). For Iran, yearly figures for 1979-2003 were obtained from the Central Bank of Iran, quarterly data for 2003Q4-2016Q4 from IFS, and 2017-2018 values from Trading Point of Financial Instruments UK Ltd (2019). For Russia, quarterly data for 1995Q1-1996Q3 were obtained from the Central Bank of Russia, and for 1997Q1-2018Q4 from OECD, while the value for 1996Q4 was interpolated.

For all other variables, the 1979-2016 dataset was extended to 2018 using the quarterly growth rates from 2016Q4 to 2018Q2.

Equity price index

The equity price series 1979Q2 to 2016Q4 are taken from Mohaddes, Kamiar and Raissi (2018). The numbers for 2016Q4 to 2017Q1 are from Bloomberg's MSCI Country Index, with quarterly averages used from 2017Q1 to 2018Q2 (Bloomberg). For Argentina, the data were taken from Bloomberg (ticker: M1AR Index) for 2009 onward. For Chile, Finland, France, India, Korea, Malaysia, the Netherlands, New Zealand, Norway, Philippines, South Africa, Sweden, and Thailand the values after 2016 were extrapolated forward using the rate of change of the Bloomberg MCSI Country Index.

Exchange rates

The exchange rate series for 1979Q2 to 2016Q4 was taken from Mohaddes, Kamiar and Raissi (2018) and for 2016Q4 to 2018Q2 from IFS (IMF 2018). The foreign exchange quarterly values for 1979Q1 to 2016Q4, taken from Mohaddes, Kamiar and Raissi (2018), originated from Bloomberg. The rest of the data series was completed to 2018 by extrapolating forward using the rate of change of the Bloomberg time series.

The following Bloomberg exchange U.S. dollar (US\$) rate tickers were used: Australia (AUD BGN), Argentina (ARS BGN), Austria (ATS BGN), Belgium (BEF BGN), Brazil (BRL BGN), Canada (CAD BGN), China (CNY BGN), Chile (CLP BGN), Colombia (COP BGN), Finland (FIM BGN), France (FRF BGN), Germany (DEM BGN), India (INR BGN), Indonesia (IDR BGN), Italy (ITL BGN), Japan (JPY BGN), Korean (KRW BGN), Malaysia (MYR BGN), Mexico (MXN BGN), the Netherlands (NLG BGN), Norway (NOK BGN), New Zealand (NZD BGN), Peru (PEN BGN), the Philippines (PHP BGN), South Africa (ZAR BGN), Saudi Arabia (SAR BGN), Singapore (SGD BGN), Spain (ESP BGN), Sweden (SEK BGN), Switzerland (CHF BGN), Thailand (THB BGN), Turkey (TRY BGN), and the U.K. (GBP BGN).

For the Euro area — Austria, Belgium, Finland, France, Germany, Italy, Netherlands and Spain — the exchange rates refer to the pre-euro exchange rates (national currency per US\$). The quarterly average of the euro exchange rate per US\$ was used to define the exchange rates in terms of the euro (Bloomberg

Appendix A: Data Sources

ticker Eur Curncy). This value was extrapolated backward from 1999Q1 using the rate of change of the national currency foreign exchange rates series. From 1990Q1 to 2016 the series is equal to the quarterly average of the euro currency expressed in US\$ (Smith and Galesi 2014).

For Russia, the exchange rates from 1929Q2 to 1991 are taken from black market estimates (Alexashenko 1992).

Long-term interest rates

The long-term interest rate series includes quarterly values for government bonds for all countries from the IFS database (Smith and Galesi 2014). The data for 1979Q2 to 2016Q4 are taken from Mohaddes, Kamiar and Raissi (2018), and for 2016Q4 to 2018Q3 from IFS (IMF 2018). The IFS data for interest rates, government securities, and government bonds are used to extend the series for all countries (except India) for which long-term interest rate data are available, namely Australia, Austria, Belgium, Canada, France, Germany, Italy, Japan, Korea, the Netherlands, New Zealand, Norway, South Africa, Spain, Sweden, Switzerland, the U.K. and the U.S.

For India, annual data for 10-year government bond yields for 1979-1996 were available from the Reserve Bank of India (RBI) and used for interpolation. Quarterly RBI data were used for 1996Q2 to 2018Q3.

For the Euro zone, the 1979-2016 dataset was extended to 2018 using the quarterly growth rates for the EU convergence criteria, known as the Maastricht criteria. For example, the Maastricht criterion bond yields (mcby) are long-term interest rates used as a convergence criterion for the European Monetary Union, based on the Maastricht Treaty (Eurostat 2019). For Australia, Canada, Japan, New Zealand, Norway and the U.S. the data set was extended to 2018 using quarterly growth rates for 10-year government bond yields from FRED.

For Iran, yearly long-term interest rates for 1979-2013 were obtained from the Central Bank of Iran and for 2017-2018 from trading.com; 2014-2016 data were interpolated. For Russia, quarterly T-bill rates for 1995Q2-2000Q3 were obtained from IFS, and quarterly rates for 180-360 day T-bills between 2000Q4-2018Q4 were taken from the Central Bank of Russia.

Oil price index

The oil price index is taken from Bloomberg (Series: Current Pipeline Export Quality Brent Blend; ticker: CO1 Comdty). To construct a quarterly series, the average of daily closing prices was obtained for all trading days in each quarter. The quarterly rate of change was then used to extrapolate forward the 2011 data to 2018 (Smith and Galesi 2014).

Agricultural raw material and metals price indices

The agriculture and metals indices were taken from the IMF monthly commodity price data (IMF 2017).

Because the IMF series starts from 1980, World Bank data for 1979 to 1980 were used to extrapolate the series back to 1979. Quarterly data represents a simple arithmetic average of monthly data (Smith and Galesi 2014). The IMF series was discontinued in June 2017. From this date the metals price series is taken from the U.S. Bureau of Labor Statistics (BLS, series COINDU.S.Z331) (FRED 2019). The agriculture raw material price is also taken from the BLS. The agriculture raw materials price index comprises “agricultural products used for industrial supplies and materials” (IR120) and is taken from (FRED 2019). As before, the quarterly rate of change was used to extrapolate forward from 2016 data to 2018.

Crude oil inventories and crude oil production

The oil inventories and production data series were taken from the EIA (2019). Crude oil production for Indonesia for August to December 2016 was taken from the EIA via a secondary source, Trading Economics (2019). Quarterly figures are a simple arithmetic average of monthly values.

PPP-GDP data

The purchasing power parity (PPP) to GDP (PPP-GDP) weights were constructed using data from the World Bank Development Indicator database.

Trade matrix

IMF Direction of Trade statistics (annual frequency data through 2017 for exports and imports) were used to construct the trade matrices (IMF 2018). Values for the Russian Federation were extrapolated using the time series for the USSR from 1981 to 1990. For Belgium and South Africa, the time series were unavailable from 1981 to 1997, so data for 1979 to 1980 were used to extrapolate the series.

Note on seasonality

Following Smith and Galesi (2014), the time series were tested for the joint significance of seasonal effects as follows:

Given seasonal dummy variables, S_1, S_2, S_3, S_4 , where S_i is equal to 1 in the i th quarter, and zero in the remaining quarters, let:

$$S_{14} = S_1 - S_4$$

$$S_{24} = S_2 - S_4$$

$$S_{34} = S_3 - S_4$$

Appendix A: Data Sources

A simple linear regression is run on $\Delta \log(Y_t)$, where Y is the variable to be tested for seasonal effects, and S_{14} , S_{12} , S_{34} . The OLS estimates of S_{14} , S_{12} and S_{34} are labeled a_1 , a_2 and a_3 , respectively. The joint significance of the seasonal components is tested under the null hypothesis that $a_1 = a_2 = a_3 = 0$ by means of the F-statistic. In cases where the null hypothesis was rejected at a 10% level of significance, the X-12 procedure was performed on the log-difference of the original time series Y (Smith and Galesi 2014).

The series $\Delta \log(Y_t)$ was adjusted using the X-12 quarterly seasonal adjustment method in Eviews under the additive option. The resulting series $\Delta \log(Y_t)_{SA}$ was then used to obtain the estimated seasonally adjusted series $\log(Y_t)_{SA}$ by taking the first value of the raw series $\log(Y_{t=1})$ and adding the first differences cumulatively. Finally, the seasonally adjusted series Y_{tSA} is obtained by taking the exponential of $\log(Y_t)_{SA}$.

Notes

A yellow geometric graphic consisting of several overlapping triangles and polygons, located in the top-left corner of the page.

Notes

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About the Authors

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About the Project

The purpose of this project is to develop an analytical framework to analyze shocks to world oil and inventory markets. The model can facilitate an investigation of the economic implications of country- and region-specific oil and inventory disruptions, such as economic sanctions, wars, financial crises, natural disasters and monetary and fiscal policy changes. The model proposed for the World Oil and Inventory Study is based on traditional Global Vector Autoregressive (GVAR) models.

Two characteristics make a GVAR-based approach particularly well suited to this research. First, it is designed to account for the interactions between many countries, each with its own political and legislative system. This is crucial, as the effects of severe shocks and global imbalances cannot be contained within one country or region. Second, GVAR can model world oil supplies and inventories jointly with key macroeconomic variables, including short- and long-term interest rates, inflation, equity prices and real gross domestic product (GDP). The framework therefore facilitates an investigation of the effects of country- and region-specific oil shocks on GDP, inflation, interest rates, inventories, exchange rates and equity prices globally.

The model developed for this project, the KAPSARC Global Oil Vector Autogression Model (GOVAR) represents a slight variation to this approach. In the case of the GOVAR, the global oil market is modeled separately, by means of a single price equation that accounts for global supply and demand conditions. Global oil supplies are included in each country-specific model, reflecting global oil supplies for all major oil producing countries. As a result, the combined system-wide model can estimate the impact of country-specific oil shocks on the global economy and the related implications for global financial markets, equity prices, interest rates and oil prices.

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