Oil Prices and the Global Economy: Is It Different This Time Around?[*]

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Abstract

The recent plunge in oil prices has brought into question the generally accepted view that lower oil prices are good for the US and the global economy. In this paper, using a quarterly multi-country econometric model, we first show that a fall in oil prices lowers interest rates and inflation in most countries, and increases global real equity prices. The effects on real output are positive, although they take longer to materialize (around 4 quarters after the shock). We then re-examine the effects of low oil prices on the US economy over different sub-periods using monthly observations on real oil prices, real equity prices and real dividends. We confirm the perverse positive relationship between oil and equity prices over the period since the 2008 financial crisis highlighted in the recent literature, but show that this relationship has been unstable when considered over the longer time period of 1946–2016. In contrast, we find a stable negative relationship between oil prices and real dividends which we argue is a better proxy for economic activity (as compared to equity prices). On the supply side, the effects of lower oil prices differ widely across the different oil producers, and could be perverse initially, as some of the major oil producers try to compensate their loss of revenues by raising production. Taking demand and supply adjustments to oil price changes as a whole, we conclude that oil markets equilibrate but rather slowly, with large episodic swings between low and high oil prices.

JEL Classifications: C32, E17, E32, F44, F47, O51, Q43.

Keywords: Oil prices, equity prices, dividends, economic growth, oil supply, global oil markets, and international business cycle.

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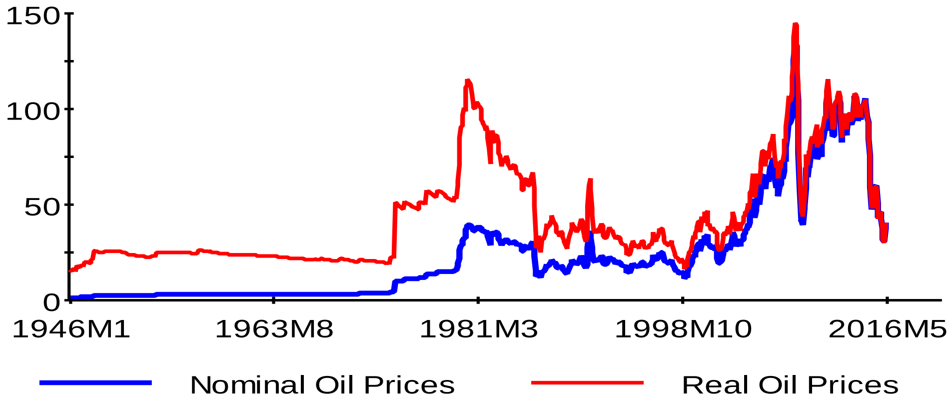
1 Introduction

Oil markets have experienced frequent episodes of boom and bust, ever since oil was produced in large commercial quantities in Pennsylvania back in 1859. Real oil prices (WTI in 2015 US dollar) have fluctuated between highs of \$145 to lows of \$15 per barrel over the period 1946M1 and 2016M6 (Figure 1). The control of oil markets by the major international oil companies, the so called Seven Sisters, backed by the UK and US governments, meant low and relatively steady oil prices until the late 1960s. However, a new era began with the foundation of OPEC in 1960, the 1968 coup in Libya which led to new agreements initially with the independent oil companies and then with the Seven Sisters across all major oil producers in the Middle East and elsewhere, not to mention the start of a downward trend in US oil production in 1971. As a result, oil markets entered a new phase as the Seven Sisters lost control to markets and oil producers, oil prices quadrupled, ushering in an era of high oil price volatility and frequent periods of boom and bust often triggered by military and political events.

Figure 1: Nominal and Real (2015 US dollars) WTI Oil Prices



Data sources: United States Energy Information Administration (EIA).

In fact, since 1986 there have been six episodes of sharp decline in oil prices (30% or more in each episode), in a relatively short period of time (within seven months), and with relatively large effects on the global economy (see Figure 1 and Baffes et al. 2015). Therefore, while the fall in oil prices since June 2014 is large, it is by no means unprecedented, and there is an extensive literature on the economic consequences of oil shocks for the global economy in terms of their impacts on real output and real equity prices, see for instance, Hamilton

(2009), Kilian (2009), Cashin et al. (2014), Mohaddes and Pesaran (2016), and Mohaddes and Raissi (2015) among others. Overall the literature suggests that the initial impacts of oil price changes differ widely across different countries, with oil importers benefiting from the fall in oil prices (once demand conditions are controlled for) and oil exporters losing from the price fall.

The recent plunge in oil prices has, however, brought into question the generally accepted view that lower oil prices are good for the US and the global economy. It has been argued that near-zero interest rates in most industrialized economies, and the fact that the US has started to export crude oil again, have altered the traditional channels through which the benefit of lower oil prices gets transmitted to the real economy (Obstfeld et al. 2016). Moreover, it has been suggested that the positive correlation between oil prices and equity markets in the past few years provides evidence of a slowdown in global economic activity, as a softening of global aggregate demand has reduced firms' profits and demand for oil (Bernanke 2016). Therefore, it is argued that the decline in oil prices this time around is not good news for the US economy, and by implication for the rest of the industrialized global economy.

But the overall net outcome for the global economy is far more complicated and depends on domestic political economy considerations and the feedback effects of oil price changes on global energy demand, interest rates, financial markets, and world trade. It is worth noting that much of the literature on oil and the macroeconomy does not use a multi-country framework, and instead uses a single-country VAR model, as representing the global economy. The majority of such studies in fact consider the effects of oil shocks exclusively on the United States, with the analysis being done mainly in isolation from the rest of the world. See, for instance, Kilian (2009). Unfortunately, these single-country models not only fail to take account of economic interlinkages and spillovers that exist between different regions, but more importantly their single-country framework does not allow them to consider heterogeneities across and within oil importers and exporters, which are arguably essential to analyzing the global oil market.

Given that there are many channels through which oil prices can affect economic activity (both real and financial) in the US and elsewhere, one could for instance use the Global Vector Autoregressive (GVAR) modelling approach to capture the complicated patterns of global economic interactions; taking into account not only the direct exposure of countries to the shocks but also the indirect effects through secondary or tertiary channels. The GVAR is a multi-country framework which links country-specific models in a coherent manner using time series and panel data techniques and has been used in bank stress testing, the analysis of China's emergence on the rest of world economy, international transmission of real and financial shocks, and forecasting (see, for instance, Chudik and Pesaran 2016). To this end, we use the GVAR-Oil model developed in Mohaddes and Pesaran (2016), estimated using quarterly data between 1979Q2 and 2013Q1, and investigate the effects that a negative short-term oil price fall has on the US and the rest of the world economy. We find that the fall in oil prices tends to lower interest rates and inflation in most countries, and increase global real equity prices, with these effects showing up relatively quickly, typically within two quarters. However, the positive real output effects, both at the global level and at the country levels, take longer to materialize following an oil price fall, with the positive median impulse responses generally manifesting themselves in the medium-term, around four quarters after a negative oil price shock.

To investigate whether there has been a change in the macroeconomic effects of recent falls in oil prices, we need to consider the output-oil price relationship over a number of sub-periods, including the recent post-2008 episode of oil boom and bust. Unfortunately, however, quarterly macro time series that exist are not sufficiently long for a reliable analysis of output-oil price relationship over different sub-periods, particularly the post-2008 crisis period. Therefore, it is not possible to use the GVAR-Oil model for this purpose, and an alternative modelling strategy is required. Instead we consider bivariate relationships between oil prices, equity prices, dividends and monthly industrial and manufacturing output, as alternative proxies for real economic activity. Using such monthly observations from the US, we illustrate that there is no stable relationship between real oil prices and equity returns over the last 71 years and so the perverse response of equity markets to oil price changes should not be taken as evidence that lower oil prices are no longer beneficial for the US and the world economy. In fact, using relatively long time series on dividends and oil prices we show that, as in previous episodes of falling oil prices, lower oil prices improve profit opportunities and dividends in the oil importing economies which is overall good for the world economy. This supports the findings from the GVAR-Oil model. However, due to uncertainties over the Brexit negotiations, economic and trade policies under the new US administration, the threat of terrorism, and the surge in financial market volatility (to mention but a few), it is likely that there will be a delay in the materialization of any economic benefits of lower oil prices for the global economy as a whole.

The remainder of this paper is organized as follows. Section 2 outlines a multi-country approach to examine the effects of lower oil prices, namely the GVAR-Oil model, and investigates the global macroeconomic consequences of a fall in oil prices using quarterly data between 1979Q2 and 2013Q1. Section 3 re-examines the effects of low oil prices on the US economy, particularly over the post-2008 period, using monthly regression analysis based on data on oil prices and indicators of market (S&P 500) and real economic activity (proxied by dividends on the S&P 500) over the 1946-2016 period. Finally, Section 4 offers some concluding remarks and argues that the response of oil producers (OPEC and non-OPEC) to price changes this time around differs markedly, mainly due to the US oil supply revolution.

2 Analyzing the oil market using a multi-country model

We use the global quarterly econometric model recently developed in Mohaddes and Pesaran (2016) to investigate the effects of oil price shocks and their transmission in the global economy. This framework is particularly suited to our purposes since it models global oil markets separately from the country-specific vector autoregressive models, by specifying an oil price equation which takes account of global demand conditions as well as oil supply conditions across some of the major oil producing countries. The model of the oil market is then integrated within a compact quarterly model of the global economy comprising 27 countries (see Table 1), with the euro area being treated as a single economy, using a dynamic multi-country framework first advanced by Pesaran et al. (2004), known as the Global VAR (or GVAR for short). This approach allows for an analysis of the international macroeconomic transmission of the effects of *country-specific* shocks, taking into account not only the direct exposure of countries to the shocks but also the indirect effects through secondary and tertiary channels.

Table 1: Countries and Regions in the GVAR-Oil Model

Major Oil Producers	**Other Countries**		
Net Exporters	**Europe**	**Asia Pacific**	**Latin America**
Canada	Euro Area	Australia	Argentina
Indonesia	*Austria*	India	Chile
Iran	*Belgium*	Japan	Peru
Mexico	*Finland*	Korea	
Norway	*France*	Malaysia	
Saudi Arabia	*Germany*	New Zealand	**Rest of the World**
	Italy	Philippines	South Africa
Net Importers	*Netherlands*	Singapore	Turkey
Brazil	*Spain*	Thailand	
China	Sweden		
United Kingdom	Switzerland		
United States			

The individual country-specific models are solved in a global setting where core macroeconomic variables of each economy (real GDP, inflation, real exchange rate, short and long-term interest rates, and oil production) are related to corresponding foreign variables, (also known as "*star*" variables) constructed to match the international trade pattern of the country under consideration. *Star* variables serve as proxies for common unobserved factors and affect the global economy in addition to the set of observed common factors (such as oil prices and global equity prices). Mohaddes and Pesaran (2016) estimate the 27 country-specific VARX* models over the period 1979Q2 to 2013Q1 separately and then combine these with the estimates from the global oil market, which they refer to as the GVAR-Oil model.

There are many advantages to using a multi-country framework. Firstly, the disaggregated nature of the GVAR-Oil model allows one to identify *country-specific* shocks and answer counterfactual questions regarding the possible macroeconomic effects of oil supply disruptions in specific geographical areas on the global economy. This is in contrast to most of the literature that focuses on the identification of *global* supply shocks, rather than shocks to a specific country or region.[1] Secondly, it allows one to deal with inherent heterogeneities that exist across countries, not only at the geopolitical level but also in terms of oil reserves and production capacities, to mention but a few.[2] Thirdly, the model allows one to take into account the economic interlinkages and spillovers that exist between different regions, thereby enabling a study of the global economy in a coherent manner as opposed to undertaking single country-by-country analyses. In this paper we use this multi-country model to investigate the effects of a fall in oil prices on the global economy, both at the country and the aggregate level. But before describing our results, we first provide a short exposition of the GVAR-Oil model.

2.1 The GVAR-Oil model

To simplify the exposition we consider the following simple dynamic oil price equation, but consider more general dynamic specification in the empirical application:

$$\tilde{p}_t^o = c_p + \phi_1 \tilde{p}_{t-1}^o + \alpha_1 y_{t-1} + \beta_1 q_{t-1}^o + u_t^o, \tag{1}$$

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[1] Note that the difficulty in identifying supply and demand shocks in single-country VAR models, has been recognized in the literature. Indeed, the main focus of the literature has been to consider alternative identification schemes in the context of VAR models without a clear consensus. The attempt to identify the *global* shocks has usually been based on a structural VAR approach making use of *a priori* sign restrictions; see, for instance, Baumeister and Peersman (2013), Cashin et al. (2014), Chudik and Fidora (2012), and Kilian (2009). Furthermore, it is unclear how a global supply shock can be motivated considering that changes to oil supplies are region and country specific.

[2] For instance, the BP Statistical Review of World Energy (June 2016) reports that 14% of the total proven oil reserves in the world is located in North America, while more than 47% is located in the Middle East, with significant heterogeneity of production costs between the two regions. See also the discussion in Esfahani et al. (2013, 2014).

where

$$y_t = \sum_{i=1}^{N} w_i y_{it}, \text{ and } q_t^o = \sum_{i=1}^{N} w_i^o q_{it}^o, \tag{2}$$

y_{it} and q_{it}^o are the real income and quantity of oil output of country i at time t, respectively, w_i and w_i^o are the weights attached to country $i's$ real income and oil production in the construction of the world GDP (y_t) and oil supply (q_t^o), $\tilde{p}_t^o$ is the weighted average of country-specific log real oil prices, defined by

$$\tilde{p}_t^o = \sum_{i=1}^{N} \omega_i \tilde{p}_{it}^o, \tag{3}$$

$$\tilde{p}_{it}^o = \ln\left(P_t^o E_{it}/P_{it}\right) = p_t^o + \left(e_{it} - p_{it}\right), \tag{4}$$

P_t^o is the nominal price of oil in US dollar, E_{it} is country i^{th} exchange rate measured by the units of country i^{th} currency in one US dollar, and P_{it} is the general level of prices in country i. u_t^o represents the global oil demand shock to be distinguished from country-specific oil supply shocks defined in the country-specific models (specified below). The above decomposition of country-specific real oil prices into the US dollar price component and the "real" exchange rate component (here defined by $ep_{it} = e_{it} - p_{it}$) is important, since only the US dollar oil price component, p_t^o, can be regarded as weakly exogenous.[3] The real exchange rate component, ep_{it}, is determined endogenously with the other variables in the country-specific models, such as interest rates and real output.

In order to integrate the oil price equation within a multi-country set-up we need to write the oil price equation in terms of p_t^o. To this end using (4) in (3) we first note that $\tilde{p}_t^o = p_t^o + ep_t$, where[4]

$$ep_t = \sum_{i=1}^{N} \omega_i ep_{it}. \tag{5}$$

Using this result the oil price equation can be written as

$$p_t^o + ep_t = c_p + \phi_1\left(p_{t-1}^o + ep_{t-1}\right) + \alpha_1 y_{t-1} + \beta_1 q_{t-1}^o + u_t^o. \tag{6}$$

In the GVAR set-up, the country-specific variables, ep_{it}, y_{it} and q_{it}^o , are determined jointly with the other macro variables. Specifically, we consider the following country-specific models

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[3] We formally test the weak exogeneity assumption and provide the test results in Appendix B.

[4] In the literature, the real oil price is typically computed by deflating the nominal oil price with the US general price index. But as our analysis shows, for global analysis such a procedure is not valid unless the law of one price holds universally, namely if $E_{it}P_{US,t} = P_{it}$ for all i. Only under such stringent conditions it follows that $\tilde{p}_t^o = p_t^o + \sum_{i=1}^{N} \omega_i \ln\left(E_{it}/P_{it}\right) = p_t^o + \sum_{i=1}^{N} \omega_i \ln\left(1/P_{US,t}\right) = p_t^o - p_{US,t}$.

(for $i = 1, 2, ..., N$)

$$\mathbf{x}_{it} = \mathbf{a}_{i0} + \mathbf{a}_{i1}t + \mathbf{\Phi}_i \mathbf{x}_{i,t-1} + \mathbf{\Lambda}_{i0}\mathbf{x}^*_{it} + \mathbf{\Lambda}_{i1}\mathbf{x}^*_{i,t-1} + \mathbf{\Upsilon}_{i0}p^o_t + \mathbf{\Upsilon}_{i1}p^o_{t-1} + \mathbf{u}_{it}, \tag{7}$$

where $\mathbf{a}_{i0}, \mathbf{a}_{i1}, \mathbf{\Phi}_i, \mathbf{\Lambda}_{i0}, \mathbf{\Lambda}_{i1}, \mathbf{\Upsilon}_{i0}$,and $\mathbf{\Upsilon}_{i1}$ are vectors/matrices of fixed coefficients that vary across countries, $\mathbf{x}_{it}$ is $k_i \times 1$ vector of country-specific endogenous variables that include ep_{it}, y_{it}, and q^o_{it} (as applicable), and $\mathbf{x}^*_{it}$ is $k^*_i \times 1$ vector of country-specific weakly exogenous (or 'star') variables. The 'star' variables are constructed using country-specific trade shares, and are defined by

$$\mathbf{x}^*_{it} = \sum_{j=1}^{N} w_{ij}\mathbf{x}_{jt}, \tag{8}$$

where w_{ij}, $i, j = 1, 2, ...N$, are bilateral trade weights, with $w_{ii} = 0$, and $\sum_{j=1}^{N} w_{ij} = 1$.[5]

In our application each country-specific model has a maximum of six endogenous variables. Using the same terminology as in equation (7), the $k_i \times 1$ vector of country-specific endogenous variables is defined as $\mathbf{x}_{it} = \left(q^o_{it},\ y_{it},\ \pi_{it},\ ep_{it},\ r^S_{it},\ r^L_{it},\ \right)'$, where q^o_{it} is the log of oil production at time t for country i, y_{it} is the log of real Gross Domestic Product, π_{it} is the rate of inflation, ep_{it} is the log deflated exchange rate, and r^S_{it} $\left(r^L_{it}\right)$ is the short (long) term interest rate, if country i is a major oil producer, otherwise $\mathbf{x}_{it} = \left(y_{it},\ \pi_{it},\ ep_{it},\ r^S_{it},\ r^L_{it},\ \right)'$.[6] The model for the US differs from the rest in two respects: given the importance of US financial variables in the global economy, the log of world real equity prices, eq_t, is included in the US model as an endogenous variable, and as weakly exogenous in the other country models ($eq^*_{it} = eq_t$), whilst US dollar exchange rates are included as endogenous variables in all models except for the United States. The endogenous variables of the US model are therefore given by $\mathbf{x}_{US,t} = \left(eq_t,\ q^o_{US,t},\ y_{US,t},\ \pi_{US,t},\ r^S_{US,t},\ r^L_{US,t}\ \right)'$.

In the case of all countries, except for the US and the euro area, the foreign variables included in the country-specific models, computed as in equation (8), are given by $\mathbf{x}^*_{it} = \left(eq^*_{it},\ y^*_{it},\ \pi^*_{it},\ ep^*_{it},\ r^{*S}_{it},\ r^{*L}_{it}\right)'$. The trade weights are computed as three-year averages over 2007–2009.[7] We excluded the foreign inflation variable, $\pi^*_{EA,t}$, from the euro model since, based on some preliminary tests, we could not maintain that $\pi^*_{EA,t}$ is weakly exogenous.

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[5] The main justification for using bilateral trade weights, as opposed to financial weights for instance, is that the former have been shown to be the most important determinant of national business cycle comovements. See Baxter and Kouparitsas (2005), among others. See also, for instance, Cashin et al. (2017b) who demonstrate that the choice of weights is of second-order importance when the underlying variables are sufficiently correlated, and that using trade, financial, or mixed weights produces very similar results.

[6] Note that long-term interest rates are not available for all countries, and short-term and long-term interest rates are not available in the case of Iran and Saudi Arabia.

[7] A similar approach has also been followed in the case of Global VAR models estimated in the literature. See, for example, Dees et al. (2007) and Cashin et al. (2017a, 2017b).

Also, given the pivotal role played by the US in global financial markets, we excluded the foreign interest rates, $r^{*S}_{US,t}$ and $r^{*L}_{US,t}$, from the US model. The exclusion of these variables from the US model was also supported by preliminary test results showing that $r^{*S}_{US,t}$ and $r^{*L}_{US,t}$ cannot be assumed to be weakly exogenous when included in the US model. A similar result was found when the foreign inflation variable, $\pi^{*}_{US,t}$, was included in the US model. In short, the US model includes only two foreign variables, namely $\mathbf{x}^{*}_{US,t} = (y^{*}_{US,t},\ ep^{*}_{US,t})'$, where $ep^{*}_{US,t} = \sum_{j=1}^{N} w_{USA,j}(e_{jt} - p_{jt})$, $w_{USA,j}$ is the share of US trade with country j, e_{jt} is the log of US dollar exchange rate with respect to the currency of country j, and p_{jt} is the log CPI price index of country j.

The country-specific VARX* models in (7) are combined with the oil price equation, (6), and solved simultaneously for all the endogenous variables collected in the vector, $\mathbf{z}_t = (p^o_t, \mathbf{x}'_{1t}, \mathbf{x}'_{2t}, ..., \mathbf{x}'_{Nt})' = (p^o_t, \mathbf{x}'_t)'$. This combined model is referred to as the GVAR-Oil model, which allows for a two-way linkage between the global economy and oil prices. Changes in the global economic conditions and oil supplies affect oil prices with a lag, with oil prices potentially influencing all country-specific variables. Similarly, changes in oil supplies, determined in country models for the major oil producers, are affected by oil prices and in turn affect oil prices with a lag as specified in the oil price equation, (6).

Although estimation is carried out on a country-by-country basis, the GVAR model is solved for oil prices and all country variables simultaneously, taking account of the fact that all variables are endogenous to the system as a whole. To solve for the endogenous variables, $\mathbf{z}_t$, using (8) we first note that $\mathbf{x}^{*}_{it} = \mathbf{W}_i\mathbf{x}_t$, where $\mathbf{W}_i$ is a $k^*_i \times (k+1)$, matrix of fixed constants (which are either 0 or 1 or some pre-specified weights, w_{ij}), $k = \sum_{i=1}^{N} k_i$, $k^*_i = \dim(\mathbf{x}^*_{it})$. Stacking the country-specific models we now have

$$\mathbf{x}_t = \boldsymbol{\varphi}_t + \boldsymbol{\Phi}\mathbf{x}_{t-1} + \mathbf{H}_0\mathbf{x}_t + \mathbf{H}_1\mathbf{x}_{t-1} + \boldsymbol{\Upsilon}_0 p^o_t + \boldsymbol{\Upsilon}_1 p^o_{t-1} + \mathbf{u}_t,$$

where

$$\boldsymbol{\Phi} = \begin{pmatrix} \boldsymbol{\Phi}_1 & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \boldsymbol{\Phi}_2 & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \boldsymbol{\Phi}_N \end{pmatrix}, \ \mathbf{H}_0 = \begin{pmatrix} \boldsymbol{\Lambda}_{10}\mathbf{W}_1 \\ \boldsymbol{\Lambda}_{20}\mathbf{W}_2 \\ \vdots \\ \boldsymbol{\Lambda}_{N0}\mathbf{W}_N \end{pmatrix}, \ \mathbf{H}_1 = \begin{pmatrix} \boldsymbol{\Lambda}_{11}\mathbf{W}_1 \\ \boldsymbol{\Lambda}_{21}\mathbf{W}_2 \\ \vdots \\ \boldsymbol{\Lambda}_{N1}\mathbf{W}_N \end{pmatrix},$$

$$\boldsymbol{\varphi}_t = \begin{pmatrix} \mathbf{a}_{10} + \mathbf{a}_{11}t \\ \mathbf{a}_{20} + \mathbf{a}_{21}t \\ \vdots \\ \mathbf{a}_{N0} + \mathbf{a}_{N1}t \end{pmatrix}, \ \boldsymbol{\Upsilon}_0 = \begin{pmatrix} \boldsymbol{\Upsilon}_{10} \\ \boldsymbol{\Upsilon}_{20} \\ \vdots \\ \boldsymbol{\Upsilon}_{N0} \end{pmatrix}, \ \boldsymbol{\Upsilon}_1 = \begin{pmatrix} \boldsymbol{\Upsilon}_{11} \\ \boldsymbol{\Upsilon}_{21} \\ \vdots \\ \boldsymbol{\Upsilon}_{N1} \end{pmatrix}, \ \mathbf{u}_t = \begin{pmatrix} \mathbf{u}_{1t} \\ \mathbf{u}_{2t} \\ \vdots \\ \mathbf{u}_{Nt} \end{pmatrix}.$$

We also note that the oil price equation (6) can be written as

$$p_t^o + \mathbf{w}_{ep}'\mathbf{x}_t = c_p + \phi_1 \left(p_{t-1}^o + \mathbf{w}_{ep}'\mathbf{x}_{t-1}\right) + \left(\alpha_1 \mathbf{w}_y' + \beta_1 \mathbf{w}_q'\right)\mathbf{x}_{t-1} + u_t^o,$$

where $\mathbf{w}_{ep}$, $\mathbf{w}_y$ and $\mathbf{w}_q$ are $k \times 1$ vectors whose elements are either zero or are set equal to the weights w_i or w_i^0, assigned to ep_{it}, y_{it} or q_{it}^o, as implied by (5) and (2), respectively. Combining the above oil price equation with the country-specific models we obtain

$$\begin{pmatrix} 1 & \mathbf{w}_{ep}' \\ -\boldsymbol{\Upsilon}_0 & \mathbf{I}_k - \mathbf{H}_0 \end{pmatrix} \begin{pmatrix} p_t^o \\ \mathbf{x}_t \end{pmatrix} = \begin{pmatrix} c_p \\ \boldsymbol{\varphi}_t \end{pmatrix} + \begin{pmatrix} \phi_1 & \phi_1 \mathbf{w}_{ep}' + \alpha_1 \mathbf{w}_y' + \beta_1 \mathbf{w}_q' \\ \boldsymbol{\Upsilon}_1 & \boldsymbol{\Phi} + \mathbf{H}_1 \end{pmatrix} \begin{pmatrix} p_{t-1}^o \\ \mathbf{x}_{t-1} \end{pmatrix} + \begin{pmatrix} u_t^o \\ \mathbf{u}_t \end{pmatrix}, \tag{9}$$

which can be written more compactly as

$$\mathbf{G}_0 \mathbf{z}_t = \mathbf{b}_t + \mathbf{G}_1 \mathbf{z}_{t-1} + \mathbf{v}_t.$$

Under the assumption that $\mathbf{I}_k - \mathbf{H}_0$ is invertible the GVAR-Oil model has the following reduced form solution

$$\mathbf{z}_t = \mathbf{a}_t + \mathbf{F}\mathbf{z}_{t-1} + \boldsymbol{\xi}_t, \tag{10}$$

where $\mathbf{a}_t = \mathbf{G}_0^{-1}\mathbf{b}_t$, $\mathbf{F} = \mathbf{G}_0^{-1}\mathbf{G}_1$, and $\boldsymbol{\xi}_t = \mathbf{G}_0^{-1}\mathbf{v}_t$.

2.2 Effects of a fall in oil prices

We use the GVAR-Oil model to examine the direct and indirect effects of negative oil price shocks on the world economy, on a country-by-country basis, and provide the time profile of the effects on real outputs across countries, interest rates, inflation and real global equity prices. As explained earlier, the modelling approach is based on that in Mohaddes and Pesaran (2016), where country-specific estimates and associated diagnostic tests can be found.[8]

Figure 2 displays the plots of generalized impulse responses for the effects of a negative short-term oil price shock on global real equity prices, long-term interest rates, as well as real output (based on PPP-GDP weighted responses of the 27 countries in our sample). It can be seen that negative oil price changes tend to increase real equity prices and reduce interest rates. The same pattern is also evident when considering the country-by-country impulse

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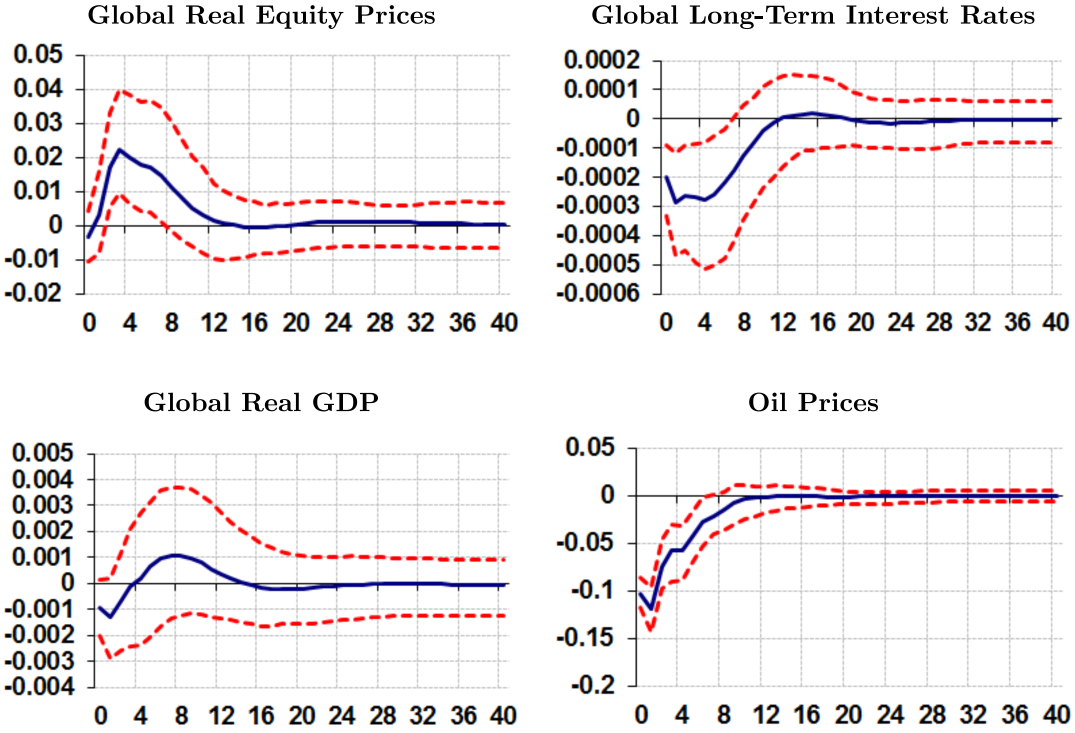
[8] In particular, see Section 4.1 of Mohaddes and Pesaran (2016) for the estimates of the oil price equation and Section 4.2 for estimates of the country-specific VARX* models including discussions about lag order selection, cointegrating relations, and persistence profiles. Evidence for the weak exogeneity assumption of the foreign variables and discussion of the issue of structural breaks in the context of the GVAR-Oil model is given in Appendix B of Mohaddes and Pesaran (2016). Finally, for various data sources used to build the quarterly dataset, covering 1979Q2 to 2013Q1, and for the construction of the variables see Appendix A.

responses. In particular, Figure 3 illustrates the fall in long-term interest rates across the major economies in the world following an oil price decline.[9] We also find strong disinflation pressures in all major (net) oil importers (see Figure 4). These results are as expected, and are in line with those reported in the literature. See, for instance, Dees et al. (2007).

Figure 2: Effects of Lower Oil Prices on Global Real Equity Prices, Long-Term Interest Rates, and Real GDP



Notes: Figures show median impulse responses to a one-standard-deviation decrease in oil prices, with 95 percent bootstrapped confidence bounds. The horizon is quarterly.

While the responses of global equity prices, long-term interest rates and inflation show up relatively quickly and within a few quarters, the effects of oil price changes on real output, both at individual country levels and globally, take longer to manifest themselves. More specifically, the impulse responses for global GDP following an oil price fall is positive in the medium-term (Figure 2), which is also the case for the individual country responses in Figure 5, although being statistically insignificant in most cases. Thus the empirical evidence based on the GVAR-Oil model (and the general shape of the impulse responses) supports the view

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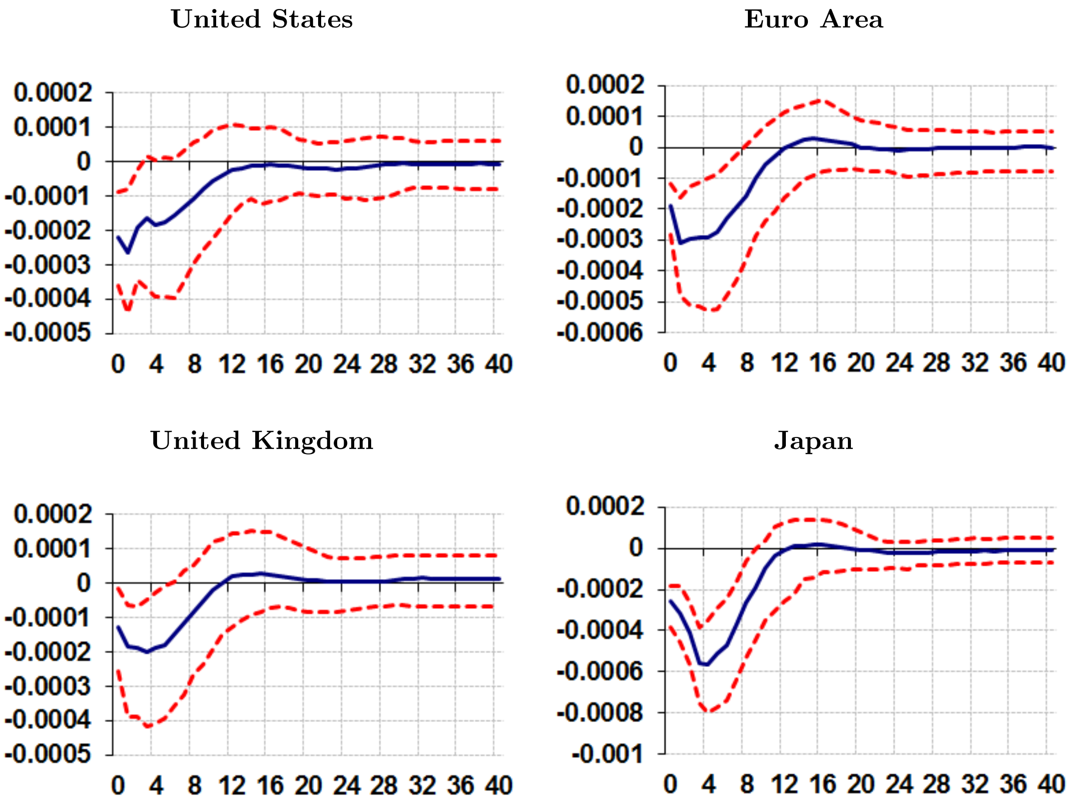
[9] The results for the other countries in our sample, listed in Table 1, are not reported here, but are available on request.

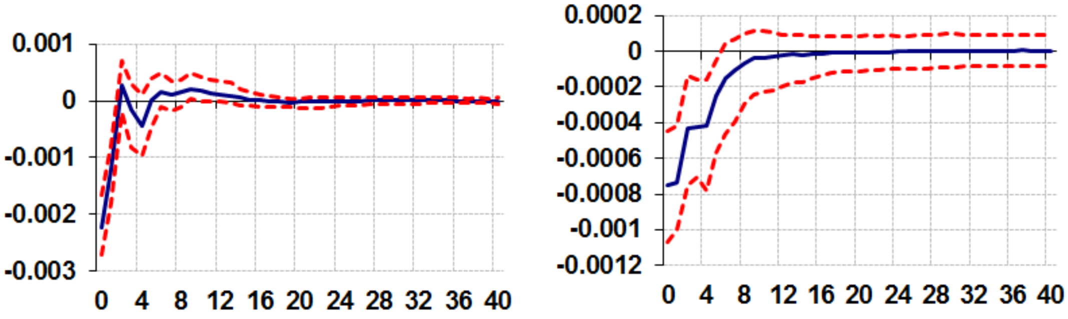
Figure 3: Effects of Lower Oil Prices on Long-Term Interest Rates in Various Countries



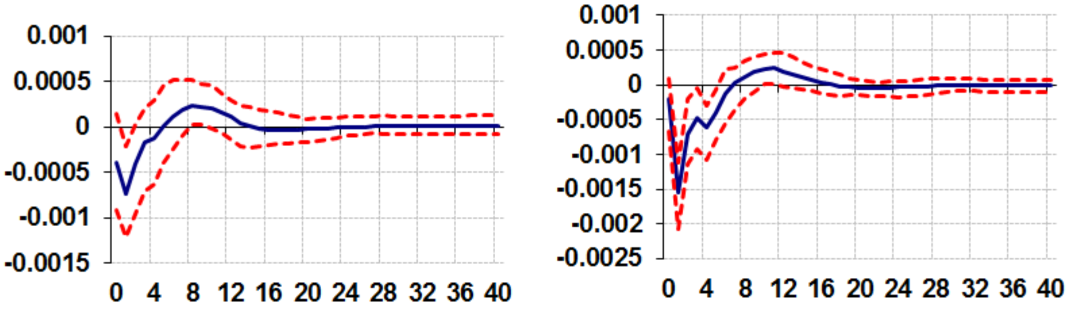
Notes: Figures show median impulse responses to a one-standard-deviation decrease in oil prices, with 95 percent bootstrapped confidence bounds. The horizon is quarterly.

that an oil price fall is good news for the US, the other major economies, as well as for the global economy.

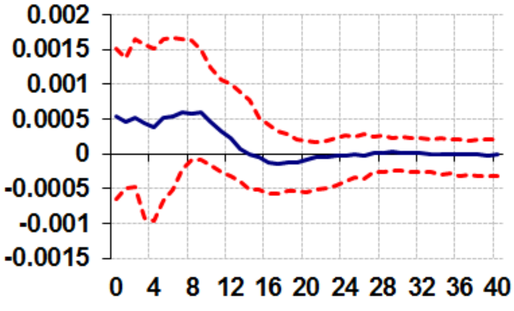
Figure 4: Effects of Lower Oil Prices on Inflation in Various Countries



United States Euro Area



United Kingdom Japan

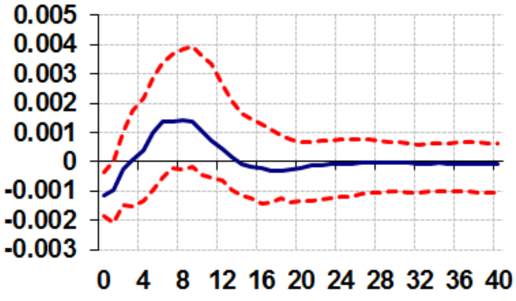


China

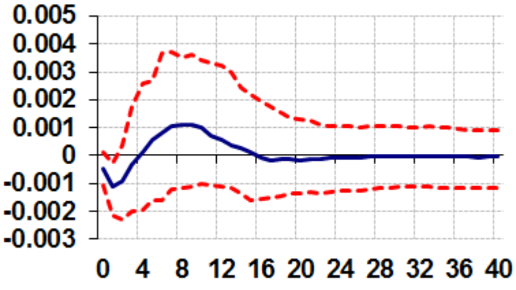
Notes: Figures show median impulse responses to a one-standard-deviation decrease in oil prices, with 95 percent bootstrapped confidence bounds. The horizon is quarterly.

Figure 5: Effects of Lower Oil Prices on Real GDP in Various Countries

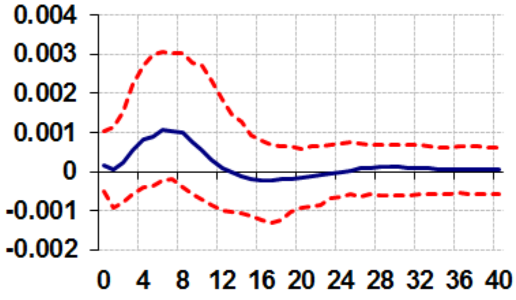
United States



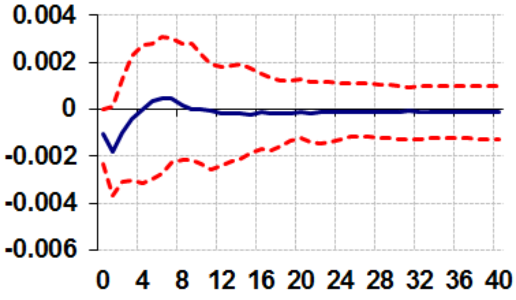
Euro Area



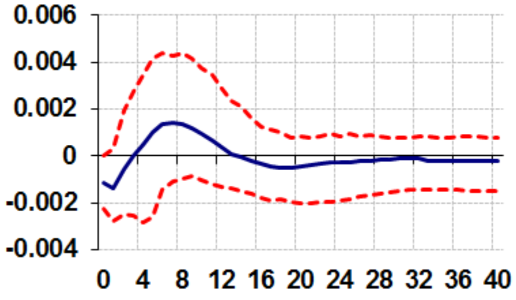
United Kingdom



Japan



China

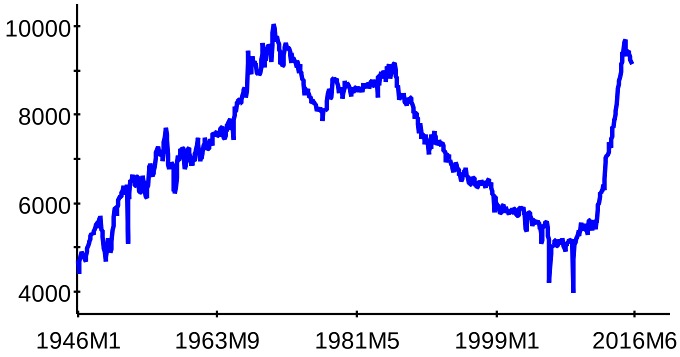


Notes: Figures show median impulse responses to a one-standard-deviation decrease in oil prices, with 95 percent bootstrapped confidence bounds. The horizon is quarterly.

3 Analyzing oil price changes using monthly data

In what follows we shall mainly focus on the effects of lower oil prices on the US economy for three reasons. Firstly, the US economy has not been dependent on oil imports as much as other industrialized economies, with oil production having first peaked in 1971 (before the shale oil revolution). In fact, the US started to export crude oil in January 2016 after a 40-year ban. Secondly, thanks to advances in hydraulic fracturing and directional drilling, oil production has significantly expanded in the US over the past 10 years (see Figure 6). US oil production has risen from 5 million barrels per day (b/d) in January 2008 to 9.2 million b/d in January 2016, around 84% increase. Thirdly, the US oil and gas sector attracted significant investment over the past decade, including small firms issuing large amounts of debt (estimated over $350 billion just between 2010 and 2014). As a result, the losses for US investors in equity and bond markets have been substantial following the recent fall in oil prices, with valuations of US energy companies falling dramatically and the number of gas and oil companies in the US filing for bankruptcy soaring, which could have indirect effects on the US economy through secondary or tertiary channels. It is, therefore, important to re-examine the effects of low oil prices on the US economy, particularly over the post-2008 period. To this end we examine the relationship between oil prices and the stock market indicator (proxied by S&P 500) and real economic activity (proxied by dividends on the S&P 500) using monthly data from 1946 to 2016.

Figure 6: US Monthly Oil Production (1000 barrels/day)

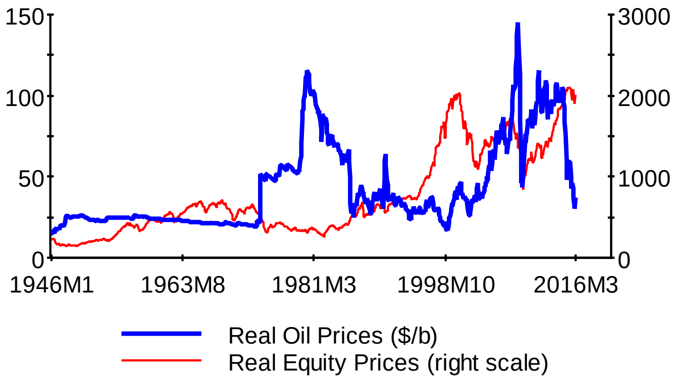


Data sources: United States Energy Information Administration (EIA).

3.1 Has the relationship between real oil and equity prices been stable over time?

Figure 7 shows the monthly evolution of real oil prices, in 2015 US dollars per barrel, and US real equity prices, as measured by the S&P 500 index. The figure clearly shows that taking a relatively long historical perspective (1946-2016), there seems little evidence of a stable relationship between oil prices and real equity prices. Moreover, Table 2 illustrates that there are sub-periods where changes in real oil prices and real equity prices are unrelated, as well as sub-periods over which they are negatively and positively correlated. However, over the full sample the simple correlation coefficient between the two variables is not statistically significant.

Figure 7: Real Oil Prices and Real US Equity Prices (S&P 500), 1946M1-2016M3



Data sources: Robert Shiller's online database, Federal Reserve Economic Data (FRED), and United States Energy Information Administration (EIA).

To conduct a more robust statistical analysis we use rolling regressions of the rate of change of real equity prices on the rate of change of real oil prices, estimated using a 10-year rolling window, and then plot the estimates of the coefficient of the rate of change of real oil prices (blue solid) and its two standard error bands (red dashed) in Figure 8. This figure shows that the coefficients were not statistically different from zero before 1990, became negative in 1991 and initially falling (being statistically significant from 1991 to 2001), and then eventually rising and becoming positive since the 2008 financial crisis (being statistically significant from 2012 onwards).[10] It is then perhaps not surprising that there is no consensus

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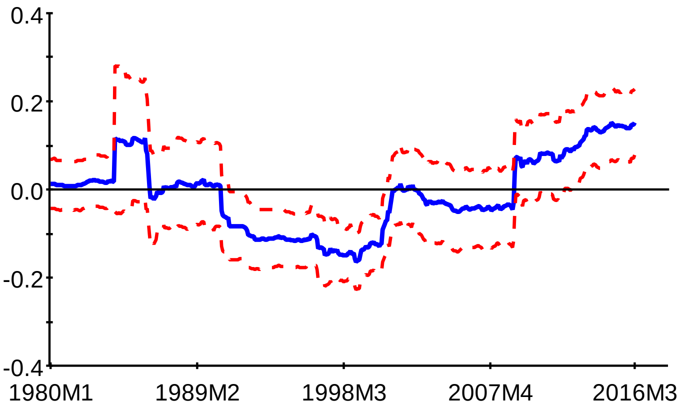
[10] We illustrate the robustness of the rolling window estimates to the size of the window in Appendix C.

Table 2: Correlations between Changes in Real Oil Prices, Equity Prices and Dividends

Period	**Real Oil and Equity Prices**	**Real Oil Prices and Dividends**
Full Period		
1946M2–2016M3	0.008 (0.035)	**-0.105** (0.034)
Sub-Periods		
1960M1–1980M12	0.018 (0.063)	-0.071 (0.063)
1981M1–2000M12	**-0.139** (0.064)	**-0.163** (0.064)
2001M1–2016M3	**0.199** (0.073)	**-0.252** (0.072)
Sub-Sub-Periods		
2001M1–2007M12	-0.144 (0.109)	-0.088 (0.110)
2008M1–2016M3	**0.404** (0.093)	**-0.329** (0.096)

Notes: A bold correlation highlights significance, with standard errors in parentheses.
Data sources: Robert Shiller's online database, Federal Reserve Economic Data (FRED), and United States Energy Information Administration (EIA).

Figure 8: Rolling Estimates of the Effects of Changes in Oil Prices on Equity Prices



Notes: Rolling estimates of the coefficient of the rate of change of real oil prices and its two standard error bands. Dependant variable is the rate of change of real US equity prices (S&P 500). The window size is 120 months.
Data sources: Robert Shiller's online database, Federal Reserve Economic Data (FRED), and United States Energy Information Administration (EIA).

in the literature on the relationship between oil and equity prices (see, for instance, Jones and Kaul 1996, Sadorsky 1999, and Wei 2003).[11]

As Table 2 and Figure 7 show, a significantly positive relationship between oil and equity prices has emerged since the global financial crisis in 2008, which has been discussed extensively by the media as well as by prominent economists (see Bernanke's blog at Brookings on February 2016 and Obstfeld et al.'s IMF blog on March 2016) over the last few months. The question is why is this the case? There could be a number of reasons. Firstly, while markets are generally efficient and therefore equity prices reflect the fundamentals, there are also episodes when real equity prices do not reflect the state of the economy. In such periods any evidence of a perverse relationship between real equity and oil prices could be due to the disconnect between equity markets and economic fundamentals and not necessarily any breaks in the relationship between oil prices and the real economy. Secondly, Sovereign Wealth Funds (SWFs) accumulated large assets during the most recent oil boom (2002-2008) and they have come to play a major role in reserve management of oil revenues.[12] The prominent examples are Norway's Government Pension Fund ($830), Abu Dhabi Investment Authority ($773), Saudi Arabia's Fund (SAMA) ($685), Kuwait Investment Authority ($592), and Qatar Investment Authority ($256), with the number in brackets referring to their market values in billions in June 2015. On average 65% of SWF assets are held in public and private equities (61% Norway; 72% SAMA; 65% Kuwait; 68% Qatar; 62% Abu Dhabi–figures based on 2014). During periods of rising oil prices, these funds are topped up with equity purchases. However, when oil prices are falling most major oil exporters withdraw money from the funds in order to maintain, for instance, their welfare expenditure. The equity transactions of SWFs in turn induce an unintended positive correlation between oil and equity prices. Whilst it is true that such effects might not be that large, they could trigger larger effects due to known market over-reactions.

Overall, the empirical evidence suggests that the relationship between real oil and stock prices is not stable over time. As such, the recent perverse relationship between equity returns and oil price changes should not be taken as evidence that lower oil prices are bad for the real economy.

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[11] The literature has also recently attempted to investigate the differential effects of oil demand and supply shocks on real and financial variables. For instance, Kilian and Park (2009) argue that oil supply shocks are much less important than demand shocks in understanding the evolution of stock prices in the US, while Kang et al. (2016) argue that both shocks are of comparable importance when it comes to explaining US real stock returns.

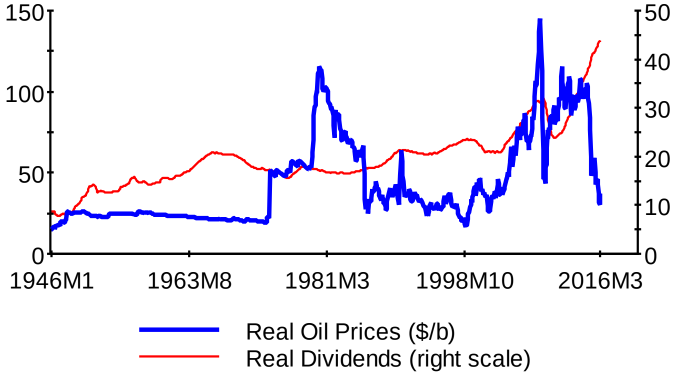
[12] For the role of SWFs in reserve management of commodity revenues in general, as well as their contribution to macroeconomic stabilization in resource-rich countries, see also Mohaddes and Raissi (2017).

3.2 Are lower oil prices beneficial for the US and the world economy?

Ideally we need to consider how oil prices and real activity are related (as opposed to equity markets). However, quarterly GDP series that exist are not sufficiently long for a reliable analysis of output-oil price relationship over different sub-periods, particularly the post-2008 crisis period. Also, unfortunately, there are no reliable monthly observations on aggregate real activity. While a number of investigators have used monthly measures of US manufacturing output, this is not sufficiently representative of an economy such as that of the US.

Instead we use real dividends on S&P 500 as a proxy for economic activity. The rationale is that if the demand for companies' products does not rise and they do not experience growth they cannot make profits, and if they do not have enough profits they could not pay dividends. While it is true that some companies strategically pay dividends even if their profitability is low, this can only be sustained in the short run (say one or two years). In the long run these companies need to be profitable in order to be able to continue paying out dividends. In other words, there has to be a relationship between real dividends and the state of the economy in the long run.

Figure 9: Real Oil Prices and Real Dividends (S&P 500), 1946M1-2016M3

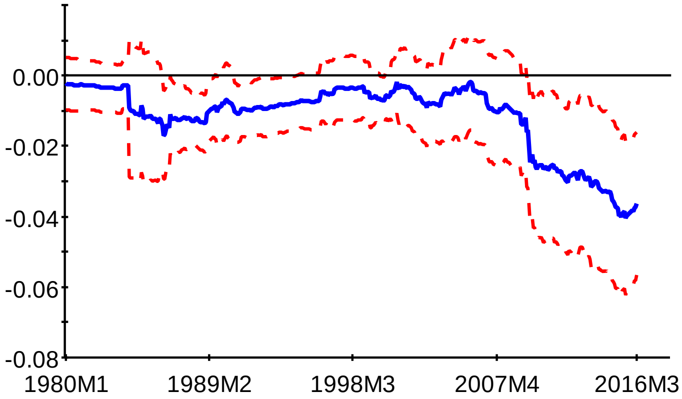


Data sources: Robert Shiller's online database, Federal Reserve Economic Data (FRED), and United States Energy Information Administration (EIA).

Figure 9 shows the relationship between real oil prices and real dividends on the S&P 500 over the last 71 years, from which we observe that generally lower (higher) oil prices have been associated with higher (lower) dividends. The last column of Table 2 reports the simple correlation between changes in real oil prices and dividends, clearly showing a negative relationship between them over all sub-periods. More specifically the relationships are statistically significant for the full sample (1946 to 2016), as well as the two sub-samples, 1981–2000 and 2011–2016, but not for the sub-period 1960–1980. More importantly we find that changes in real oil prices are negatively related to changes in real dividends over the post-2008 crisis period, a relationship which is also statistically highly significant.

Using a relatively long monthly time series data on dividends and oil prices (1970–2016) we estimate rolling regressions (with 10-year windows) of the rate of change of real dividends on the rate of change of real oil prices, and plot the estimated coefficients of the rate of change of real oil prices (blue solid) and their two standard error bands (red dashed) in Figure 10. As can be seen the rolling estimates of the coefficient of real oil price changes on dividends have been negative over the whole sample period, being statistically significant for most of the period. Interestingly enough, the beneficial effects of lower oil prices on dividends have become even stronger over the more recent periods, with the rolling estimates becoming particularly large and statistically significant post-2009.[13]

Figure 10: Rolling Estimates of the Effects of Changes in Oil Prices on Real Dividends



Notes: Rolling estimates of the coefficient of the rate of change of real oil prices and its two standard error bands based. Dependant variable is the rate of change of real dividends (S&P 500). The window size is 120 months.
Data sources: Robert Shiller's online database, Federal Reserve Economic Data (FRED), and United States Energy Information Administration (EIA).

The rolling estimates give a clear indication of the changing nature of the relationships between oil prices, equity prices, and dividends, but do not allow for changing dynamics

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[13] Note that these results are robust to the size of the window, see Appendix C.

between these variables. Therefore, to check the robustness of the results to the dynamics of adjustments between oil price changes and the economy, we also estimated autoregressive distributed lag (ARDL) models, one with the rate of change of real equity and oil prices and another with the rate of change of real dividends and oil prices.[14] Instead of rolling windows we estimated the ARDL models on the full sample period (1970M1 to 2016M4) and three sub-samples, namely 1970M1–1989M12, 1990M1–2007M12, and 2008M1–2016M4. We selected the lag order of the ARDL regressions with equity prices using the Akaike Information Criterion (AIC) with a maximum lag order set to 12.

The estimates of the long-run coefficient of real oil prices on real equity prices are reported in panel (a) of Table 3, from which we can see that the coefficients are negative and statistically significant for the full sample and in the two sub-samples, 1970–1989 and 1990–2007, but the long-run estimate is positive and statistically significant for the 2008–2016 sub-sample. This provides further evidence that the relationship between these two variables are not stable, and matches the results in Section 3.1 and Figure 8.

The estimates of the ARDL regressions with real dividends and real oil prices, are summarized in panel (b) of Table 3. As can be seen, the estimated coefficient of the oil price variable on the real dividend variable is negative and statistically significant in all sub-samples even in the post-2008 period.[15] These results are in line with those using simple correlations in Table 2 and rolling estimates in Figure 10, and therefore suggest that lower oil prices have been good for the US economy, even if we only consider the period after the Great Recession.

For completeness, we also considered other measures of monthly economic activity, namely US industrial production and manufacturing indices, which are widely used in empirical work with monthly data. As before we estimated ARDL models over the full sample and the three sub-samples, now between the oil price variable and these two new measures of economic activity. The results for the ARDL models with industrial production are reported in panel (c) and for the ones with manufacturing production in panel (d) of Table 3. The coefficient of the oil price variable is negative in all sample periods and for both activity measures, but they are statistically significant only for the full sample and the first sub-sample, 1970M1–1989M12, thus supporting the results provided in panel (b) of Table 3.

To summarize, unlike the relationship between equity and oil prices, we find a stable

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[14] In a series of papers, Pesaran and Smith (1995), Pesaran (1997), and Pesaran, Shin, and Smith (1999) show that the traditional ARDL approach can be used for long-run analysis, and that the ARDL methodology is valid regardless of whether the regressors are exogenous, or endogenous, and irrespective of whether the underlying variables are $I(0)$ or $I(1)$. See also the discussion in Chudik et al. (2016, 2017)

[15] In the case of the ARDL models with real dividends, we initially selected the lag orders using the AIC, however, given the smoothness of the real dividend series and given that AIC selected a large number of lags, the estimates were not reliable. We therefore based the lag order selection on the Schwarz Bayesian Criterion.

Table 3: Estimates of the Long-run Coefficients of Real Oil Prices based on Various ARDL Regressions and Sub-samples, 1970M1–2016M4

	1970M1–2016M4	1970M1–1989M12	1990M1–2007M12	2008M1–2016M4
(a) ARDL Model with Real Equity Prices				
Oil Price Coefficient	-0.159^{**}	-0.176^{*}	-0.185^{***}	0.202^{*}
	(0.073)	(0.100)	(0.039)	(0.118)
ARDL Order	$(6, 12)$	$(2, 12)$	$(1, 1)$	$(4, 4)$
(b) ARDL Model with Real Dividends				
Oil Price Coefficient	-0.016	-0.046^{***}	-0.092^{**}	-0.111^{**}
	(0.017)	(0.014)	(0.043)	(0.048)
ARDL Order	$(1, 3)$	$(2, 1)$	$(5, 0)$	$(1, 0)$
(c) ARDL Model with Industrial Production				
Oil Price Coefficient	-0.053^{**}	-0.084^{***}	-0.019	-0.098
	(0.025)	(0.029)	(0.014)	(0.075)
ARDL Order	$(12, 11)$	$(2, 11)$	$(3, 3)$	$(12, 10)$
(d) ARDL Model with Manufacturing Production				
Oil Price Coefficient	-0.075^{***}	-0.116^{***}	-0.022	-0.067
	(0.027)	(0.036)	(0.017)	(0.063)
ARDL Order	(3,11)	$(2, 11)$	(3,3)	(12,8)

Notes: Symbols ***, **, and * denote significance at 1%, 5%, and 10% levels, respectively. The lag order of the ARDL regressions with real equity prices, industrial and manufacturing production indices were selected using the Akaike Information Criterion with a maximum lag order set to 12. For the ARDL models with real dividends the lag order was selected using the Schwarz Bayesian Criterion; see also footnote 15.
Data sources: Robert Shiller's online database, Federal Reserve Economic Data (FRED), and United States Energy Information Administration (EIA).

negative relationship between oil prices, dividends and monthly real activity measures such as industrial production, which supports the results from the GVAR-Oil model (see Figure 5), and does not support the view that lower oil prices have not been good for the US economy since the 2008 financial crisis.

Nevertheless, the fall in oil prices has hit the major oil exporters the hardest given that almost all of them substantially expanded their welfare programs during the period of unusually high oil prices that preceded the current price falls. For instance, post-2011, the Gulf Cooperation Council (GCC) countries increased their social spending by around $150 billion. Saudi Arabia increased government employees pay and benefits by $93 billion and similar increases in welfare were put into effect by other GCC countries (Bahrain, Kuwait, Oman, Qatar, and the UAE); see, for instance, Abdel Ghafar (2016) and Devarajan (2016). In Iran, despite the sanctions and the threat of more sanctions, the Ahmadinejad government initiated monthly cash payments to all households irrespective of their income or wealth, and raided the oil stabilization fund (rather than enhancing it) to partly pay for the program; see Mohaddes and Pesaran (2014). It is not surprising therefore that the fall in oil prices has forced oil exporters to cut back on their welfare programs, withdraw from their oil funds, and attempt to diversify their economies.

At the world level, however, we would expect the increase in spending by oil importers to exceed the decline in expenditure by oil exporters (given their different marginal propensities to consume/invest), and so eventually lower oil prices should also be beneficial for the world economy. This was also clearly illustrated within the GVAR-Oil framework in Section 2.2; see, in particular, the responses of global and country level GDPs following a fall in oil prices in Figures 2 and 5. This in turn implies that demand for energy is going to start to rise, which will put upward pressure on oil prices in the medium term, and the equilibrating process starts to take place.

4 Concluding remarks

As with all markets, lower oil prices will eventually lead to higher demand and lower supplies. The beneficial income effects of lower oil prices will show up in higher oil demand by oil importers including the US, while the loss of revenues by oil exporters will act in the opposite direction, but the net effect is likely to be positive. On the supply side, the response to price changes is likely to differ markedly across major oil producers. Non-OPEC producers, particularly US oil producers, tend to respond reasonably quickly and positively (negatively) to oil price rises (falls). As noted earlier, US production had been rising since 2008, but peaked around April 2015 (at 9.45 million b/d) and since then, with continued low oil prices, has fallen to 8.45 million b/d in the first week of October 2016 (see Figure 6). This large fall in oil production is mainly due to the fact that unconventional oil (which now forms around half of US oil output) tends to respond to oil price changes very much like any other manufacturing process. In fact, since mid-2014 the number of US oil and gas companies that have filed for bankruptcy has risen substantially and is soon expected to overtake the 68 bankruptcies that were filed at the peak of the dot-com bust in 2002-2003 (see Reuters on 4 May, 2016). Moreover, the European Central Bank (2016) recently estimated that energy related investments in the United States have fallen by 65% cumulatively since mid-2014, with the energy sector contribution to GDP growth in the US being overall negative.

In contrast to the US, oil production from OPEC is likely to be less responsive to price changes, with political factors playing a significant role in the process. It has long been argued, dating back to the first oil crisis of 1973/74, that major oil exporters that heavily depend on oil revenues, set their oil production to achieve a given level of oil revenues (the so-called target revenue model, see Bénard (1980), Crémer and Salehi-Isfahani (1980), and Teece (1982)), and as a result respond perversely to price changes. The result is a backward-bending supply curve where a sustained fall in oil prices can lead to increased oil production from some OPEC member countries who own large reserves of low cost oil, a demanding welfare program, and a fragile political system.

There is an important analogy between the Ricardian theory of rent on agricultural land and modelling of oil prices. David Ricardo, the famous British economist, observed that rent rises as land of lower quality are brought under cultivation in conditions of rising demand for agricultural products. In the same way, profit from productive oil fields rise as costlier fields are brought into production. With significant heterogeneity of breakeven production costs across fields in different parts of the world, as well as across different types of oil fields within a given region, it is not surprising that it is the production of the high cost unconventional oil that is first to be negatively affected by lower oil prices. This means that oil markets equilibrate, but very slowly. Oil prices are likely to fluctuate within a wide range, the ceiling being the marginal cost for US shale oil producers (around $60 per barrel). This episodic process gets further accentuated by new reserve discoveries, technological advances in oil production and alternative energy sources.

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A Data appendix

A.1 Data sources

The main data source used to estimate the GVAR-Oil model is Smith and Galesi (2014), which provides quarterly observations for the majority of the variables covering the period 1979Q2-2013Q1. This data can be downloaded from: https://sites.google.com/site/gvarmodelling. We augment this database with quarterly observations for Iran and for oil production. Data on consumer price index, GDP, and the exchange rate for Iran for the period 1979Q1-2006Q4 are from Esfahani et al. (2014). These series are updated using the Central Bank of Iran's (CBI) online database as well as several volumes of the CBI's *Economic Report and Balance Sheets* and *Monthly CPI Workbook*. The Iranian GDP data were updated using the International Monetary Fund's (IMF) *International Financial Statistics* and *World Economic Outlook* databases, while the exchange rate data are from the IMF *International Financial Statistics* (for the official exchange rate) and IMF *INS* database (for the "free market" rate).[16] Finally, we obtain quarterly oil production series (in thousand barrels per day) from the U.S. Energy Information Administration *International Energy Statistics*.[17]

The analysis in Section 3 was conducted using data from two main sources: real monthly US equity prices (S&P 500) and real dividends (S&P 500) between 1946M1 and 2016M3 are from Robert Shiller's online database: http://www.econ.yale.edu/~shiller/data.htm, while monthly data on industrial production, manufacturing production, and real oil prices are from the Federal Reserve Economic Data (FRED) database: https://fred.stlouisfed.org/.

A.2 Construction of the variables

Log real GDP, y_{it}, the rate of inflation, π_{it}, short-term interest rate, r_{it}^S, long-term interest rate, r_{it}^L, the log deflated exchange rate, ep_{it}, and log real equity prices, eq_{it}, are six variables included in our GVAR-Oil model, as well as most of the GVAR applications in the literature. These six variables are constructed as

$$\begin{aligned} y_{it} &= \ln(GDP_{it}), \quad \pi_{it} = p_{it} - p_{it-1}, \quad p_{it} = \ln(CPI_{it}), \quad ep_{it} = \ln\left(E_{it}/CPI_{it}\right), \\ r_{it}^S &= 0.25\ln(1 + R_{it}^S/100), \quad r_{it}^L = 0.25\ln(1 + R_{it}^L/100), \; eq_{it} = \ln\left(EQ_{it}/CPI_{it}\right), \quad (11) \end{aligned}$$

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[16] Data on the "free market" rate are only available from the IMF between 1979Q1 to 2011Q3. We therefore make use of data from online traders, such as Eranico: www.eranico.com, to complete the series until 2013Q1.

[17] These data are only available from 1994Q1, so quarterly series from 1979Q2 to 1993Q4 were linearly interpolated (backward) using annual series. For a description of the interpolation procedure see Section 1.1 of Supplement A of Dees et al. (2007).

where GDP_{it} is the real Gross Domestic Product at time t for country i, CPI_{it} is the consumer price index, E_{it} is the nominal exchange rate in terms of US dollar, EQ_{it} is the nominal Equity Price Index, and R^S_{it} and R^L_{it} are short-term and long-term interest rates, respectively. In addition to the above variables we also include the log of oil prices, p^o_t, and the log of oil production, q^o_{it} in our dataset.

For Iran only, as in Esfahani et al. (2013), we construct ep_{it} as a geometrically weighted average of the log of the free $(e_{Iran,t})$ and the official rates $(e_{IranOF,t})$

$$e_{Iran,\delta,t} = \delta e_{Iran,t} + (1-\delta)e_{IranOF,t}, \tag{12}$$

where δ represents the proportion of imports by public and private agencies that are traded at the free market rate, on average. There is little hard evidence on δ although, due to the gradual attempts at currency unification, it is reasonable to expect δ to have risen over time. Initially we set $\delta = 0.70$, but smaller values of $\delta = 0.65$ and 0.60 resulted in very similar estimates and test outcomes. We, therefore, only report the results using $e_{Iran,\delta,t}$ with $\delta = 0.70$.

The world equity prices, eq_t, are computed as a weighted average of country-specific equity indices (when available), namely

$$eq_t = \sum_{i=1}^{N} w_i^{eq} eq_{it}, \text{ with } \sum_{i=1}^{N} w_i^{eq} = 1, \tag{13}$$

where $w_i^{eq} \geq 0$ measures the importance of each country's equity market in the global economy. The weight w_i^{eq} is set to zero in the case of countries without substantial equity markets. For countries with important equity markets one possibility would be to use PPP-GDP weights. But using such weights would understate the importance of the U.S. in the world equity markets which is much more substantial than the 25% PPP-GDP weight of the United States in the world economy (see Table 4). Therefore, to reflect the relative importance of U.S. financial markets we set $w_{US}^{eq} = 0.50$ and allocate the remaining 50% of the weights to the remaining countries using PPP-GDP weights. The resultant weights, w_i^{eq}, are summarized in Table 4.

Table 4: PPP-GDP Weights and Global Equity Weights (in percent), averages over 2007–2009

Country	PPP GDP Weights (w_i)	Global Equity Weights (w_i^{eq})	Country	PPP GDP Weights (w_i)	Global Equity Weights (w_i^{eq})
Argentina	0.99	1.03	Norway	0.48	0.50
Australia	1.42	1.48	New Zealand	0.22	0.23
Brazil	3.44	–	Peru	0.42	–
Canada	2.25	2.33	Philippines	0.55	0.58
China	14.49	–	South Africa	0.88	0.91
Chile	0.42	0.44	Saudi Arabia	1.02	–
Euro Area	17.86	18.56	Singapore	0.44	0.46
India	6.15	6.39	Sweden	0.62	0.65
Indonesia	1.60	–	Switzerland	0.60	0.62
Iran	1.43	–	Thailand	0.95	0.98
Japan	7.47	7.76	Turkey	1.79	–
Korea	2.28	2.37	UK	3.87	4.02
Malaysia	0.67	0.69	USA	24.93	50.00
Mexico	2.75	–			

Notes: The euro area block includes 8 of the 11 countries that initially joined the euro on January 1, 1999: Austria, Belgium, Finland, France, Germany, Italy, Netherlands, and Spain. Source: World Bank *World Development Indicators*, 2007-2009.

Table 5: Trade Weights, averages over 2007–2009

	Argentina	Australia	Brazil	Canada	China	Chile	Euro Area	India	Indonesia	Iran	Japan	Korea	Malaysia	Mexico	Norway	New Zealand	Peru	Philippines	South Africa	Saudi Arabia	Singapore	Sweden	Switzerland	Thailand	Turkey	UK	USA
Argentina	0	0.00	0.11	0.00	0.01	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Australia	0.01	0	0.01	0.00	0.03	0.01	0.01	0.04	0.04	0.00	0.05	0.03	0.03	0.00	0.00	0.25	0.00	0.02	0.02	0.01	0.04	0.01	0.01	0.05	0.01	0.01	0.01
Brazil	0.31	0.01	0	0.01	0.02	0.08	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.07	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02
Canada	0.01	0.01	0.02	0	0.02	0.02	0.02	0.01	0.01	0.00	0.02	0.01	0.01	0.04	0.03	0.02	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.21
China	0.13	0.19	0.14	0.07	0	0.17	0.13	0.15	0.12	0.19	0.24	0.27	0.14	0.06	0.04	0.12	0.15	0.16	0.13	0.12	0.13	0.04	0.03	0.14	0.09	0.07	0.16
Chile	0.06	0.00	0.03	0.00	0.01	0	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Euro Area	0.17	0.11	0.23	0.06	0.18	0.18	0	0.20	0.09	0.25	0.11	0.10	0.10	0.08	0.45	0.12	0.15	0.10	0.30	0.16	0.10	0.54	0.65	0.10	0.48	0.52	0.16
India	0.01	0.04	0.02	0.01	0.03	0.02	0.02	0	0.04	0.12	0.01	0.02	0.03	0.01	0.00	0.01	0.01	0.01	0.03	0.04	0.04	0.01	0.01	0.02	0.02	0.02	0.02
Indonesia	0.01	0.03	0.01	0.00	0.02	0.00	0.01	0.03	0	0.00	0.04	0.03	0.04	0.00	0.00	0.03	0.00	0.02	0.01	0.02	0.10	0.00	0.00	0.04	0.01	0.00	0.01
Iran	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.04	0.00	0	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
Japan	0.02	0.17	0.05	0.03	0.15	0.09	0.05	0.04	0.17	0.14	0	0.14	0.12	0.03	0.02	0.10	0.06	0.17	0.09	0.16	0.08	0.02	0.03	0.20	0.02	0.03	0.08
Korea	0.01	0.06	0.03	0.01	0.11	0.06	0.02	0.04	0.07	0.09	0.08	0	0.05	0.03	0.01	0.04	0.04	0.06	0.02	0.10	0.06	0.01	0.01	0.04	0.02	0.01	0.03
Malaysia	0.01	0.03	0.01	0.00	0.03	0.00	0.01	0.03	0.06	0.01	0.03	0.02	0	0.01	0.00	0.03	0.00	0.05	0.01	0.01	0.16	0.00	0.00	0.07	0.01	0.01	0.02
Mexico	0.03	0.01	0.03	0.03	0.01	0.04	0.02	0.01	0.00	0.00	0.01	0.02	0.01	0	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
Norway	0.00	0.00	0.01	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.01	0.04	0.00
New Zealand	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Peru	0.01	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Philippines	0.01	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.02	0.00	0.00	0.01	0.00	0	0.00	0.01	0.03	0.00	0.00	0.02	0.00	0.00	0.01
South Africa	0.01	0.01	0.01	0.00	0.01	0.00	0.02	0.01	0.00	0.03	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0	0.02	0.00	0.01	0.01	0.01	0.01	0.02	0.01
Saudi Arabia	0.00	0.01	0.02	0.00	0.02	0.00	0.02	0.03	0.02	0.01	0.04	0.05	0.01	0.00	0.00	0.01	0.00	0.04	0.04	0	0.03	0.01	0.01	0.03	0.03	0.01	0.02
Singapore	0.00	0.05	0.01	0.00	0.03	0.00	0.01	0.06	0.16	0.02	0.03	0.04	0.20	0.00	0.01	0.04	0.00	0.11	0.01	0.04	0	0.00	0.01	0.07	0.00	0.01	0.02
Sweden	0.00	0.01	0.01	0.00	0.01	0.01	0.06	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.11	0.01	0.01	0.00	0.01	0.01	0.00	0	0.01	0.00	0.02	0.02	0.01
Switzerland	0.01	0.01	0.02	0.01	0.01	0.00	0.09	0.02	0.00	0.02	0.01	0.00	0.01	0.00	0.01	0.01	0.02	0.00	0.02	0.01	0.01	0.01	0	0.02	0.04	0.02	0.01
Thailand	0.01	0.04	0.01	0.00	0.02	0.01	0.01	0.02	0.04	0.00	0.04	0.02	0.06	0.00	0.00	0.03	0.01	0.05	0.02	0.03	0.05	0.00	0.01	0	0.01	0.01	0.01
Turkey	0.01	0.00	0.00	0.00	0.01	0.01	0.04	0.01	0.01	0.07	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.02	0.00	0	0.02	0.01
UK	0.01	0.05	0.02	0.03	0.03	0.01	0.19	0.05	0.01	0.02	0.02	0.02	0.02	0.01	0.22	0.04	0.01	0.01	0.07	0.02	0.03	0.09	0.05	0.02	0.07	0	0.04
USA	0.12	0.10	0.19	0.70	0.21	0.18	0.17	0.15	0.09	0.00	0.19	0.14	0.14	0.69	0.06	0.12	0.25	0.16	0.11	0.19	0.13	0.07	0.11	0.12	0.08	0.14	0

Notes: Trade weights are computed as shares of exports and imports, displayed in columns by country (such that a column, but not a row, sum to 1). Source: International Monetary Fund *Direction of Trade Statistics*, 2007-2009.

A.3 Trade weights

The trade weights, w_{ij}, used to calculate the five foreign variables $\left(y_{it}^{*},\ \pi_{it}^{*},\ ep_{it}^{*},\ r_{it}^{*S},\ r_{it}^{*L}\right)$, are based on data from the International Monetary Fund's *Direction of Trade Statistics* database, and are given in the 27×27 matrix provided in Table 5.

B Tests for weak exogeneity of oil prices

In the GVAR-Oil framework we have provided theoretical arguments that oil prices can be treated as weakly exogenous in individual country oil supply and income equations. But such theoretical conditions need not hold in the case some of the major oil producers such as Saudi Arabia and the United States. Therefore, it is important that we check the validity of our maintained assumption that oil prices can be treated as weakly exogenous in the country-specific oil supply and income equations. Note that the issue of testing weak exogeneity of global and country-specific foreign variables has been an important consideration in the GVAR modelling approach and has been discussed extensively in Pesaran et al. (2004) and Dees et al. (2007).[18]

Table 6: F Tests for Weak Exogeneity of Oil Prices in Country-specific Models

Net Exporters	Test Statistics*	Net Importers	Test Statistics*
Canada	0.11 (2.68)	Brazil	0.48 (3.07)
Indonesia	0.67 (2.68)	China	0.00 (3.08)
Iran	0.00 (3.92)	United Kingdom	3.01 (3.07)
Mexico	1.02 (2.68)	United States	0.89 (2.68)
Norway	0.01 (3.07)		
Saudi Arabia	0.67 (3.93)		

Notes: * 5% critical values in brackets. For more details on testing the weak exogeneity assumption see Section B.2 of Appendix B of Mohaddes and Pesaran (2016).

Table 6 reports the F-statistics for testing the weak exogeneity of oil prices for the ten major oil produces together with their associated critical values at the 5% significance level.[19] The test results support our maintained assumption that international oil prices can be regarded as weakly exogenous in individual country models. The test statistics for all the major oil producing countries are well below their critical value with the exception of UK where the test statistic is just significant at the 5% level. But overall the null hypothesis

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[18] See Chapter 24 of Pesaran (2015) for details and derivations.

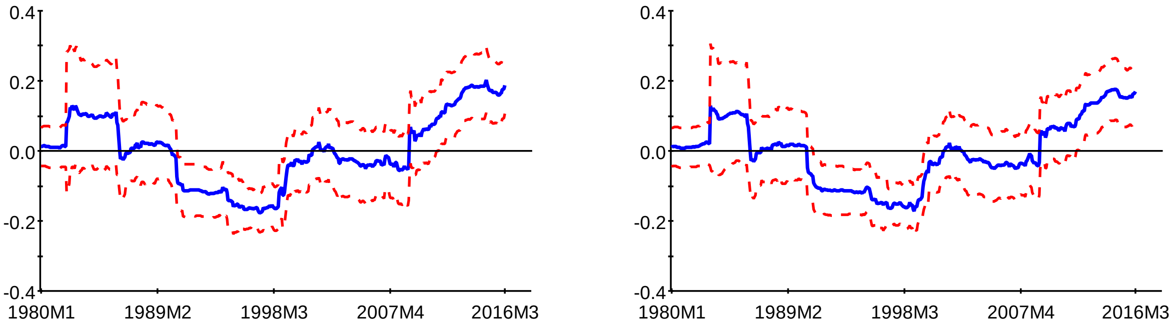
[19] See Section 3.4 of Dees et al. (2007) for more details.

that international oil prices can be taken to be weakly exogenous cannot be rejected. This is particularly so for Saudi Arabia, Iran and the US.

C Robustness of the rolling window estimates

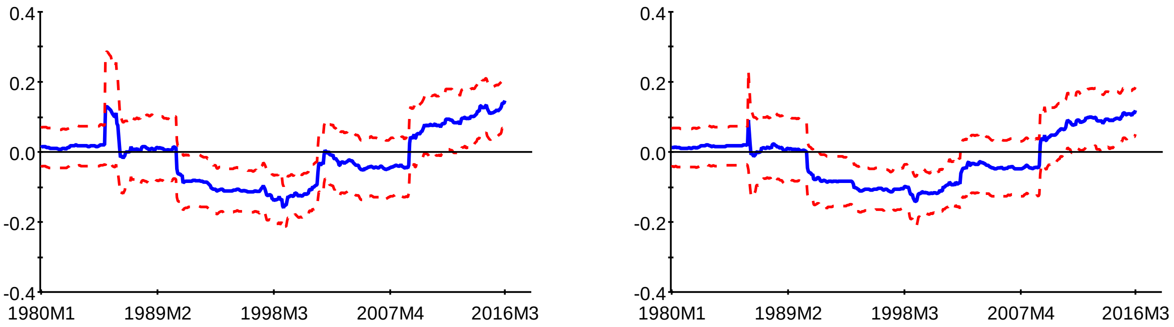
In this section we check the robustness of our results based on the rolling window estimates in Sections 3.1 and 3.2 to the size of the rolling window. To this end we estimate rolling regressions of the rate of change of real equity prices on the rate of change of real oil prices with 8, 9, 11, and 12-year rolling windows, and plot the estimated coefficients of the rate of change of real oil prices (blue solid) and their two standard error bands (red dashed) in Figure 11.

Figure 11: Rolling Estimates of the Effects of Changes in Oil Prices on Equity Prices



(a) Window Size: 8 Years **(b) Window Size: 9 Years**

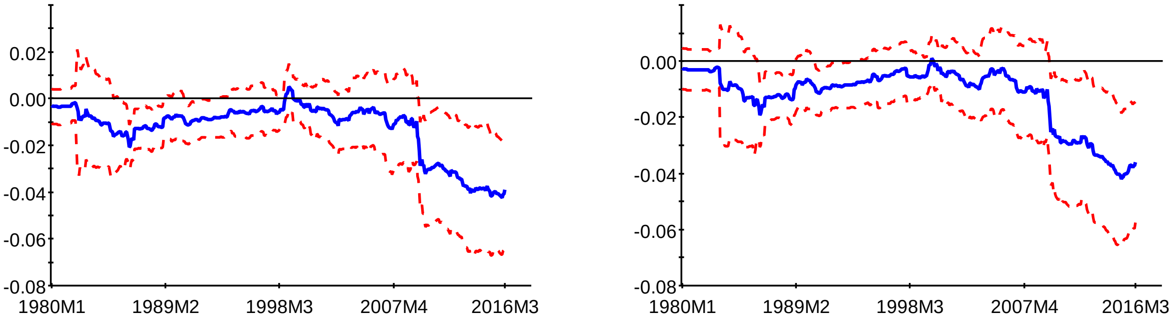
(c) Window Size: 11 Years **(d) Window Size: 12 Years**



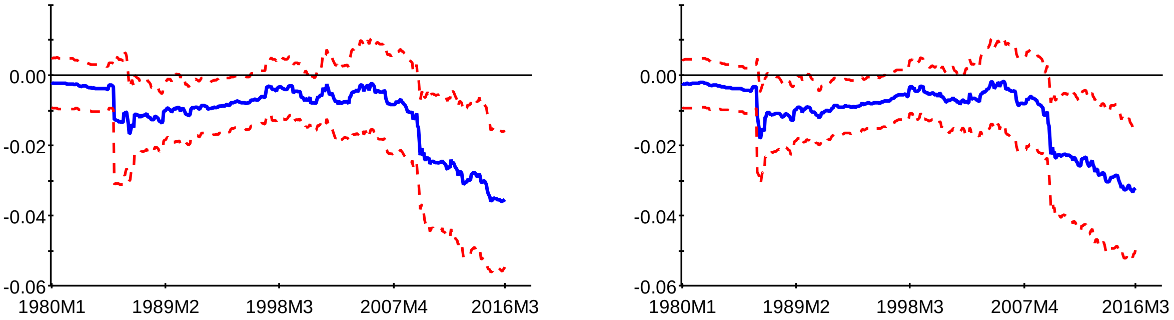
Notes: Rolling estimates of the coefficient of the rate of change of real oil prices and its two standard error bands. Dependant variable is the rate of change of real US equity prices (S&P 500).
Data sources: Robert Shiller's online database, Federal Reserve Economic Data (FRED), and United States Energy Information Administration (EIA).

Very much in line with the results based on a 10-year rolling window reported in Figure 8 of Section 3.1, figures (a) to (d) show that the coefficients were not statistically different from zero before 1990, became negative in 1991 and initially falling (being statistically significant from 1991 to 2001), and then eventually rising and becoming positive since the 2008 financial crisis (being statistically significant from 2012 onwards).

Figure 12: Rolling Estimates of the Effects of Changes in Oil Prices on Real Dividends



(a) Window Size: 8 Years **(b) Window Size: 9 Years**



(c) Window Size: 11 Years **(d) Window Size: 12 Years**

Notes: Rolling estimates of the coefficient of the rate of change of real oil prices and its two standard error bands based. Dependant variable is the rate of change of real dividends (S&P 500).
Data sources: Robert Shiller's online database, Federal Reserve Economic Data (FRED), and United States Energy Information Administration (EIA).

We also estimate rolling regressions (with 8, 9, 11 and 12-year rolling windows) of the rate of change of real dividends on the rate of change of real oil prices, and plot the estimated coefficients of the rate of change of real oil prices (blue solid) and their two standard error bands (red dashed) in Figure 12. As can be seen the rolling estimates of the coefficient of real oil price changes on dividends have been negative and statistically significantly for most of the period; therefore being similar to those with a 10-year window reported in Figure 10 of Section 3.2. Note that as before, the beneficial effects of lower oil prices on dividends have become even stronger over the more recent episodes, with the rolling estimates becoming particularly large and statistically significant post-2009.