ONLINE APPENDIX TO
Transitory and Permanent Shocks in the Global Market for Crude Oil

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1 Introduction

In this online appendix we provide details on the sources of data, results of the cointegration tests with a structural break, and the theoretical specification of the estimated model. Thereafter, we discuss results of conditional correlations between the endogenous variables.

2 Data Sources

2.1 Global real activity

In the related literature, readers have been witnessing hot debates on the best indicator for economics activity at monthly frequency. Kilian (2009) constructed an index based on the cost of shipping as proxy for global economic activity. Since, this index has been widely used. Hamilton (2019) puts forward many critics against such index and suggests different sources including monthly industrial production for the OECD plus six other major countries. Dvir and Rogoff (2014) declare using the OECD+6 monthly GDP data — available from 1970Q1 — which they consider as the broadest measure of global income available at monthly frequency, including all developed economies as well as the BRIC countries, Indonesia and South Africa. In reality, the series used by the authors corresponds to one of the Composite Leading Indicators (CLIs) that the OECD developed in early 70s to track turning points in economic activity. Further, the OECD used the index of industrial production (IIP) as a reference until 2012. Since then, it is using the OECD declared that the IIP is no more considered as a reliable proxy for GDP and the main rationale was that the share of services has increased substantially in the global activity. Besides, the CLIs is commonly adopted as a qualitative rather than quantitative information on short-term economic movements. Thus, to have a time consistent and better measure of the global economic activity, we propose constructing a Purchasing Power Parity (PPP) converted real quarterly GDP in U.S. dollars for all OECD members plus six emerging countries (Brazil, China, India, Indonesia, Russia, South Africa) aggregated using .

Quarterly OECD and South Africa real GDP in US dollars (current prices, current PPPs, and seasonally adjusted) are extracted from OECD.Stat covering the period from 1973Q1 until 2018Q1. For the remaining countries — namely, Brazil, China, Indonesia, and India — quarterly nominal GDP is available only starting from 1996Q1 (Brazil), 1992Q1 (China), 1996Q2 (India), and 1990Q1 (Indonesia). To construct the earlier periods' observations, we first use annual data from the World Bank Indicators database for all countries in local currencies. Then, we transform the annual GDP data to PPP measure using the implied PPP conversion rate (national currency per international dollar) published in the World Economic Outlook database by the International Monetary Fund.[1] Then, we use the Litterman frequency conversion method, while using the OECD quarterly GDP as an indicator, to obtain the quarterly GDP for the early periods of each of the five countries. Finally, the global activity variable is constructed by summing the seasonally adjusted OECD and country specific GDP PPP in USD, which we devide by the consumer price index in the US to obtain the it in real terms.

2.2 Oil market variables

We extracted world oil production data from the U.S. Energy Information Administrations website: `http://www.eia.gov/totalenergy/data/monthly/query/mer_data_excel.asp?table=T11.01B`. The available data is presented in thousands of barrel per day at monthly frequency from January 1973 to August 2018. To be as accurate as possible, we take into account the difference of number of days of February between common years- where it is 28 days- and leap years- where it is 29 days. After that, we transform the series from monthly to quarterly frequency. We collected OECD petroleum stocks from the same source (`http://www.eia.gov/totalenergy/data/monthly/query/mer_data_excel.asp?table=T11.03`). However, as the data is available on monthly frequency from 1988 and on yearly frequency from 1973, we follow Kilian and Murphy (2014), Dvir and Rogoff (2014) and Baumeister and Hamilton (2019) to construct quarterly stocks from 1973Q1 by scaling U.S. crude oil inventory data by the ratio of OECD petroleum inventories over U.S. petroleum inventories.

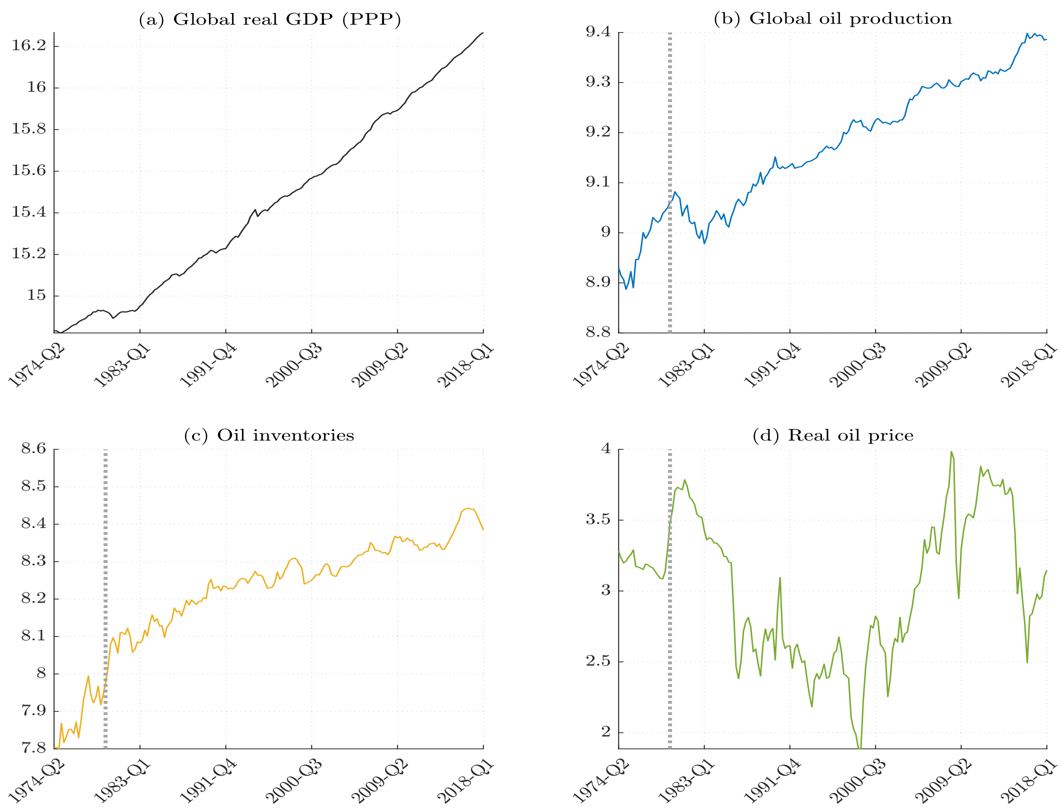
We constructed our series of Global oil availability in the same way of Dvir and Rogoff (2014). Oil availability is measured as the sum of global stock of the previous quarter and the production of the current quarter.

For nominal oil prices, we use U.S. Crude Oil Imported Acquisition Cost by Refiners (Dollars per Barrel) from the U.S. Energy Information Administration as in Dvir and Rogoff (2014). The authors suggest that this series is more stable comparing to alternative ones, as it did not witnessed regulatory pressure during 70s and early 80s like West Texas Intermediate

[1] Since the PPP index is only available starting from 1980, we calculate a linear trend based on the 10 subsequent year, which we reversely apply to obtain the index in the previous years up to 1973.

(WTI). The data ranges from January 1974 to October 2018 and was downloaded from . Finally, we deflate nominal oil prices and global GDP by the U.S. consumer price index for All Urban Consumers from Federal Reserve Economic Data. Federal Reserve Bank of St. Louis website: https://fred.stlouisfed.org (All Items, Index 1982-1984=100, Quarterly, Seasonally Adjusted)

Figure A.1: Historical Data



3 Unit Roots and Cointegration

3.1 Unit Roots

We begin our empirical exercise by testing the non-stationarity in our data series. Using regular unit roots including ADF (Dickey and Fuller, 1979), and PP (Phillips and Perron, 1988), KPSS(Kwiatkowski et al., 1992) could be misleading. Those tests ignore any potential structural break in the series (see the discussion in Baum, 2004). We implement Clemente et al. (1998) unit root with structural breaks to avoid biased results and to deal with this kind of problem. The test provides the user with information about two potential structural breaks points in the series. Further, it suggests two different models, namely the additive outliers (AO) model and the innovational outliers (IO) model. Each model has his own characteristics. The (AO) model captures a sudden change in the mean of a series, while the (IO) model is more suitable to describe a gradual shift.

Table A.1 describes results of Clemente et al. (1998) test. It shows that none of the 5 test statistics of considered series exceed their approximate 5 percent critical values series (at level), even though the t-statistics for both time break are very significant. This is true in both model (AO and IO). Thus, results indicate the existence of unit root and significant level shifts in all the series. We applied the same test on all series at first difference and we confirmed that variables are stationary and integrated of order 1.[2]

Table A.1: Clemente-Montanes-Reyes Unit Root Test with Structural Breaks

Variable	**Additive outliers**				**Innovative outliers**			
	t-stat. ($\rho = 1$)	TB1	TB2	Unit root	t-stat. ($\rho = 1$)	TB1	TB2	Unit root
x_t	−2.887(2)	1995Q1***	2008Q1***	yes	−1.388(5)	1982Q2***	2003Q1**	yes
z_t	−2.830(4)	1988Q4***	2002Q4***	yes	−3.305(5)	1987Q1***	2003Q1***	yes
i_t	−3.841(4)	1978Q3***	1990Q3***	yes	−4.467(4)	1978Q4**	1996Q1***	yes
p_t	−4.957(1)	1986Q4***	2004Q4***	yes	−4.750(3)	1985Q3***	2003Q3***	yes

Note: Lag order k is between the parentheses. The 5 percent critical value for both model to reject the null of unit root test is -5.490. The stars ***, ** indicate significance of the time break at 1 and 5 percent level, respectively.

3.2 Cointegration

To test whether oil variables are cointegrated or not, we use Gregory and Hansen (1996) cointegration test, which accounts for endogenous structural break in the cointegrating equation. Gregory and Hansen (1996) demonstrates that results of most usual cointegration test including Engle and Granger (1987), Johansen (1990) and Enders and Siklos (2001) are biased if the series contains structural break. Gregory and Hansen (1996) recommend four models:

- **Model 1**: Level Shift (C)

[2] Results of Clemente-Montañés-Reyes unit root test at first difference are available upon request.

- **Model 2**: Level Shift with Trend (C/T)
- **Model 3**: Regime Shift Where Intercept and Slope coefficients Change (C/S)
- **Model 4**: Regime Shift Where Intercept, Slope Coefficients and Trend Change (C/S/T)

Gregory and Hansen (1996) approach is an extension of Engle and Granger (1987) which tests the null hypothesis of no cointegration against the alternative of cointegration while taking into account one structural break at an unknown date. In other words, the structural break is endogenously detected. Authors propose three statistics namely ADF^*, Z_t^*, and Z_α^*, which are extensions of the traditional ADF and Phillips test type of unit root on the residuals.

Table A.2: Cointegration: Oil Variables

	Test Statistic	Break Date	Asymptotic Critical Values 1%	5%	10%
Model 1: Change in Level					
ADF^*	−5.86	1980Q3	−5.44	−4.92	−4.69
Z_t^*	−9.58	1980Q3	−5.44	−4.92	−4.69
Z_α^*	−109.72	1980Q3	−57.01	−46.98	−42.49
Model 2: Change in Level and Trend					
ADF^*	−6.32	1980Q3	−5.8	−5.29	−5.03
Z_t^*	−10.06	1980Q3	−5.8	−5.29	−5.03
Z_α^*	−118.92	1980Q3	−64.77	−53.92	−48.94
Model 3: Change in Regime					
ADF^*	−5.81	1980Q3	−5.97	−5.5	−5.23
Z_t^*	−10.24	1980Q3	−5.97	−5.5	−5.23
Z_α^*	−122.77	1980Q3	−68.21	−58.33	−52.85
Model 4: Change in Regime and Trend					
ADF^*	−5.81	1980Q3	−5.97	−5.5	−5.23
Z_t^*	−10.24	1980Q3	−5.97	−5.5	−5.23
Z_α^*	−122.77	1980Q3	−68.21	−58.33	−52.85

In the first step, we implement Gregory and Hansen (1996) approach to test the null hypothesis of no cointegration against the alternative between oil variables namely World availability, Global inventories and real oil prices. Results of the four models are presented in Table A.2. In the second step, we test the no cointegration hypothesis against the alternative between oil market variables and the global GDP. This is important to check whether oil market variables and global GDP share the same sources non-stationarity or not. Results of the four models are presented in Table A.3.

Table A.3: Cointegration: Oil Variables + Global GDP

	Test Statistic	Break Date	Asymptotic Critical Values 1%	5%	10%
Model 1: Change in Level					
ADF*	−4.16	2004q2	−5.77	−5.28	−5.02
Z_t^*	−4.38	2003q3	−5.77	−5.28	−5.02
Z_α^*	−31.35	2003q3	−63.64	−53.58	−48.65
Model 2: Change in Level and Trend					
ADF*	−4.52	2004q1	−6.05	−5.57	−5.33
Z_t^*	−4.97	2004q3	−6.05	−5.57	−5.33
Z_α^*	−40.92	2004q3	−70.27	−59.76	−54.94
Model 3: Change in Regime					
ADF*	−4.84	2003q1	−6.51	−6	−5.75
Z_t^*	−5.25	2003q1	−6.51	−6	−5.75
Z_α^*	−45.95	2003q1	−80.15	−68.94	−63.42
Model 4: Change in Regime and Trend					
ADF*	−4.95	2002q1	−6.89	−6.32	−6.16
Z_t^*	−5.9	2003q1	−6.89	−6.32	−6.16
Z_α^*	−55.39	2003q1	−90.84	−78.87	−72.75

Table A.2 reveals that the absolute value of the three tests statistics (in all four models) are greater than its critical values at 1 percent. Thus, we can reject the null hypothesis of no cointegration and accept the alternative. Moreover, all four models suggest 1980Q3 as break date.[3]

However, when testing the cointegration between oil variables and global GDP using the same approach, the absolute values of three test statistics (in all four models) are lower than its critical values, even at 10 percent (see Table A.3). Thus, we cannot reject the null hypothesis of no cointegration. Further, the date breaks are different among the alternative models. These results confirm our guess that sources of non-stationarity between oil variables and Global GDP are different.

4 Estimated Model

To identify the transitory and permanent shocks in the model, we adapt the methodology proposed by Uribe (2020) in the context of identification of transitory and permanent monetary shocks, which allows identifying shocks with sign restrictions along with using the Kalman filter to account for unobserved variables — more shocks than endogenous variables in the augmented SVAR model specification.

Let y_t be a vector collecting the endogenous variables defined as $y_t \equiv [x_t \ \ z_t \ \ i_t \ \ p_t]'$, where x_t denotes the logarithm of real global output, z_t the logarithm of global oil production, i_t the logarithm of global oil inventories, and p_t the logarithm of global real oil price. In order to explicitly account for shocks to the trend — oil supply and demand — consistently with the results of the cointegration tests, we define the transformed vector of endogenous variables, $\tilde{y}_t$, as follows

$$\tilde{y}_t \equiv \begin{bmatrix} x_t - \Psi_t^d \\ z_t - \Psi_t^s \\ i_t - \Psi_t^s \\ p_t - \Psi_t^s \end{bmatrix}$$

Let $\hat{y}_t$ denote the deviation of $\tilde{y}_t$ from its unconditional mean: $\hat{y}_t \equiv \tilde{y}_t - \mathrm{E}(\tilde{y}_t)$

The law of motion of $\hat{y}_t$ takes the autoregressive form

$$\hat{y}_t = \sum_{j=1}^{L} A_j \hat{y}_{t-j} + B u_t \tag{1}$$

where $u_t \equiv [\psi_t^s \ \ \phi_t^{sp} \ \ \phi_t^s \ \ \psi_t^d \ \ \phi_t^d]'$, $\psi_t^s \equiv \Delta\Psi_t^s - \mathrm{E}(\Delta\Psi_t^s)$, and $\psi_t^d \equiv \Delta\Psi_t^d - \mathrm{E}(\Delta\Psi_t^d)$; with Δ denoting the time-difference operator. The objects A_j, for $j = 1, ..., L$, are 4-by-4 matrices

[3] We have also ran Johansens cointegration test and found that there is at most one cointegrating equation

of coefficients, B is a 4-by-5 matrix of coefficients, and L is a scalar denoting the lag length of the empirical model. The vector u_t is assumed to follow a stationary process of the form

$$u_{t+1} = \kappa\ d_{t+1} + \rho\ u_t + \omega\ \varepsilon_{t+1} \tag{2}$$

where ρ is a 5-by-5 diagonal matrix of coefficients in $[0, 1)$, ω is a 5-by-5 diagonal matrix capturing the variances of the innovations, and ε_{t+1} is a 5-by-1 i.i.d. normal shocks with variances equal to 1.[4]

The observable variables used in the estimation of the empirical model are growth rates expressed in percent per quarter of global output, global oil production, inventories and real oil prices. The observables variables are linked to the variables included in the unobservable system Equations (1) and (2) through the following relations

$$\begin{aligned}
\Delta x_t &= \Delta\Psi^d + \hat{x}_t - \hat{x}_{t-1} + \psi_t^d \\
\Delta z_t &= \Delta\Psi^s + \hat{z}_t - \hat{z}_{t-1} + \psi_t^s \\
\Delta i_t &= \Delta\Psi^s + \hat{i}_t - \hat{i}_{t-1} + \psi_t^s \\
\Delta p_t &= \Delta\Psi^s + \hat{p}_t - \hat{p}_{t-1} + \psi_t^s
\end{aligned} \tag{3}$$

We denote o_t be the vector of variables observed in quarter t, which corresponds to $o_t = [\Delta x_t \;\; \Delta z_t \;\; \Delta i_t \;\; \Delta p_t]'$. The state-space representation of the system composed of Equations (1) to (3) can be written as follows:

$$\zeta_{t+1} = C\zeta_t + D\varepsilon_{t+1}$$

$$o_t = G' + H'\zeta_t$$

where $\zeta_t = [\hat{y}_t \;\; \hat{y}_{t-1} \;\; \ldots \;\; \hat{y}_{t-L+1} \;\; u_t \;\; d_t]'$. The matrices C, D, G, and H are known functions of $A_i, i = 1, ...L$, B, ρ, ω, $\mathrm{E}(\Delta\Psi_t^d)$, and $\mathrm{E}(\Delta\Psi_t^s)$. More specifically, we define $A \equiv [A_1 \cdots A_L]$ I_j as an identity matrix of order j, $\emptyset_j$ is a square matrix of order j with all elements equal to zero, while $\emptyset_{i,j}$ denotes a matrix of order i by j with all entries equal to zero. Further, let L, S, and V denote, respectively, the number of lags (=4), the number of shocks (=45), and the number of endogenous variables included in the empirical model (=4). Hence, for $L \geq 2$, we have

[4] Note that the estimated model assumes the shocks to be not autocorrelated implying $\rho \equiv \emptyset_{5,5}$.

$$C = \begin{bmatrix} A & B\,\rho & \emptyset_{V,1} \\ [I_{V(L-1)} \;\; \emptyset_{V(L-1),V}] & \emptyset_{V(L-1),S} & \emptyset_{V(L-1),1} \\ \emptyset_{S,VL} & \rho & [-\kappa \;\; \emptyset_{(S-1),1}] \\ \emptyset_{1,VL} & \emptyset_{1,S} & 0 \end{bmatrix}, \quad D = \begin{bmatrix} B\,\omega \\ \emptyset_{V(L-1),S} \\ \omega \\ \emptyset_{1,S} \end{bmatrix},$$

$$G = \left[\mathrm{E}(\Delta\Psi_t^d) \;\; \mathrm{E}(\Delta\Psi_t^s) \;\; \mathrm{E}(\Delta\Psi_t^s) \;\; \mathrm{E}(\Delta\Psi_t^s)\right], \quad \text{and} \quad H' = \left[M_\zeta \quad \emptyset_{V,V(L-2)} \quad M_u\right]$$

where the matrices M_ζ and M_u take the form

$$M_\zeta = \begin{bmatrix} 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 \end{bmatrix} \quad \text{and} \quad M_u = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

5 Conditional Correlations

Table A.4 presents estimates of both unconditional and conditional correlations between the endogenous variables of our benchmark empirical model. Although one can have a broadly clear idea about the sign of the conditional cross-correlations through the impulse-response functions, it is important to complement the aforementioned relations with the evaluation of a numerical evaluation of the co-movement between some key variables.

The first line of Table A.4 shows a weak unconditional correlation between the growth rates of global GDP and oil production. This result is mainly driven by the negative conditional comovement following permanent demand innovations, which explain about 27 percent and 10 percent of the volatilities of global GDP and oil production, respectively. Note that a speculative shock also yields a negative correlation between the two variables; however, the variance decomposition exercise reveals a relatively weak role of this shock in explaining the short- and long-term dynamics of global GDP and oil production. We argue that this is a novel finding in our analysis. In fact, the global activities defined by Kilian and Murphy (2014) and Baumeister and Hamilton (2019) also exhibit a low correlation with the oil production; however, the only shock that yields a negative correlation between the two variables is the speculative shock, which amplifies its contribution in the variance decomposition. Besides, it is hard to read the magnitude of the conditional correlations from the impulse-response functions reported in the two papers as they frequently exhibit sign changes and erratic trajectories.

Table A.4: Conditional Correlations

Correlation	Observed	Unconditional correlation	Conditional correlation				
			$\Delta\Psi_t^s$	ϕ_t^s	ϕ_t^{sp}	$\Delta\Psi_t^d$	ϕ_t^d
$Corr(\Delta x_t, \Delta z_t)$	0.13	0.10 $[-0.03, 0.22]$	0.33 $[-0.16, 0.73]$	0.27 $[-0.09, 0.58]$	-0.47 $[-0.84, -0.02]$	0.29 $[-0.39, 0.72]$	0.38 $[-0.07, 0.83]$
$Corr(\Delta x_t, \Delta i_t)$	-0.12	-0.14 $[-0.26, -0.02]$	0.47 $[0.03, 0.76]$	-0.32 $[-0.68, 0.12]$	-0.65 $[-0.92, -0.19]$	0.20 $[-0.61, 0.68]$	-0.90 $[-0.97, -0.48]$
$Corr(\Delta x_t, \Delta z_t)$	-0.15	-0.16 $[-0.28, -0.05]$	-0.75 $[-0.90, -0.46]$	-0.39 $[-0.73, -0.07]$	-0.51 $[-0.87, 0.00]$	0.65 $[-0.06, 0.83]$	0.94 $[0.80, 0.98]$
$Corr(\Delta z_t, \Delta i_t)$	0.18	0.21 $[0.09, 0.32]$	0.17 $[-0.33, 0.65]$	-0.43 $[-0.77, 0.17]$	0.91 $[0.78, 0.97]$	0.41 $[-0.63, 0.90]$	-0.31 $[-0.81, 0.27]$
$Corr(\Delta z_t, \Delta p_t)$	-0.18	-0.13 $[-0.24, -0.02]$	-0.15 $[-0.63, 0.37]$	-0.84 $[-0.91, -0.75]$	0.93 $[0.83, 0.98]$	0.65 $[-0.36, 0.94]$	0.37 $[-0.06, 0.83]$
$Corr(\Delta i_t, \Delta p_t)$	-0.09	-0.07 $[-0.18, 0.03]$	-0.88 $[-0.95, -0.74]$	0.56 $[-0.06, 0.85]$	0.92 $[0.81, 0.98]$	0.63 $[-0.77, 0.94]$	-0.85 $[-0.96, -0.41]$

Notes: The observed correlations are computed directly from the data whereas the unconditional and conditional correlations estimates are based upon the benchmark empirical model where we iteratively assume that each of the five structural shocks is the only shock hitting the economy. Numbers in square brackets represent the 5 and 95$^{\text{th}}$ percentile confidence bands.

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