Online Database Documentation

Real-time Forecast Combinations for the Oil Price

Anthony Garratt

Shaun Vahey

Yunyi Zhang

Contents

1 The Real time Data Set

In this document we describe a real-time data set for the oil market, which is similar to that used and described in Baumeister & Kilian (2012, 2015) [hereafter BK2012 and BK2015 respectively] where we follow their nowcasting and backcasting methods. The main differences between this data set and BK2012 and BK2015 is that we extend the sample to 2018:06, and we include Brent crude oil prices. Using this data set, in Garratt et al. (2018), we replicate the analysis described in BK2015. We find economically similar although not identical results, both over their original sample and the extended sample and using the Brent oil price measure, which this data set allows.

There are 17 time-series variables, 14 at a monthly and 3 at a quarterly frequency, which we split into variables with and without revisions, the details of which are summarised in Tables 1 and 2 respectively.[1] The 9 *revised* variables (in Table 1) are: (i) Brent (ii) West Texas Intermediate (WTI) and (iii) US refiners acquisition cost for crude oil imports (RAC), oil prices; (iv) world crude oil production; inventories for (v) U.S. crude oil (vi) U.S. petroleum and (vii) OECD petroleum; (viii) the U.S. consumer price index (CPI) for all urban consumers and (ix) the world real economic activity index. The remaining 8 variables (in Table 2), available *without any revisions* are: (i) NYMEX WTI Light Sweet Crude Oil Futures, (ii) Intercontinental exchange (ICE) Brent crude oil futures, and (iii) RAC, (iv) WTI, and (v) Brent oil price forecasts from the *Short-Term Energy Outlook* published by the U.S. Energy Information Administration (EIA); (vi) gasoline prices, (vii) heating oil prices, and (viii) an index of industrial raw materials.

Following the conventional terminology in the real-time macroeconomic forecasting literature, we define the "vintage" of data as the historical time series observed by forecasters at a specific point in time (known as the "vintage date"); for example, the 2018:06 vintage includes observations only available at the end of June 2018. There are 319 vintages in

[1] In Garratt et al. (2018), we only report monthly results, the quarterly results are available on request.

total, starting in 1991:12 ending in 2018:06, where the historical start dates vary for each series, but mostly begin in the early 1970's. See the Tables for details.

The structure of the *with revisions* Table, Table 1, is as follows. The columns document, in order, the unit of measurement, first observation $\underline{\tau}$, the last observation $\bar{\tau}$, the sample period and number of observations in a vintage, the publication delay (e.g. at time t, if the observation is available till to time t-1, then the publication delay will equal to 1), the average number of observations revised and the data sources and details on source codes.

The *without revision* table, Table 2, has a slightly different format, where the columns summarise the series' unit of measurement, frequency, maturities (or forecast horizons), first observation $\underline{\tau}$, the last observation $\bar{\tau}$, whether the series have missing values, and the data source and details on source codes under each column. The inclusion of EIA forecasts' data enables a replication of the comparison, made by BK2015, between the quarterly forecasts from their combination and the EIA's quarterly forecasts of RAC. Moreover, BK2015 specify EIA quarterly forecasts according to the timing of *Short-Term Energy Outlook* issues, a monthly EIA publication. The timing convention, *timing convention I*, employs the end-of-quarter issues of the publication (i.e., March, June, September and December), while *timing convention II* utilises the first month of the following quarter (i.e., April, July, October and January), which is consistent with the definition used in BK2015. The data set uses for each variable, 319 observations commencing in 1991:12 and ending in 2018:06.

Table 1: Real-time variables, for vintages dated 1991:12 to 2018:06

Series	Unit of measurement	$\underline{\tau}$	$\bar{\tau}$	Sample[1]	The publication delay	Average number of Obs. revised	Data Sources
Brent	Dollars per Barrel	1980:01	1991:11-2018:05	1991:12-2018:06: 132-461	1	1	FRED (POILBREUSDM /DCOILBRENTEU)
WTI	Dollars per Barrel	1973:01	1991:11-2013:06 /2013:08-2018:06[2]	1991:12-2013:07: 227-486 /2013:08-2018:06: 488-546	1991:12-2013:07: 1 /2013:08-2018:06: 0	1991:12-2013:07: 1 /2013:08-2018:06: 0	FRED (WTISPLC)
RAC	Dollars per Barrel	1974:01	1991:09-2005:04 /2005:06-2018:04[3]	1991:12-2005:07: 213-376 /2005:08-2018:06: 378-532	1991:12-2005:07: 3 /2005:08-2018:06: 2	3.88	*Monthly Energy Review* published by U.S. Energy Information Administration (Crude oil price summary)
World crude oil production	Thousand Barrels per Day	1975:01	1991:09-2018:03	1991:12-2018:06: 189-451	3	15.17	*Monthly Energy Review* published by U.S. Energy Information Administration (International petroleum)
U.S. crude oil inventories	Million Barrels	1973:01	1991:11-2018:05	1991:12-2018:06: 227-545	1	2.72	*Monthly Energy Review* published by U.S. Energy Information Administration (Petroleum stocks)
U.S. petroleum inventories	Million Barrels	1973:01	1991:11-2018:05	1991:12-2018:06: 227-545	1	2.92	*Monthly Energy Review* published by U.S. Energy Information Administration (Petroleum stocks)
OECD petroleum inventories	Million Barrels	1973:01	1991:07-2002:05 /2002:07-2016:02 /2016:04-2018:03	1991:12-2002:10: 223-353 /2002:11-2016:06: 355-518 /2016:07-2018:06: 520-543	1991:12-2002:10: 5 /2002:10-2016:06: 4 /2016:07-2018:06: 3	10.37	*Monthly Energy Review* published by U.S. Energy Information Administration (Petroleum stocks in OECD countries)
The U.S. consumer price index (CPI) for all urban consumers	INDEX	1973:01	1991:11-2018:05	1991:12-2018:06: 227-545	1	4.35	The economic indicators published by *Council of Economic Advisers* and the real-time dataset provided by the Federal reserve Bank of Philadelphia (Consumer prices—All urban consumers)
World real economic activity (rea) index[4]	INDEX	1973:01	1991:11-2018:05	1991:12-2018:06: 227-545	1	——[5]	*Drewry Shipping Consultants Ltd* and Bloomberg (BDIY:INDEX)

NOTES: In the real-time data set, a vintage is defined as the vector of historical data observed at a specific point in time, given in the columns of each sheet containing real-time variables. For example, the column Jun-18 in the BRENT sheet is a vintage that includes observations first available in June 2018. There are 319 vintages (columns) commencing in 1991:12 and concluding in 2018:06, in each sheet of real-time variables. The data for each vintage (column) are $\underline{\tau}, ..., \bar{\tau}$, where $\underline{\tau}$ and $\bar{\tau}$ are the first and last observations available in the vintages (columns) dated 1991:12 to 2018:06. For example, the column Jun-18 in the sheet of BRENT includes data starting in Jan-1980 (row 86, $\underline{\tau}$) and ending in Jun-2018 (row 547, $\bar{\tau}$).

[1] The range shown after the dates is the number of observations available in the vintages (columns). For example, there are 132 observations (rows) in the 1991:12 vintage, and 461 observations (rows) in the 2018:06 vintage (column), in the BRENT sheet of the real-time data set. Note also that this data set incorporates nowcasts, and hence, the number of rows with observations in each column is the sample size plus the publication delay. For example, here are 133 observations (rows) in vintage (column) 1991:12, and 462 observations (rows) in 2018:06 vintage (column) in the sheet of BRENT.

[2] WTI in the FRED data base combines two sources: (A) the Wall Street Journal's commodity energy prices with one-month lag, discontinued on August 2013; and (B) the monthly oil spot prices reported by the U.S. Department of Energy, calculated as the average of the daily observations.

[3] Dates separated by a slash indicate a change in the EIA publication delay, between the date of the time series observation and its release. For example, in the vintages (columns) 1991:09-2005:04, there is a 3-month publication delay, while in the 2005:08-2018:06 vintages there is a 2-month delay.

[4] The world real economic activity (rea) index uses information on: (A) the average monthly single voyage freight rates for the period between 1970:05 and 1985:11, collected by Drewry Shipping Consultants Ltd; and (B) the nominal shipping rate raw data (the Baltic Dry Cargo Index), available post-1985.01. Details of the construction are available in the data documentation.

[5] All observations for each vintage (colum) of the rea index are revised as a result of changes to the U.S. CPI and detrending.

Table 2: Variables without revisions, 1991:12 to 2018:06

Series	Unit of measurement	Frequency	Maturity	$\underline{\tau}$	$\overline{\tau}$	Missing values	Data Sources
WTI futures[1]	Dollars per Barrel	Monthly	1-24 months	Maturities 1-17 months: 1991:12 /Maturities 18 and 21 months: 1992:01 /Maturities 19, 20 and 22-23 months: 1991:12 /Maturity 24 months: 1992:04[2]	2018:06	Maturities 1-17 months: NONE /Maturities 18 and 21 from 1991:12 to 1995:06 /Maturities 19, 22 and 24 from 1991:12 to 1995:08 /Maturities 20 and 23 from 1991:12 to 1995:07	Bloomberg (CL1:COM to CL24:COM)
Brent futures	Dollars per Barrel	Monthly	1-24 months	Maturities 1-8 months: 1991:12 /Maturity 9 months: 1992:02 /Maturities 10-11 months: 1994:04 /Maturity 12 months: 1994:07 /Maturities 13, 16, 19, and 22 months: 1997:12 /Maturities 15, 18, and 21 months: 1998:01 /Maturities 14, 17, 20, and 23-24 months: 1998:02	2018:06	Maturities 1-8 months: NONE /Maturities 9-11 from 1991:12 to 1994:03 /Maturities 12, 15, 18, and 21 from 1991:12 to 2004:12 /Maturities 13, 16, 19, and 22 from 1991:12 to 2004:11 /Maturities 14, 17, 20, and 23-24 from 1991:12 to 2005:01	Bloomberg (CO1:COM to CO24:COM)
RAC forecasts[3]	Dollars per Barrel	Quarterly	Convention I: 1-7 quarters /Convention II: 1-8 quarters	Conventions I&II (1-4 quarters): 1991$Q4$[4]	Conventions I&II (1-4 quarters): 2018$Q1$	Conventions I&II (1-4 quarters): NONE /Conventions I&II (5-7(8) quarters)	*Short-Term Energy Outlook* from U.S. Energy Information Administration (Energy Prices)
WTI forecasts	Dollars per Barrel	Quarterly	Convention I: 1-7 quarters /Convention II: 1-8 quarters	Conventions I&II (1-4 quarters): 1991$Q4$	Conventions I&II (1-4 quarters): 2018$Q1$	Conventions I&II (1-4 quarters): NONE /Conventions I&II (5-7(8) quarters)	*Short-Term Energy Outlook* from U.S. Energy Information Administration (Energy Prices)
Brent forecasts	Dollars per Barrel	Quarterly	Convention I: 1-7 quarters /Convention II: 1-8 quarters	Conventions I&II (1-4 quarters): 1991$Q4$	Conventions I&II (1-4 quarters): 2018$Q1$	Conventions I&II (1-4 quarters): NONE /Conventions I&II (5-7(8) quarters)	*Short-Term Energy Outlook* from U.S. Energy Information Administration (Energy Prices)
Gasoline prices[5]	Dollars per Gallon	Monthly	−−	1973:01	2018:06	NONE	U.S. Energy Information Administration (eer_epmru_pf4_y35ny_dpgd)
Heating oil prices	Dollars per Gallon	Monthly	−−	1973:01	2018:06	NONE	U.S. Energy Information Administration (eer_epd2f_pf4_y35ny_dpgd)
Industrial raw materials prices (non-oil)	INDEX	Monthly	−−	1973:01	2018:06	NONE	Commodity Research Bureau (BVY00)

NOTES: The data described in this Table are not revised. For each data series the sample period is $\underline{\tau}, ..., \overline{\tau}$, where $\underline{\tau}$ and $\overline{\tau}$ are the first and last observations.
[1] For each maturity the futures data for the WTI and Brent measures are in the columns, and the rows contain the time series from $\underline{\tau}$ to $\overline{\tau}$ respectively.
[2] The first observations of series with different futures' maturities are not available at the same time. Hence, we separately report the first observations timing at different maturities, denoted using a forward slash.
[3] The forecasts for RAC, WTI, and Brent oil price measures are available in one sheet of the real-time data set. The columns for each measure contain different forecast horizons, and the rows are time series from $\underline{\tau}$ to $\overline{\tau}$ respectively.
[4] Here we only consider the EIA forecasts without missing values. Hence we only report the timing of the first observation of EIA quarterly forecasts ($\underline{\tau}$) for 1-4 quarters in this table.
[5] In the real-time data set, gasoline, heating oil and industrial raw materials (non-oil) prices are provided in each sheet as: columns for vintages and rows for time series, but there is no publication delay nor revisions.

2 The *Monthly Energy Review* and Real-Time Data Revisions

2.1 Organisation of the Data

The main source of our real-time data is the monthly issue of the *Monthly Energy Review*, published by the EIA, which reports the latest vintage of five oil market data series including RAC, world crude oil production, U.S. crude oil inventories, and the U.S. and OECD petroleum inventories.[2] Prior to 1996:01, this publication is not available in electronic format. The construction of the real-time data set from the historical issues is described in detail below.

As shown in Figure 1, the vintages are constructed as columns. We organise all observations that are available for that month in columns; for example, the historical observations available in 1991:12 are placed in the first column, while the final column is the most recently released vintage. The last observation in each column represents the first released data. Hence the diagonal of the data set are first released observations without any subsequent revisions. The EIA publish monthly observations that track back a maximum of 3 years, with the remainder of the historical data at annual frequency. The revisions of the historical observations are at monthly frequencies (as shown in the red box).

We construct real-time data consisting of vintages for 1991:12 through to 2018:06, with each vintage's start date extending back to 1973:01. We update the data set on a monthly basis. The data differ from the previous issue of the *Monthly Energy Review* due to revisions on the historical data and through the addition of newly released observations. For all data series, monthly observations (the red box) going back to a maximum of three years' worth of history are used by BK2012 (pp. 327). [3]

[2] Available at https://www.eia.gov/totalenergy/data/monthly/previous.php

[3] It's worth noting that the EIA provides a more comprehensive history by recording the revised measurements for the annual growth rates, with varying start dates, but we choose not to use this data as the size of the revisions are very small.

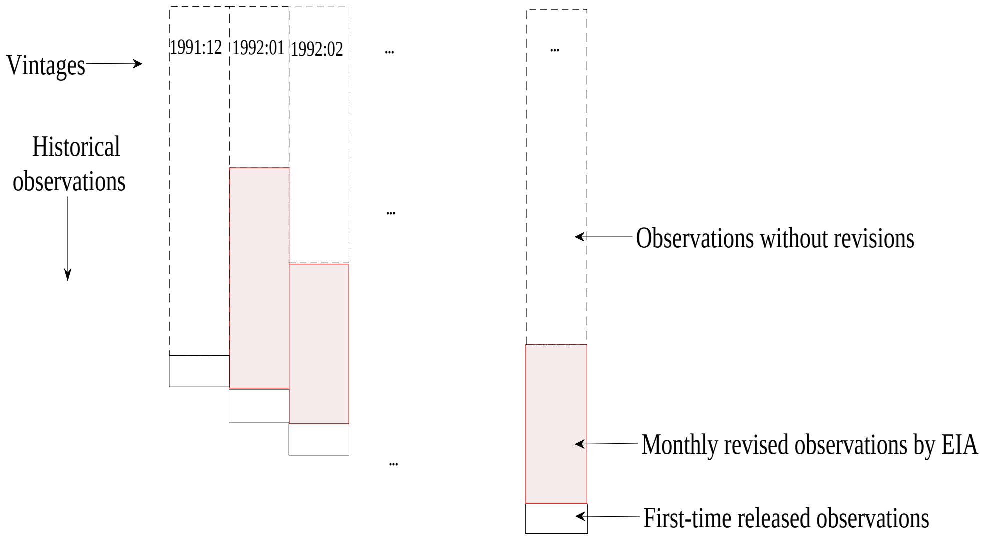

Figure 1: Mechanism of revisions for series from *Monthly Energy Review*

2.2 The Revisions

In Table 3 we describe some basic statistics on the data revisions where, as in BK2012, we make a distinction between in-report and post-report revisions (adopting their terminology). To understand the difference we define ex-post revised data as being constructed from the most up-to-date data downloaded from the EIA website. For BK2015 the most recent data set available at the time of their paper was for 2013:03, but as recent data is considered preliminary, they discard the last six months data. The remaining data, for 1991:12-2012:09, are then treated as in-report vintages when evaluating forecasts and constructing revisions. In our data set, we extend the sample to the 2018:06 vintage of data, and therefore our ex-post revised data is the 2018:06 vintage. The in-report sample for any exercise are the 1991:12-2017:12 vintages. Table 3 considers descriptive statistics on data revisions for the BK2015 sample and the extended sample, in the upper and lower panels respectively.

Following BK2012, we use the notion of in-report revisions which are defined as the average percentage change between the value in the most recent vintage available for that date in subsequent issues of the *Monthly Energy Review* and the value released on the first vintage. For example, consider a value is first released in the 1991:12 vintage. The in-report revision for this value is the average percentage change between the value reported in subsequent vintages from 1992:01 to 2017:12 and the 1991:12 value when it was first released level. The number of first release values are identical with the number of vintages. More specifically, the number of observations (or the in-sample vintages) in BK2015 sample is 250, while in our the extended sample it is 305. The in-report revisions (%) reported in the first column of Table 3 are the average of in-report revisions for the corresponding samples i.e. the average over time and across first, second and so on revisions.

The post-report revisions are measured as the average percentage change between the value reported in the ex-post vintage and the corresponding value reported in the most recent vintage available in subsequent issues of the *Monthly Energy Review*. For example, the first post-report revision of the value released in the 1991:12 vintage is calculated as the average percentage change between its value reported in ex-post vintage 2018:06, and the second, third post-report revisions and so in vintages from 1992:01. The post-report revisions (%) displayed in the second column of Table 3 are the average of post-report revisions for values first released in each vintage within the in-report sample. Standard deviations of in- and post-report revisions relative to the standard deviation of the ex-post data are reported in the third and fourth columns in Table 3. In-report and post-report revisions are differences in levels (as opposed to percentage changes), which gives a direct comparison with respect to ex-post observations. We also present subsequent revisions (%) in Table 3. The 1^{st} revision is the average of percentage changes of the second released observations relative to the first. The 2^{nd} is the average of percentage changes of the third released observations relative to the first, and so on. The last column provides the average number of in-report revisions.

Table 3: Descriptive statistics on data revisions of series obtained from *Monthly Energy Review*

Variables	Ave. Revisions (%)		Std. Dev. relative to ex-post data (levels)		Subsequent revisions (%)			Ave. number of in-report revisions
	In-report	Post-report	In-report	Post-report	1^{st}	2^{nd}	3^{rd}	
	In-report vintage: 1991:12-2012:09 (post-report vintage: 2013:03)							
U.S. Consumer Price Index	−0.057%	−0.015%	0.338%	0.201%	0.131%	−0.015%	−0.230%	3.98
U.S. refiners' acquisition cost of crude oil imports	0.062%	0.034%	2.940%	1.426%	−0.351%	−0.006%	2.055%	3.86
World crude oil production	0.193%	0.139%	1.400%	0.830%	0.387%	0.144%	0.706%	12.51
U.S. crude oil inventories	−0.231%	−0.010%	1.953%	1.368%	−1.637%	0.219%	0.764%	2.58
U.S. petroleum inventories	−0.020%	0.104%	4.406%	1.244%	−1.170%	−1.789%	−0.573%	2.80
OECD petroleum inventories	−0.070%	0.009%	3.323%	1.002%	1.128%	0.818%	−0.705%	9.52
	In-report vintage: 1991:12-2017:12 (post-report vintage: 2018:06)							
U.S. Consumer Price Index	−0.051%	−0.032%	0.292%	0.036%	0.131%	−0.015%	−0.231%	4.35
U.S. refiners' acquisition cost of crude oil imports	0.030%	−0.022%	2.487%	0.039%	−0.351%	−0.006%	2.055%	3.88
World crude oil production	0.175%	0.150%	1.052%	0.216%	0.387%	0.143%	0.706%	15.17
U.S. crude oil inventories	−0.207%	−0.045%	2.115%	0.218%	−1.637%	0.221%	0.766%	2.72
U.S. petroleum inventories	0.024%	0.129%	3.813%	0.239%	−1.170%	−1.789%	−0.571%	2.92
OECD petroleum inventories	−0.047%	0.010%	2.786%	0.342%	1.128%	0.817%	−0.707%	10.37

NOTES: The descriptions of each column is detailed in text. In- and post-report revisions' average of percentage changes and its standard deviation relative to ex-post data are lower than 5% and essentially zero for all variables considered in both BK2015 and extended samples. Extending the sample of the real-time data set, the average number of in-report revisions is increasing, indicating a raising frequency of revisions. The reasons of subsequent revisions are reported in corresponding part of issues of *Monthly Energy Review*.

A general observation, consistent with BK2012, is that the monthly revisions are small relative to actual values of the variables. Moreover, comparing revisions in BK2015's sample relative to our extended sample, we observe that the average number of in-sample revisions is increasing. The relative frequency of revisions declines overtime, but where the subsequent 1^{st}, 2^{nd} and 3^{rd} revisions suggest that this process is not monotonic.

3 Nowcasts of Variables with the Publication Delay

Following BK2012 (pp.329) we adopt two nowcasting methods. One for the RAC oil price using other crude oil price measures, the other for the remaining variables with a publication using historical averages. [4]

3.1 RAC

The real-time RAC oil price becomes available at a point in time, with a lag of 3 months for the period 1991:12 to 2005:07, and with a lag of 2 months post-2005:07. To fill in the values given this delay we extrapolate the RAC oil price using the rate of growth of the WTI oil price as follows:

1. Calculate the growth rate of the WTI oil price, denoted as r_t^{WTI}, at time t as:

$$r_t^{WTI} = \frac{(WTI_t - WTI_{t-1})}{WTI_{t-1}}$$

   where $t = [\bar{\tau} - 2, \bar{\tau} - 1, \bar{\tau}]$ for vintages from 1991:12 to 2005:07, and $t = [\bar{\tau} - 1, \bar{\tau}]$ for the remaining vintages, while $\bar{\tau}$ is the final month in each vintage; for example, $\bar{\tau}$ is 1991:11 from the 1991:12 vintage.

2. Nowcast the missing values $\widehat{RAC}_t$ by

$$\widehat{RAC}_t = (1 + r_t^{WTI})RAC_{t-1}$$

   where $t = [\bar{\tau} - 2, \bar{\tau} - 1, \bar{\tau}]$ for vintages 1991:12 to 2005:07, and $t = [\bar{\tau} - 1, \bar{\tau}]$ for the remainder.

[4] BK2012 nowcasting methods improves the out-of-sample forecast accuracy. In Garratt et al. (2018), we do not show the improvements of forecasting accuracy from the nowcasts, but the related results are available on request.

3.2 The Oil Market Data Published in the *Monthly Energy Review*

The second nowcasting method is applied to the oil market data published in the *Monthly Energy Review* (generically denoted X_t in vintage t), which includes world crude oil production, U.S. crude oil inventories, U.S. petroleum inventories, and OECD petroleum inventories. In general the variables have different publication lags, detailed in Table 1 under 'The publication delay', which we denote by lag below. Following BK2012 (pp. 329), we extrapolate based on the historical average rate of change up to that point in time by:

$$\widehat{X_{t-j}} = X_{t-lag} + \frac{\sum_{i=\underline{\tau}}^{n-lag}(X_{i+1} - X_i)}{t - \underline{\tau} - lag} * (lag - j)$$

where $n = [227, \ldots, 527]$ in vintages t=[1991:12, ..., 2017:12] respectively, and $j = [0, \ldots, lag - 1]$. $\underline{\tau}$ is the timing of the first observation in each vintage defined in table 1, and X_{t-lag} is the final observation in each vintage.

4 Backcasts

This real-time data set contains vintages from 1991:12 to 2018:06, each covering data extending back to 1973:01. To achieve this, for RAC and OECD petroleum stocks we have backcast as they are only available after 1974:01 and 1988:01, respectively. Here we describe the method for extrapolating backwards to construct these missing observations.

4.1 RAC

In constructing the monthly RAC from 1973:01 to 1974:01, we follow BK2012. This procedure involves scaling the monthly percentage rate of change in the U.S. crude oil producer price index (PPI for oil), provided by the U.S. Bureau of Labor Statistics (available at: https://data.bls.gov/timeseries/PCU333132333132), for 1973:01 to 1974:01, by the ratio of the growth rate in the annual RAC over the growth rate in the annual U.S. PPI for crude oil. The process is:

1. Estimate the approximate monthly RAC growth rate, $g_{M,t}^{RAC}$, where t=[1973;01, ..., 1973:12], as:

$$g_{M,t}^{RAC} = \frac{g_{M,t}^{PPI} \times g_{A,1974}^{RAC}}{g_{A,1974}^{PPI}}$$

   where, $g_{M,t}^{PPI}$ is the monthly PPI growth rate for oil at time t, $g_{A,1974}^{RAC}$ and $g_{A,1974}^{PPI}$ are the annual growth rates of RAC and PPI oil prices in 1974 respectively. The annual PPI for oil in 1973 and 1974 are calculated as the average of the monthly observations. The start points of the process use observations of the RAC price in 1973 and 1974 of 4.08 and 12.52 dollars per barrel respectively (Available at https://www.eia.gov/opendata/qb.php?category=293676&sdid=PET.R1300____3.A).

2. The backcasts of RAC then are calculated through:

$$RAC_t = \frac{RAC_{t+1}}{1 + g_{M,t+1}^{RAC}}.$$

4.2 OECD Petroleum Stocks

For OECD petroleum stocks prior to 1988:01, we extrapolate the percentage change in OECD inventories, $Inv_t^{OECD.p}$, backwards at the rate of growth of U.S. petroleum inventories ($g_t^{US.p}$), following Kilian & Murphy (2014):

$$Inv_t^{OECD.p} = \frac{Inv_{t+1}^{OECD.p}}{1 + g_{t+1}^{US.p}}$$

where t=[1973;01, . . . , 1987:12].

Additionally, we adjust the real-time OECD petroleum inventory data to account for changes in the set of OECD members reporting inventories in 2001:12. EIA (2001) report three changes: (1) South Korea is added to the table; (2) data for the Czech Republic, Hungary, and Poland are added to "OECD Europe"; (3) data for Mexico are added to "Other OECD", and OECD is recalculated to reflect the changes in other columns. To preserve the consistency of the real-time and the ex-post revised inventory data overtime, we made adjustments to the pre 2001:12 vintages provided by BK2012. This involved adding in inventories for these countries, consistent with BK2012, to ex-post revised data from the EIA supplement the petroleum inventories to construct real-time equivalents of the OECD petroleum inventory data in vintages prior to 2001:12.

5 Variables Requiring Specific Processing

In this section we describe the construction of an index of global real economic activity, expected OECD crude oil inventories, oil futures prices at maturities 1-24 months, and EIA's forecasts respectively.

5.1 Activity Indexes

The index proposed by Kilian (2009) known as the global real economic activity (rea) index is one of the regressors when estimating unrestricted global oil market vector autoregression (VAR) models. Data used for constructing the rea index include the single voyage freight rates collected by Drewry Shipping Consultants Ltd., historical exchange rates available in Bloomberg (quoted as GBPUSD), the U.S. Consumer Price Index (CPI), and the Baltic Dry Cargo Index available in Bloomberg (quoted as BDIY:INDEX).

Kilian's (2009) rea index updated on http://www-personal.umich.edu/~lkilian/reaupdate.txt, uses single voyage freight rates as follows:(1) Access the single voyage freight rates collected by Drewry Shipping Consultants Ltd. for various bulk dry cargoes comprising grain, oilseeds, coal, iron ore, fertilizer and scrap metal, which are provided for different commodities, routes and ship sizes; (2) take averages of the freight rates; (3) compute the period-to-period growth rates for each series; (4) take the equal-weighted average of these growth rates, and cumulate the average growth rate, having normalised 1968:01 to unity; (5) deflate this series with the U.S. CPI; and (6) linearly detrend.

Our real-time rea index constructed in this database, for ease when working with real-time data, uses two methods. For 1970:05 to 1985:11, we use average monthly single voyage freight rates. For post 1985:01, we use nominal shipping rate raw data, namely the Baltic Dry Cargo Index (the overlapping period uses an average). Using the Baltic Dry Cargo Index, also utilised to construct Kilian's real economic index for analysing the oil market models, enables real-time data to be updated electronically, whereas using single freight rates are only available in hard copy form. We collected the raw data, published in the Shipping Statistics and Economics Journal (ISSN: 0306-1817, No.1–282, 1970–1994).

We provide more details of our approach as follows:

1 Single voyage freight rates from 1970:05 to 1985:11 are collected by Drewry Shipping Consultants Ltd. (only available in hard copy).[5] Various bulk dry cargoes are considered including grain, coal, iron ore, fertiliser and chemicals, oilseeds, scrap metal, iron, steel, miscellaneous products, sugar, other agricultural products,[6] manufactured products,[7] forest products, and other ores and minerals,[8] which

[5]The data published in the Shipping Statistics and Economics journal are only available back to 1970:05.

[6]Inclusive of citrus pellets, lentils, logs, flour, soya, and tallow.

[7]Inclusive of agricultural products, rice, cement, and petroleum coke.

[8]Inclusive of alumina, barytes, concentrates, bauxite, chrome ore, tincal borate, magnesite and manganese ore.

are provided for different commodities, routes and ship sizes. During the period considered here, since some of these items are priced in sterling (GBP), the GBP value is converted into USD through the monthly historical exchange rates calculated as the average of the daily last observations (available in Bloomberg, quoted as GBPUSD).

2 Take the average of the single voyage freight rates by bulk dry cargoes, shown in the first (top) panel in Figure 2. Hence we have an average for each type of cargo.

3 Take the average across by bulk dry cargoes, and then normalising 1985:01 to 1,000, as the Baltic Dry Cargo Index begins with 1,000 in 1985:01. This is shown in the second panel of Figure 2. The Baltic Dry Cargo Index is shown in the third panel.

4 Combine the equal-weighted dry cargo index and the Baltic Dry Cargo Index, where the over-lapping portions (1985:01 to 1985:11) are the average of the two. Then, the combined index normalises 1970:05 to unity, as shown in the fourth panel.

5 The real-time Real Economic Activity Index is recursively constructed as the combined index deflated with U.S. CPI and linearly detrended, and scaled by times 100. The final vintage of 2018:06 is shown in the last panel.

Echoing Kilian (2009), we also indicate events in the oil market after 1973 in Figure 2, including the Yom Kippur War/OPEC oil embargo (1973–1974), the Iranian Revolution (1978–1979), the Iran–Iraq War (1980–1988), the Gulf War (1990–1991), Venezuela's civil unrest (2002), the Iraq War (2003–2011), the financial crisis (2008), the Gaza War (2009), and the European sovereign debt crisis (2010–2014). The combined index is shown in Figure 2. Note, the real-time rea changes over vintages, due to the revisions of U.S. CPI, linear detrending and rescaling processes.

Hamilton (2018) proposes an 24-month cumulative growth rate of real shipping rates as an alternative measure of global activity, which involves performing steps 1-4 as described above, followed by a fifth step below, see a detailed discussion at http://econbrowser.com/archives/2018/08/measuring-global-economic-activity. See Kilian & Zhou (2018) and Kilian (2018) for discussions of various measures of activity.

. . .

5 Deflate the combined index with U.S. CPI, denoted as $Index_t$. Then, the Hamilton activity index is recursively constructed as $Index_t - Index_{t-24}$, scaled by 100.

Both series are provided in the data base. Figure A-1 in the online appendix plots the two series.

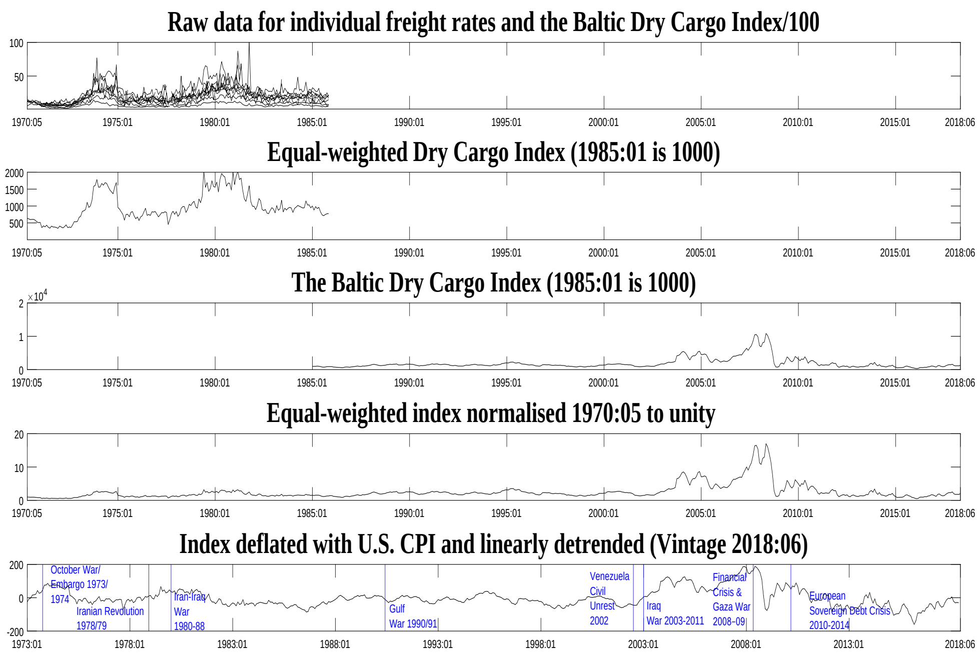

Figure 2: Monthly index of global real economic activity based on dry cargo bulk freight rates and the Baltic Dry Cargo Index (1973:01-2018:06)

5.2 Expected OECD Crude Oil Inventories

Following BK2012 the expected OECD crude oil inventory is calculated as the ratio between the petroleum inventory in the OECD and the petroleum inventory in the U.S.

times the crude oil inventory in the U.S.The ratio, r_t, is calculated as

$$r_t = \frac{petinv_t^{OECD}}{petinv_t^{US}}$$

where $petinv_t^{OECD}$ and $petinv_t^{US}$ are petroleum oil inventories in OECD countries and in U.S. without nowcasts respectively. r_t is calculated in vintages 1991:12-2002:10 with 5 months delay, in vintages 2002:11-2016:06 with 4 months delay, and after vintage 2016:06 with 3 months delay. The ratio using the vintage 2016:06 is presented in Figure 3. To take account of the lagged observations in the OECD petroleum inventory data, we nowcast the missing ratios as the last observed ratio in the corresponding vintage.

Figure 3: Ratio between petroleum inventory in the OECD and the U.S.

5.3 Oil Futures Prices at Maturities 1-24 Months

WTI and RAC crude oil price futures are traded on the New York Mercantile Exchange (NYMEX), while the Brent oil price futures are traded on the trading floor of Intercontinental Exchange Futures Europe (ICE). We collect this data at a monthly frequency, at maturities from 1 to 24 months where available, from Bloomberg, calculated as the average of the daily last prices (quoted as cl'n':com and co'n':com for WTI and Brent, respectively, where 'n' is the maturity).

However, this futures data used in forecasting models for the oil price, often has missing values from the online sources; for WTI and RAC futures at the 18 to 24 month maturity for the period 1991:12 to 1995:08; and for Brent futures, at the 9 to 24 month maturity between 1991:12 and 1994:04, and at the 12 to 24 month maturity for the 1994:04 to 2005:02 period. Here we document how we fill in these missing values.

Values for monthly missing data are added (recursively) through the following process, see more detailed discussions in Hevia et al. (2016) and Garratt & Petrella (2018). Specifically, the log of futures price, $f_{jt,h}$ at time t expiring in h months, is assumed to be a function of level and slope, where j denotes WTI and Brent measures respectively:

$$f_{jt,h} = \beta_{0,jt} + \frac{h}{12}\beta_{1,jt} + \frac{1 - e^{-\lambda_j h/12}}{\lambda_j}\beta_{2,jt} + \varepsilon_{jt,h} \tag{1}$$

where $\beta_{0,jt}$ corresponds to the implied log of the spot price derived from the entire futures curve, while $\beta_{1,jt}$ and $\beta_{2,jt}$ are respectively the level and slope of the cost-of-carry. $\varepsilon_{jt,h}$ is assumed an *iid* measurement error. The joint dynamics of the factors follow a restricted VAR(1):

$$\beta_{j,t} = c_j + \Phi_j \beta_{j,t-1} + u_{j,t}$$

where $\beta_{j,t}$ is a vector $[\beta_{0,jt},\ \beta_{1,jt},\ \beta_{2,jt}]'$, and $u_{j,t}$ $N(0, \Omega_j)$. We assume Φ_j and Ω_j are diagonal matrices, and utilise the Kalman Filter to estimate the model, dealing with the unbalanced nature of the data (see Harvey (1990) for more details). We then construct the futures price for the missing values, $\hat{F}_{jt,h}$, based on equation (1), as:

$$\hat{F}_{jt,h} = exp[\beta_{0,jt} + \frac{h}{12}\beta_{1,jt} + \frac{1 - e^{-\lambda_j h/12}}{\lambda_j}\beta_{2,jt}]$$

For the purpose of a real time data, we recursively estimate $\hat{F}_{jt,h}$ over sample 1991:12-2018:06. In other words, t is [1983:03, ..., $\underline{\tau}$] for the WTI measure and [1988:06, ..., $\underline{\tau}$] for the Brent measure, where $\underline{\tau}$ is the timing of the last observation over our sample period from 1991:12 to 2018:06. We check the fit of the recursive estimates, $\hat{F}_{jt,h}$, over period 1991:12-2018:06 through the average R_h^2 at horizon h. The smallest R_h^2 is over 99%, indicating a very good fit of the entire futures curve. Thereafter, we fill the missing of futures prices over period 1991:12 to 2018:06 by recursively estimated $\hat{F}_{jt,h}$.

5.4 Oil Price Forecasts from U.S. Energy Information Administration

The data source for the EIA's oil price forecasts is their *Short-Term Energy Outlook*[9]. The publication provides quarterly forecasts of the U.S. refiners' acquisition cost for imports at horizons 1 to 7 quarters, and recent publications include the quarterly forecasts of WTI (since 2000:10) and Brent crude oil (since 2012:07) prices. Given the irregular pattern of the reports, however, consistent time series of quarterly forecasts dating back to 1991 can only be obtained for horizons from 1 to 4 quarters ahead.

For the 1991 to 1996 period, the *Short-Term Energy Outlook* is issued every quarter, while from 1997 onwards the publication is released on a monthly basis, but only reports quarterly forecasts.[10] The monthly publications are typically issued within the first 2 weeks of each month. The EIA updates its quarterly forecasts in each monthly report, incorporating new information as it becomes available.

To make the forecast comparison meaningful it is important to match the information set of the EIA as closely as possible with our information set. Following BK2015, for *timing convention I*, the oil price reported for the current quarter is taken as the nowcast and the oil prices reported for the subsequent quarters represent the forecasts. The corresponding real oil price forecasts are obtained by adjusting the nominal EIA oil price

[9]Available at https://www.eia.gov/outlooks/steo/outlook.php

[10]Monthly forecasts have been available in the EIA's *Short-Term Energy Outlook* since August 2004 for RAC and WTI, and since July 2012 for Brent. EIA monthly nominal forecasts for RAC, WTI and Brent crude oil prices are included at horizons of 1 to 24 months in the data set.

forecasts for expected inflation. The process is embodied in the following forecasting model of quarterly EIA forecasts $\hat{R}^{oil,Q}_{t+h|t}$ at horizon h on quarter t:

$$\hat{R}^{oil,Q}_{t+h|t} = R^{oil,Q}_{t}(1 + P^{h,EIA}_{t} - s_t - E_t(\pi^{h}_{t+h}))$$

where $R^{oil,Q}_{t}$ is the real quarterly observation of crude oil measures (deflated by the U.S. CPI), $P^{h,EIA}_{t}$ is the log of the current EIA forecasts at horizon h quarter(s), s_t is the corresponding log spot oil price, and $E_t(\pi^{h}_{t+h})$ is the expected quarterly U.S. inflation, as the average U.S. CPI inflation available at time t, where the averaging begins in 1986:Q3, hence:

$$E_t(\pi^{h}_{t+h}) = [1 + \frac{1}{\overline{\tau} - \underline{\tau}} \sum_{t=\underline{\tau}}^{\overline{\tau}} (ln(CPI_{t+1}) - ln(CPI_t))]^h - 1$$

where $t = [\underline{\tau}, ..., \overline{\tau}]$, $\underline{\tau}$=1986Q3 and $\overline{\tau}$ is the quarter of the final observation in a specific vintage. This method is consistent the forecasts from an oil futures spread based model, introduced in BK2015 (pp. 348).

Under *timing convention II*, the price reported for the previous quarter (e.g., the Q1 price in the April issue) is considered the nowcast, and the price quoted for the current quarter (e.g., Q2 in the April issue) is the one-quarter-ahead forecast. As illustrated in BK2015, we also found that the forecasts of EIA *timing convention II* are far more accurate than of *timing convention I*.

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