Physical Market and WTI/Brent Price Spread

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Abstract

West Texas Intermediate (WTI) and Brent Crude are primary benchmarks in oil pricing. Despite difference in locations, WTI and Brent are of similar quality and are used for similar purposes. Under oil market globalization assumption (Weiner, 1991), prices of crude oils with same quality move closely together all the time. However, empirical evidence shows that notable variations exist in WTI/Brent spread, particularly after 2010, creating risks as well as potential arbitrage opportunities for oil market participants. In this paper, we study the dynamics of WTI/Brent price spread for the period between January 1994 to March 2016 and investigate how WTI/Brent spread responds to different types of physical market shocks. First, a procedure suggested by Bai and Perron (1998, 2003) is used to test for structural breaks in WTI/Brent price spread. It is found that WTI/Brent price spread changed from a stationary time series to a non-stationary time series in December 2010. Then we examine the impacts of physical-market fundamentals on the dynamics of WTI/Brent price spread. A Structural Vector Autoregressive Model (SVAR) is estimated for each sub-sample period separated by the structural break to show how WTI/Brent price spread responds to different shocks in physical market, including shocks in WTI supply, Brent supply, US demand and international demand. Impulse response function graphs show that WTI/Brent spread only has significant and consistent response to shocks in Brent supply variable, which is proxied by Norway crude oil production.

1. Introduction

Crude oil is the one of the most important industrial commodities. A variety of crude oils of different characteristics are produced and traded around the world. Among them, West Texas Intermediate (WTI), Brent and Dubai Crude are three primary benchmarks. WTI and Brent are both light (low density) and sweet (low sulfur) crude oils, making them ideal for refining petroleum products. Dubai/Oman is a medium sour crude oil with higher density and sulfur content. WTI is produced and

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primarily used as a benchmark in the U.S. It is delivered by pipeline system and mainly responds to conditions within the U.S. Brent crude is a combination of four crude streams in the North Sea. Since Brent is waterborne and can be easily transported to distant locations by oil tankers, it serves as an international crude oil benchmark and is more responsive to global market fundamentals. Dubai/Oman is produced mainly in Persian Gulf area and is typically used as a main reference for Persian Gulf oil delivered to the Asian market.

The concept of "globalization" in oil market has been brought up by Weiner (1991). The basic idea of oil market globalization is that supply and demand shocks to oil prices in one region can be transferred into other regions quickly, making prices of crude oils with same quality move closely together. Based on this hypothesis, price spread between crude oils with similar quality should only consists of quality discount, transportation cost, and time discount. Even though, in terms of quality WTI is slightly lighter (and thus more valuable), WTI and Brent are both considered light and sweet forms of crude oil. Therefore spread between WTI and Brent is supposed to be nearly constant over time (Fattouh, 2010). However, empirical evidence shows that notable variations exist in WTI/Brent spread, particularly after 2010 (see Figure 1). In this paper, I study the dynamics of WTI/Brent price spread by investigating two questions. (1) Is WTI/Brent price spread stationary over time? (2) What factors are driving the variations in WTI/Brent spread? (i.e. How WTI/Brent spread responds to different types of shocks?)

The United States has been divided into five Petroleum Administration for Defense Districts (PADD) (see Figure 2). PADD3 (Gulf Coast), with around half of the U.S.'s production and refining capacities, is the primary oil production and refining area. In addition, PADD3 receives more than 50% of the imported crude oil, mainly transported from harbors on the Gulf Coast. WTI is distributed mainly by the pipeline system, which is considered more flexible, and can be delivered to 'landlocked' areas. Cushing, Oklahoma, is a hub with many intersecting pipelines as well as storage facilities. It has served as the price settlement point for WTI on the New York Mercantile Exchange since 1983 and the inventory level at Cushing is believed to have important impact on WTI price (Büyüksahin et al., 2013; Li, Mizrach and Otsubo, 2015).

The applications of hydraulic fracturing and horizontal drilling technologies have caused a boom in shale oil production starting in 2008. Shale oil production somewhat changes the crude oil production map in the U.S. Historically, crude oil has been transported by pipeline from PADD3, via Cushing, to other PADDs with limited production or refining capacity, such as PADD1 and PADD2. More recently, the large amount of crude oil production from some major shale formations in the North (North Dakota, Canada, etc.) made it necessary to transport crude oil from the North to Cushing and then to Gulf Coast, which is opposite to the direction of the pre-existing pipelines. From 2008 onwards, the increasing crude oil inflows from the North to Cushing exceeded the pipeline capacity from Cushing to the Gulf Coast and created a supply glut in Cushing. Both the reversal of existing pipelines and the construction of new pipelines takes time. Between 2009 and 2014, the crude oil pipeline network has increased by around 26% or 14,000 miles (WSJ, 2015). Several pipeline projects, such as the reversal of the Seaway pipeline and Gulf Coast portion of the TransCanada's Keystone XL, have already been completed. New pipelines have relieved the inventory in Cushing, the WTI price settlement point. By contrast, the production of Brent crude has been relatively stable. Brent crude is waterborne and usually shipped in oil tankers, which makes infrastructures less likely to cause bottlenecks.

The properties of WTI/Brent price spread as a time series have been studied in the existing literature. Before 2010, most authors find WTI/Brent spread to be a stationary process. Gülen (1997, 1999) finds that oil prices in different markets move closely both in the short run and in the long run. Fattouh (2010) also finds that several pairs of different crude oil price differentials all follow stationary processes. After 2011, consistent with Figure 1, different evidence has been put forward. Buyuksahin et al. (2013) show strong evidence to support their hypothesis that there are two breakpoints in the WTI/Brent spread in 2008 and 2010. Chen, Huang and Yi (2015) find that WTI/Brent crude oil price spreads changes from a stationary time series to a non-stationary time series in 2010.

However, the reasons behind the variations in WTI/Brent spread have not been studied much. Some factors are identified as contributing to WTI/Brent price spread includes inventory in Cushing Oklahoma (Büyüksahin et al., 2013; Li, Mizrach and Otsubo, 2015), macroeconomic conditions or business activity (Büyüksahin et al., 2013), Chinese demand (Li, Mizrach and Otsubo, 2015), Canadian crude imported into PADD2 (Büyüksahin et al., 2013), and financial market liquidity and activity (Büyüksahin et al., 2013; Heidorn, 2015).

In this essay, structural break test in WTI/Brent spread using the procedure from Bai and Perron (1998, 2003) is conducted. Then a Vector Error Correction Model (VECM) is estimated to explore the response of WTI/Brent spread to different types of structural shocks from physical market, both supply shocks and demand shocks.

2. Methodology

2.1. Structural Change Test

An implicit assumption of econometric models is that within-sample parameters should be constant over time. So before building the econometric model, structural break test is conducted to avoid instability in parameters. In this part, a procedure suggested by Bai and Perron (1998, 2003) for testing multiple structural breaks will be applied to WTI / Brent price spread. This procedure allows to test for the presence of multiple structural changes in a sequential way and construct confidence intervals around the estimated break dates without pre-specifying the breaking time.

2.2. Variables Selection

In this part, several physical market factors that can possibly explain the WTI/Brent spread are proposed.

(1) Supply

WTI is referred to as the U.S. benchmark price. We follow Büyüksahin et al (2013) and use U.S. crude oil production together with import from Canada to approximate WTI supply. More specifically, supply of WTI is calculated as the sum of monthly (per day) U.S. Field Production of Crude Oil and the monthly (per day) amount of Canadian crude imported into PADD2(Midwest). Both data series are published by the EIA.

Brent includes four crude streams from four different oil fields (Brent Blend, Forties Blend, Oseberg and Ekofisk) in the North Sea. Due to the limited availability of Brent production, we use Norway production as a proxy for Brent production.

(2) Demand

Purchasing Managers' Index (PMI) is an indicators of the economic health of manufacturing sector. The data for the index are derived from monthly surveys of companies in the manufacturing sector on seven different fields. Given that a large part of crude oil is consumed by manufacturing sector, PMI in U.S. is used as a proxy for WTI demand.

Hamilton (2009) points out that global demand for crude oil experienced strong growth in the recent three decades, and most of the contribution is from the international demand, especially demand from developing economies such as China and India. Economic activity drives the demand for transportation service as well as demand for industrial commodities. Kilian (2009) introduces “a measure of monthly global real economic activity” using bulk freight rate data. The index constructed by Kilian (2009) is used as a proxy for international crude oil demand.

(3) Logistics

Geographical differences between production locations and refining locations result in transportation cost and inventory. Brent crude is carried by tankers, so the freight rate factors into the cost of Brent. Given that the freight rate is already considered in the index for global economic activity, it will not be double-counted here.

WTI crude is mainly transferred by pipelines, constraints on the pipeline capacity can create surplus or shortage in different areas, and thus affect the price. Due to fluctuations in production and limitation on pipeline capacity, crude oil storage is created in Cushing, Oklahoma, the delivery point for WTI. Higher inventory level will push price lower and vise versa. Cushing storage has been used extensively in literature as a factor to explain oil price (Buyuhsahin et al, 2013; Heidorn, 2015). However, Cushing storage shows very high collinearity with WTI supply data, thus it's not included in our model.

2.3. Structural Vector Autoregressive Model (SVAR)

Following Killian (2011), a Structural Vector Autoregressive Model (SVAR) model is set up. Y_t is a 5× 1 vector that includes WTI and Brent supply, US and International demand and WTI/Brent Spread (in real dollars).

$$Y_t = \begin{bmatrix} Y_t^{WTI\_supply} \\ Y_t^{Brent\_supply} \\ Y_t^{WTI\_demand} \\ Y_t^{Int\_demand} \\ Y_t^{rspread} \end{bmatrix} \quad (1)$$

where $\mathrm{t} = 1,2, \ldots, \mathrm{T}$.

Assume that Y_t can be modeled using a structural VAR of a finite order p, i.e.

$$B_0 Y_t = B_1 Y_{t-1} + B_2 Y_{t-2} + \cdots + B_p Y_{t-p} + \varepsilon_t \quad (2)$$

where ε_t are structural shocks that are mean zero and serially uncorrelated,

$$\mathrm{E}(\varepsilon_t | Y_{t-1}, Y_{t-2}, \ldots, Y_{t-P}) = 0 \quad (3)$$

$$\mathrm{E}(\varepsilon_t \varepsilon_t') \equiv \Sigma_\varepsilon = \begin{bmatrix} \sigma_1^2 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_p^2 \end{bmatrix} \quad (4)$$

The SVAR model in a compact form is

$$B(L)Y_t = \varepsilon_t \quad (5)$$

where $B(L) \equiv B_0 - B_1 L - B_2 L^2 - \cdots - B_p L^p$ is the autoregressive lag order polynomial.

To make estimation possible, SVAR model is converted to its reduced form, VAR model, by pre-multiplying both side by B_0^{-1}

$$B_0^{-1} B_0 Y_t = B_0^{-1} B_1 Y_{t-1} + B_0^{-1} B_2 Y_{t-2} + \cdots + B_0^{-1} B_p Y_{t-p} + B_0^{-1} \varepsilon_t \quad (6)$$

Thus model (2) can be rewritten in the reduced form as

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots + A_p Y_{t-p} + u_t \quad (7)$$

where $A_i = B_0^{-1} B_i, i = 1, 2, \dots, p, u_t = B_0^{-1} \varepsilon_t, t = 1, 2, \dots, T$.

The structural shocks are serially uncorrelated, while the reduced-form residuals are not. Consistent estimates of the reduced-form parameters $A_i,, i = 1, 2, \dots, p$ and the reduced-form errors u_t can be obtained. However, the reduced-form errors u_t are basically weighted average of structural shocks ε_t, and thus cannot tell us about the response of Y_t to structural shocks. As a result, the main task would be to identify the transformation matrix B_0^{-1}.

2.4. Identification of SVAR Model: Recursiveness Assumption

For a 6-dimensional vector Y_t, B_0^{-1} is a 5×5 matrix with 10 free parameters. Identification can be achieved by imposing restrictions on the elements of B_0. Restrictions on the parameters can take on many forms, such as recursiveness assumption, short-run restrictions, long-run restrictions, sign-restrictions, etc (Kilian, 2011). In recursively identified models, reduced-form residuals are made to be uncorrelated, or “orthogonalized”, so that structural residuals can be separated from reduced-form residuals (Kilian, 2011). Short/Long-run restrictions assume short/long-run response of variables to shocks, and sometimes they can be combined in estimating B_0^{-1}(Kilian, 2011). Identifications by sign restrictions are achieved by restricting the sign of the response of variables to structural shocks (Kilian, 2011).

The model in this paper is identified by recursiveness assumption. Recursiveness assumption has been extensively used in literatures on energy market (Kilian, 2009). Justifications of recursiveness assumption come from the economic rationale. Since frequent changes to either production or import plan is costly, supply does not respond contemporaneously to demand shocks, while demand can respond to supply shocks right away (Stevens, 2014). Based on this consideration, supply shocks are put before demand shocks in the vector of structural shocks ε_t. Storage shock is located after the demand shocks for the reason that supply and demand changes can be immediately reflected in storage. In addition, because oil prices respond to supply shocks, demand shocks and storage shocks contemporaneously, WTI/Brent spread shock is the last one in ε_t.

Under recursiveness assumption, the reduced-form residuals are orthogonalized by using Cholesky decomposition (Kilian, 2011), and B_0^{-1} becomes a low triangular matrix. Thus $u_t = B_0^{-1}\varepsilon_t$ is written as

$$\begin{bmatrix} u_t^{WTI\_supply} \\ u_t^{Norway\_production} \\ u_t^{PMI} \\ u_t^{Kilian} \\ u_t^{rspread} \end{bmatrix} = \begin{bmatrix} b_{11} & 0 & 0 & 0 & 0 \\ b_{21} & b_{22} & 0 & 0 & 0 \\ b_{31} & b_{32} & b_{33} & 0 & 0 \\ b_{41} & b_{42} & b_{43} & b_{44} & 0 \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{WTI\_supply\_shock} \\ \varepsilon_t^{Norway\_production\_shock} \\ \varepsilon_t^{PMI\_shock} \\ \varepsilon_t^{Kilian\_shock} \\ \varepsilon_t^{rspread\_shock} \end{bmatrix} \qquad (8)$$

3. Data

Monthly data from January 1994 to March 2016 are used to implement the methodology described in the previous section, there are 267 observations in total. Five data series are used in SVAR analysis: WTI_supply, Norway Production, PMI, Kilian's index and WTI/Brent price spread. Monthly WTI and Brent prices, WTI supply and Norway production data are sourced from US Energy Information Administration. PMI is from Datastream Professional Database and Kilian's index is downloaded from Kilian's website. Time series plots of all five variables are shown in Figure 1, Figure 3, Figure 4*: Norway Production*

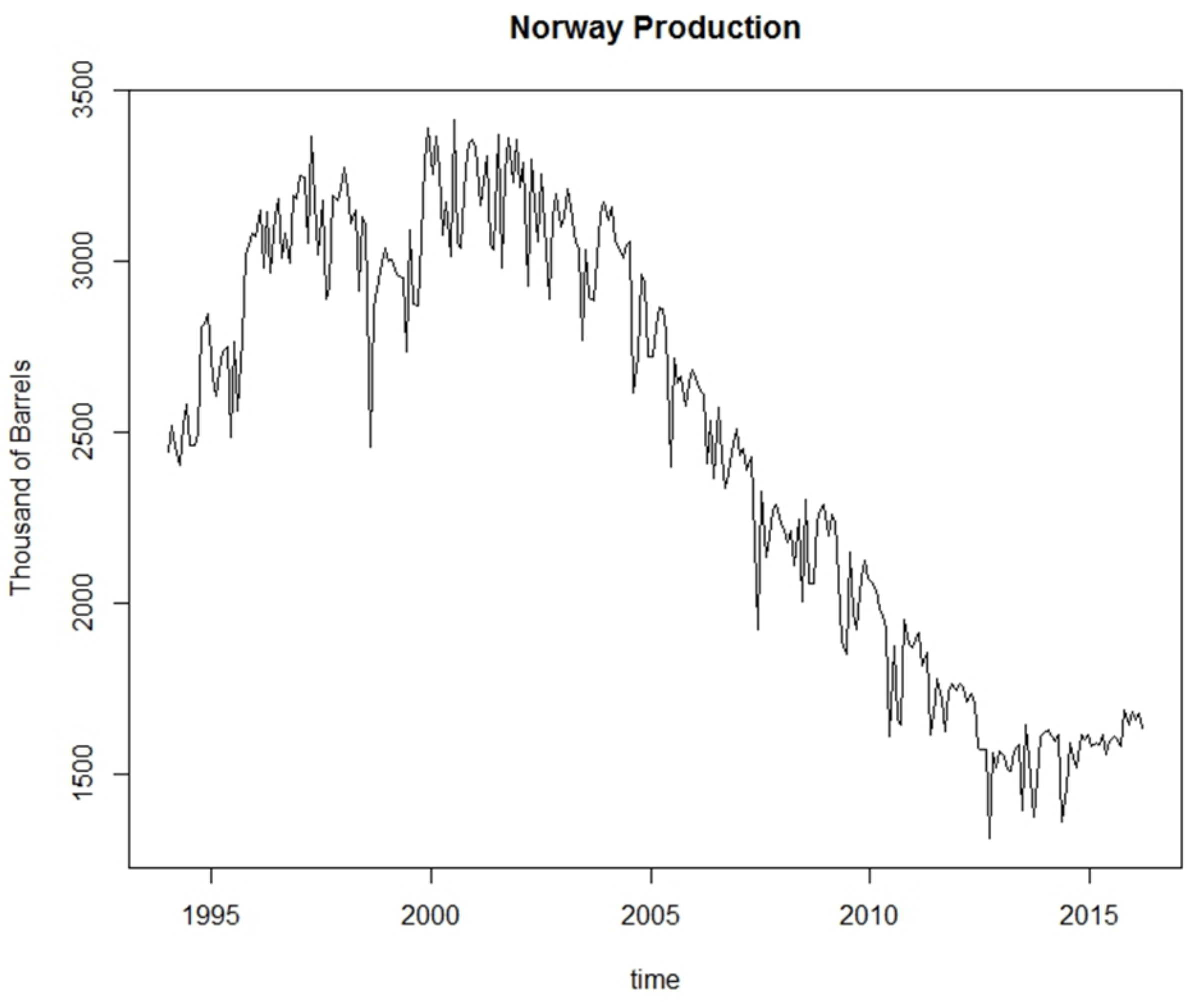

Figure , Figure , **Error! Reference source not found.**, respectively. Table 1 below presents the descriptive statistics of five variables used in SVAR model.

4. Results

4.1 Structural Break Test

Bai and Perron (1998, 2003) procedure is applied to WTI/Brent price spread to test for possible structural breaks. It suggests a structural break in December 2010. In addition, the 95% confidence interval gives a ranges from August 2010 to January 2011. Two sub-sample periods separated by the breakpoint are considered in the following analysis. The first sample period span from January 1994 to November 2010 (203 observations), the second sample period last from December 2010 to March 2016 (64 observations).

4.2 Structural Vector Autoregressive (SVAR)

Given that a structural break presents in WTI/Brent price spread, two SVAR models are specified for the two sub-sample periods, respectively.

The optimal lags are selected using the Schwarz Criterion. The optimal lag orders for both sub-sample periods are 1 under Schwarz Criterion. With lag orders specified, each SVAR model is then estimated and impulse response functions are produced. Impulse Responses function describes the response of a variable to a one standard deviation unexpected shock from another variable, keeping all other variables constant. In this paper, we focus on examining the response of WTI/Brent price spread to shocks in WTI supply, Norway production, PMI index and Kilian's index.

In Figures 7 to 10, the estimated impulse responses with the corresponding 95% standard error bands are presented. The responses of the dependent variables are obtained by considering one standard deviation shocks. Figure 7 (A) and (B) show how WTI/Brent spread responds to unexpected one standard deviation increase in WTI supply. In sub-sample 1, WTI/Brent price spread shows negative response to an unexpected increase in WTI supply almost instantaneously after the shock, the effect becomes smaller and finally becomes insignificant after 2 months. In sub-sample 2, while WTI/Brent spread doesn't show significant reaction right after the shock in WTI supply, it shows positive response to an unexpected increase in WTI supply only after the 3rd month. The impulse responses of WTI/Brent price spread to Norway production shocks (Figure 8 (A) and (B)) indicate that an unexpected increase in Norway oil production is generally followed by an increase in WTI/Brent price spread, or a decrease in Brent price relative to WTI. Time series evolution of the effect is consistent for both sample period: it is very small at the beginning but keep increasing and reaches the maximum in the 2^{nd} or 3^{rd} month after the shock, and the effect generally fades away after that. The impact is significant during sub-sample 1 but insignificant during sub-sample 2. It can be seen from Figure 9 (A) and (B) that shocks in PMI, which is a proxy for US demand for crude oil, doesn't have significant impact on WTI/Brent price spread. Similarly, WTI/Brent price spread doesn't react significantly to shocks in Kilian's global real economic activity index, which is interpreted as an indicator of international demand for crude oil.

5. Conclusion

This paper analyzes the time series dynamics of WTI/Brent spread and how it responds to different physical market shocks, including supply shocks, demand shocks and inventory shocks. Bai-Perron procedure(1998, 2003) is used to test for possible structural breakpoints in the time series. Test result shows that a structural break happens at December 2010, with the 95% confidence interval ranging from Aug 2010 to January 2011. Two sub-sample periods separated by the structural break are then specified, one spans from January 1994 to November 2010 and the other lasts from December 2010 to March 2016. A Structural Vector Autoregressive (SVAR) model is estimated for each sub-sample period and impulse response functions are produced. The impulse response function graphs show that among four physical market variables, WTI/Brent spread only responds significantly towards unexpected shocks in supply variables and consistently only towards unexpected shocks in Norway production. More specifically, a decrease in Brent price relative to WTI price is always followed by an increase in Norway production. The impact starts right after the shock and the peak response occurs a few months after the shock. Closely monitoring Norway production is important for forecasting WTI/Brent price spread.

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Figure 1: WTI/Brent Price Spread (Jan 1994 - Mar 2016)

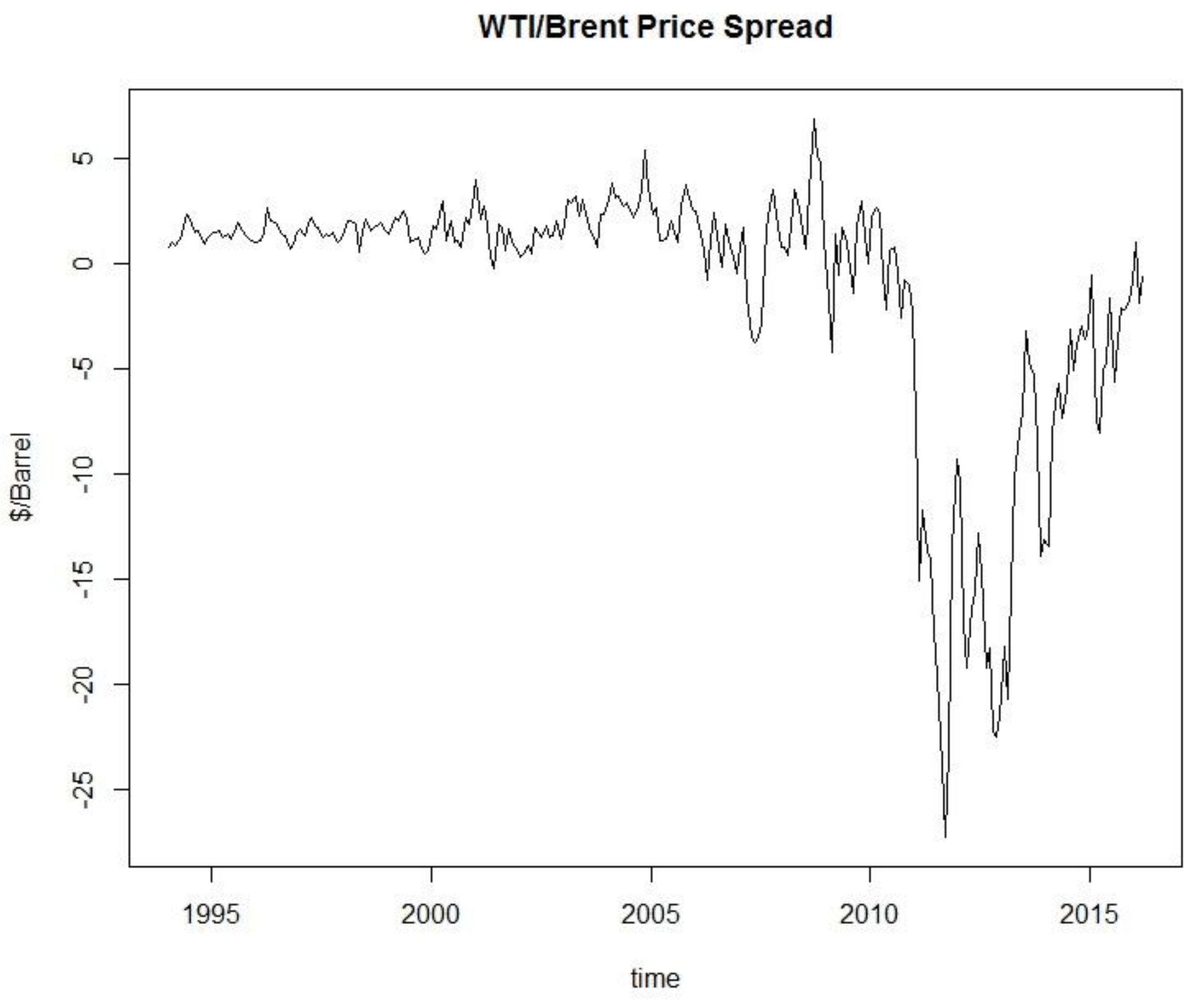
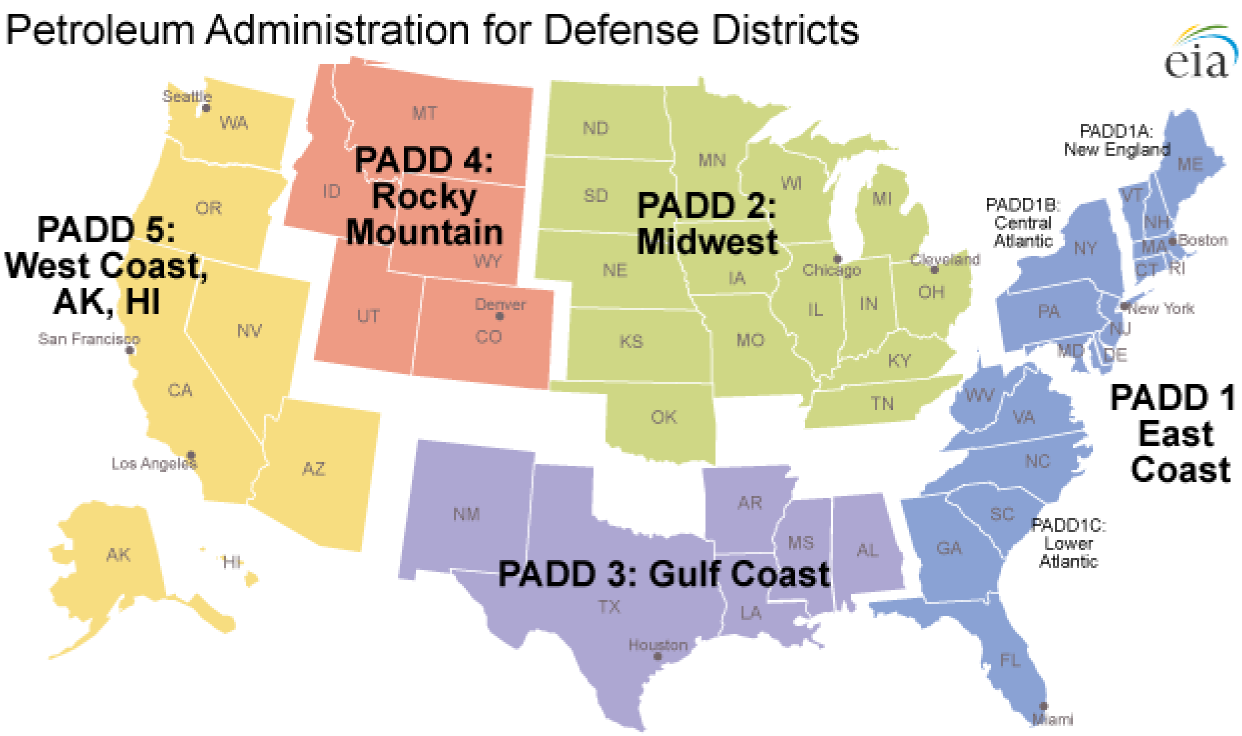


Figure 2:U.S. Petroleum Administration for Defense Districts (PADDs)



Source: Energy Information Administration

Figure 3:WTI Supply Quantity

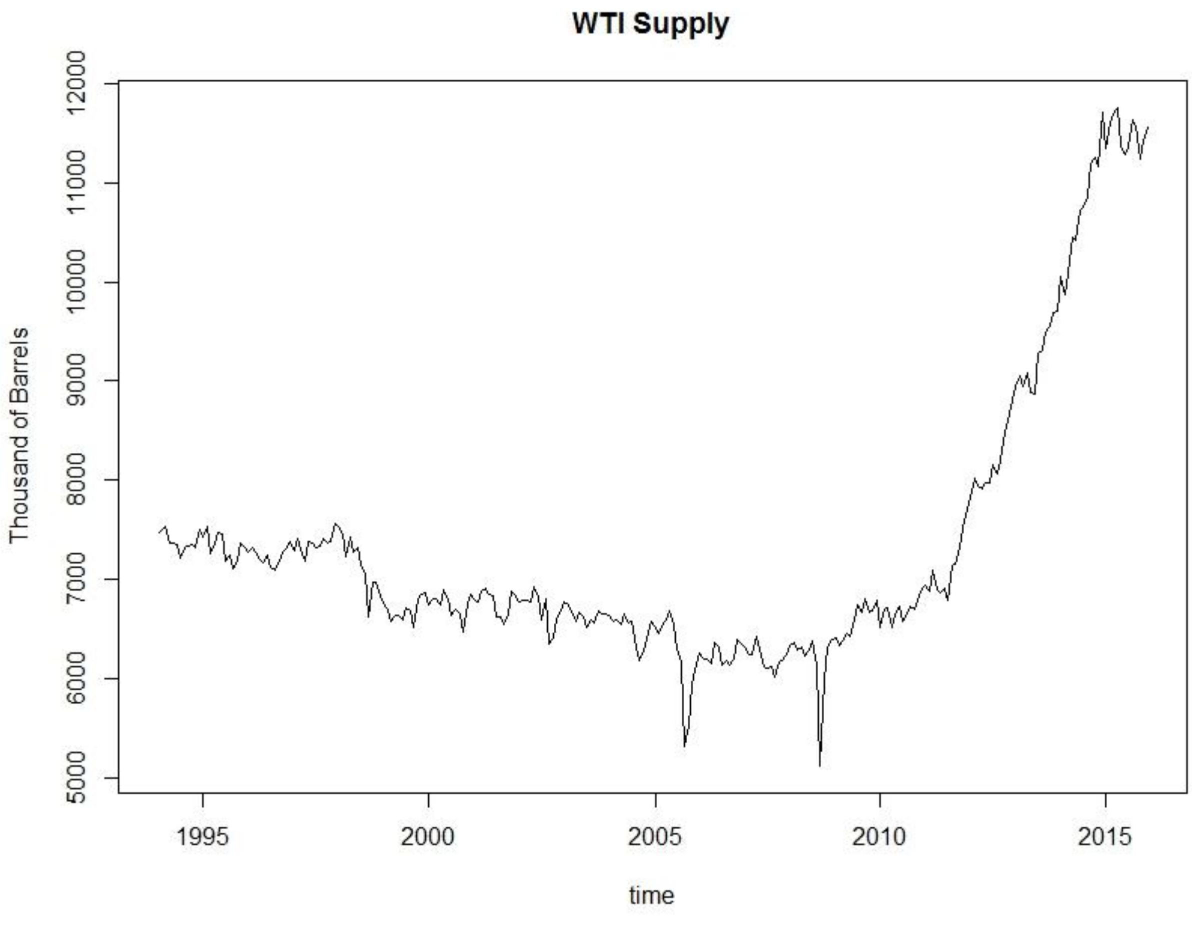


Figure 4: Norway Production

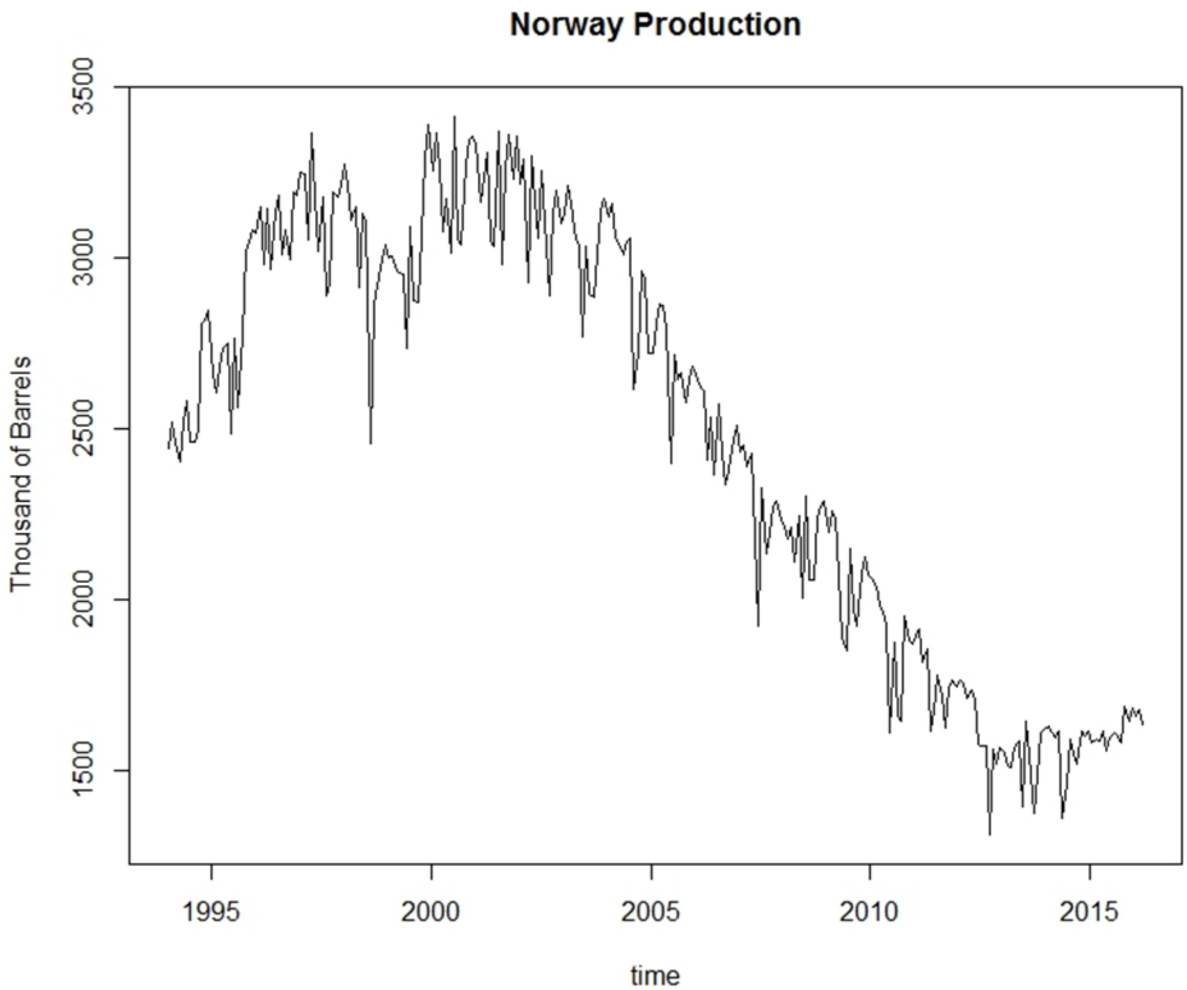


Figure 5: ISM Purchasing Manager Index (PMI)

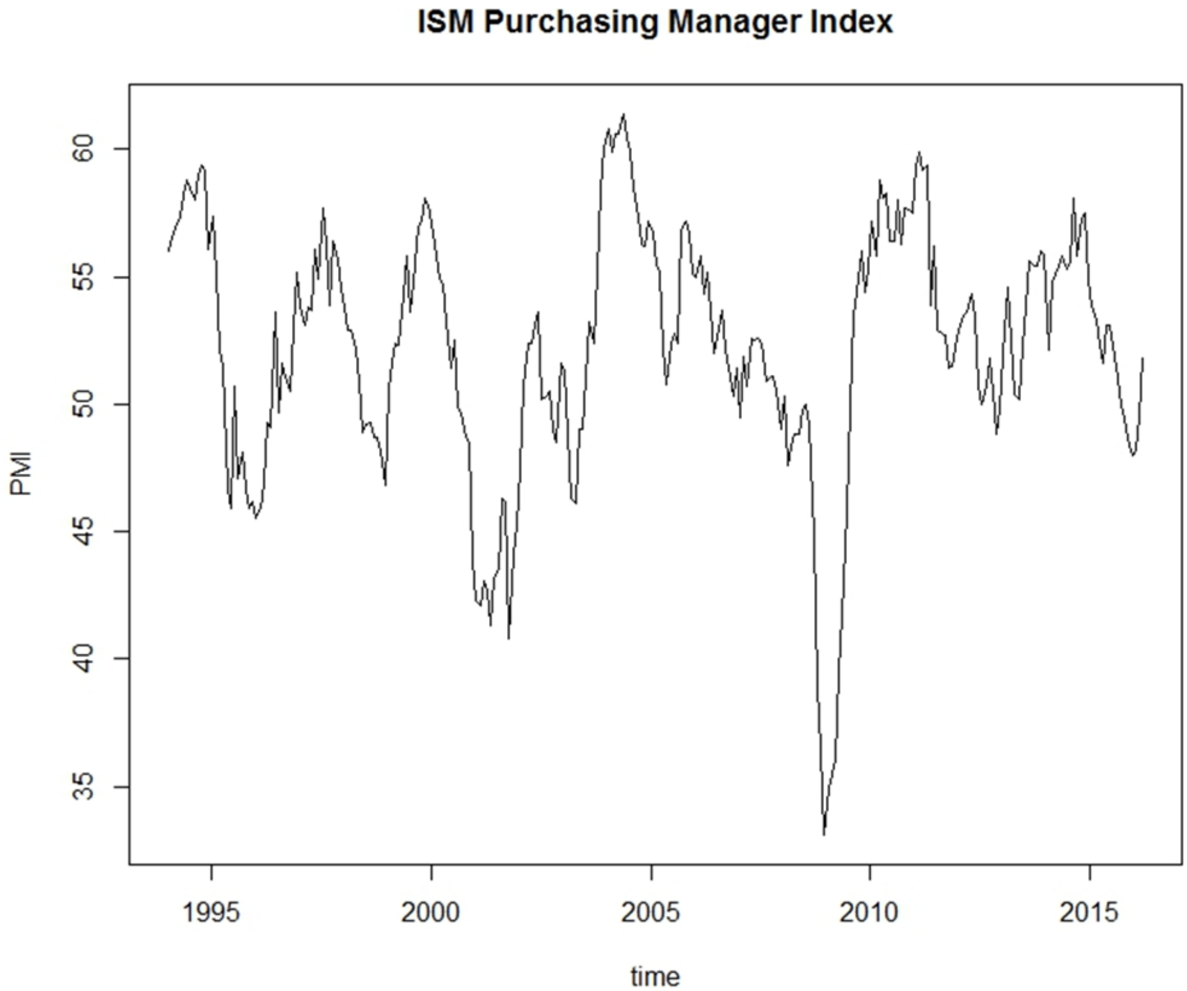


Figure 6: Kilian's Index (2009) of Global Economic Activity

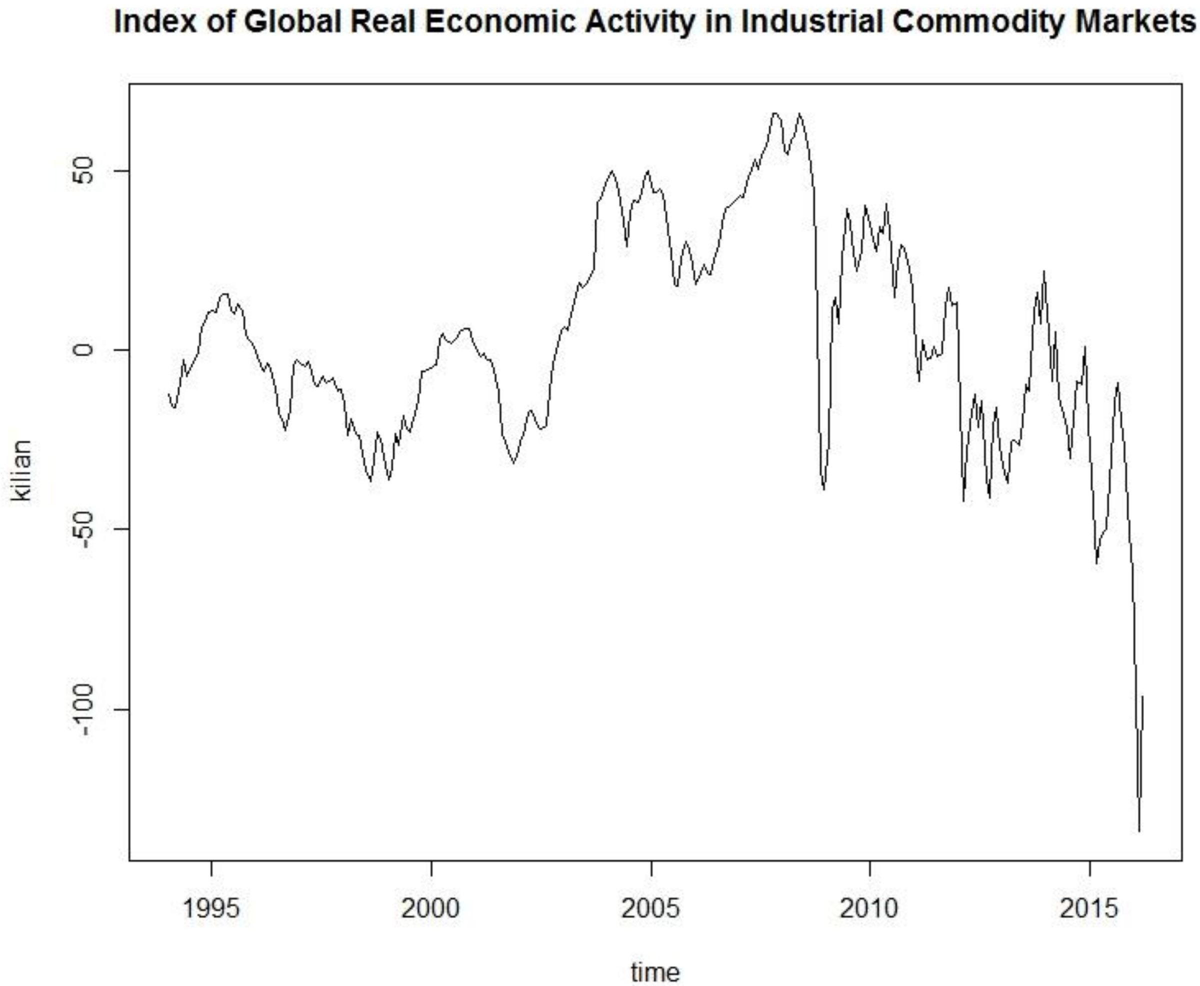


Figure 7(A) : Impulse Response Function Graphs: WTI Supply Shocks (Jan 1994 – Nov 2010)

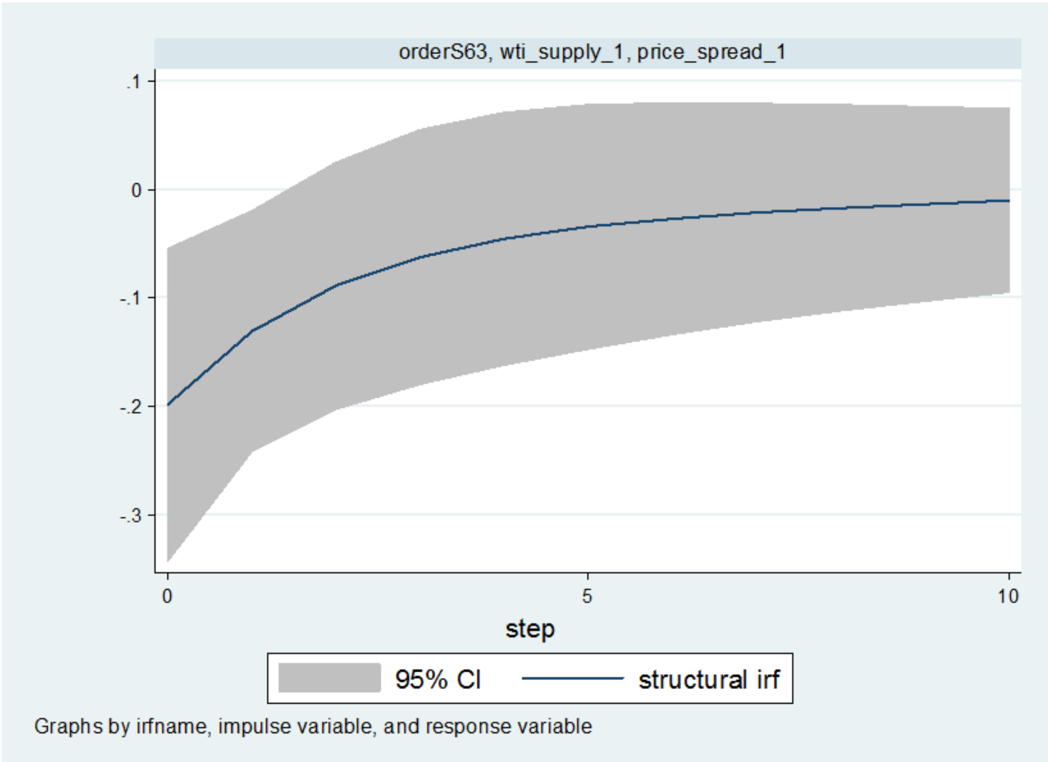


Figure 7(B): Impulse Response Function Graphs: WTI Supply Shocks (Dec 2010 – Mar 2016)

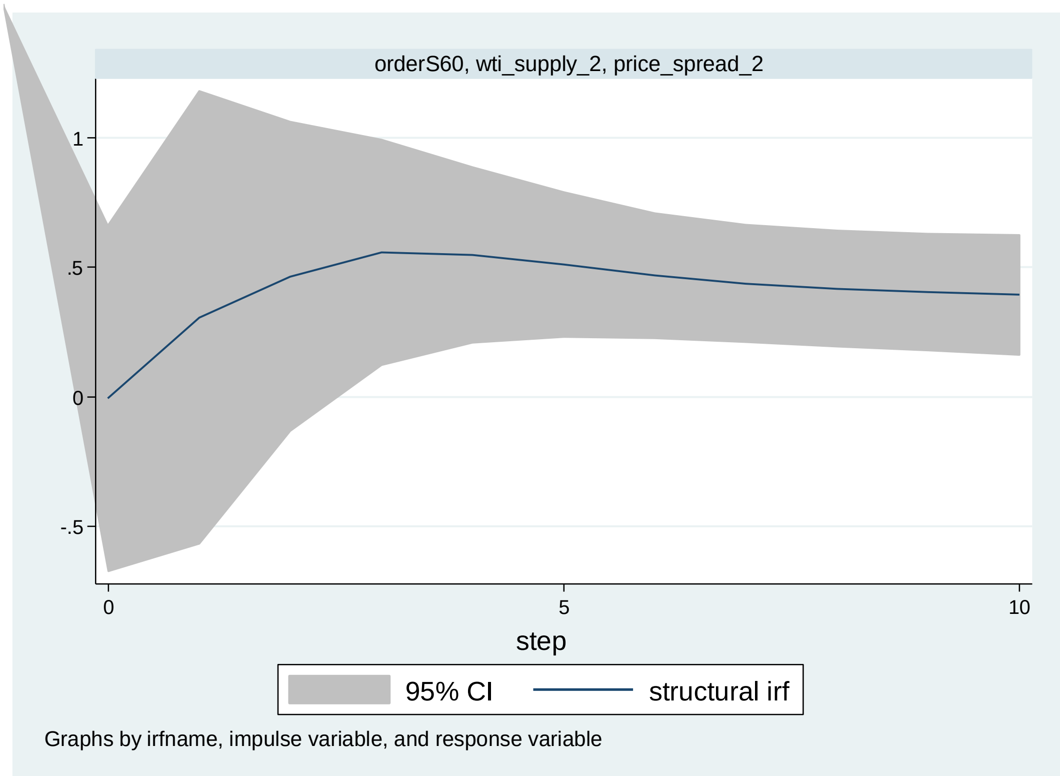


Figure 8(A): Impulse Response Function Graphs: Norway Production shocks (Jan 1994 - Nov 2010)

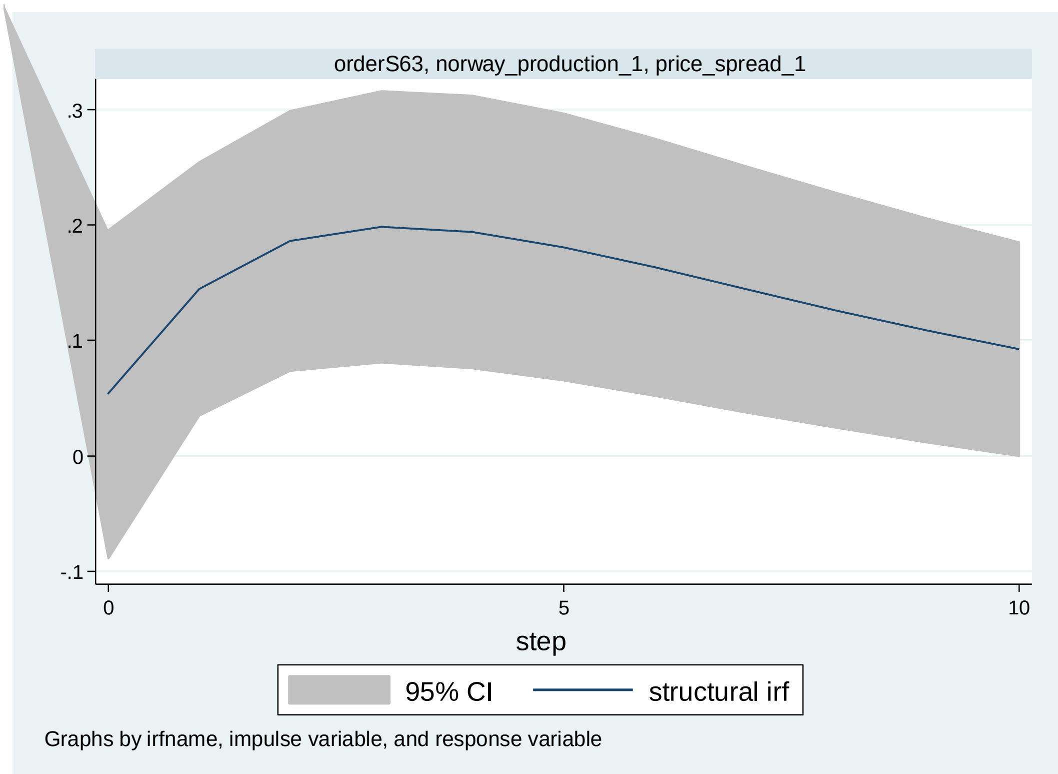


Figure 8(B): Impulse Response Function Graphs: Norway Production shocks (Dec 2010 – Mar 2016)

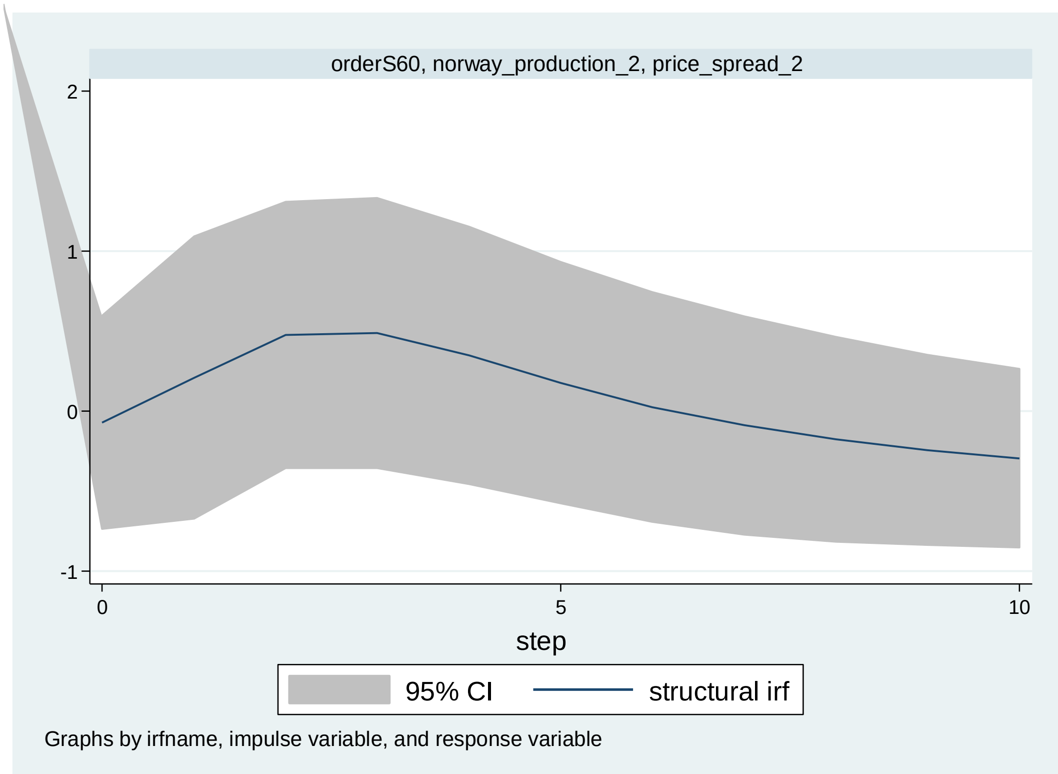


Figure 9(A): Impulse Response Function Graphs: PMI Shock (Jan 1994 - Nov 2010)

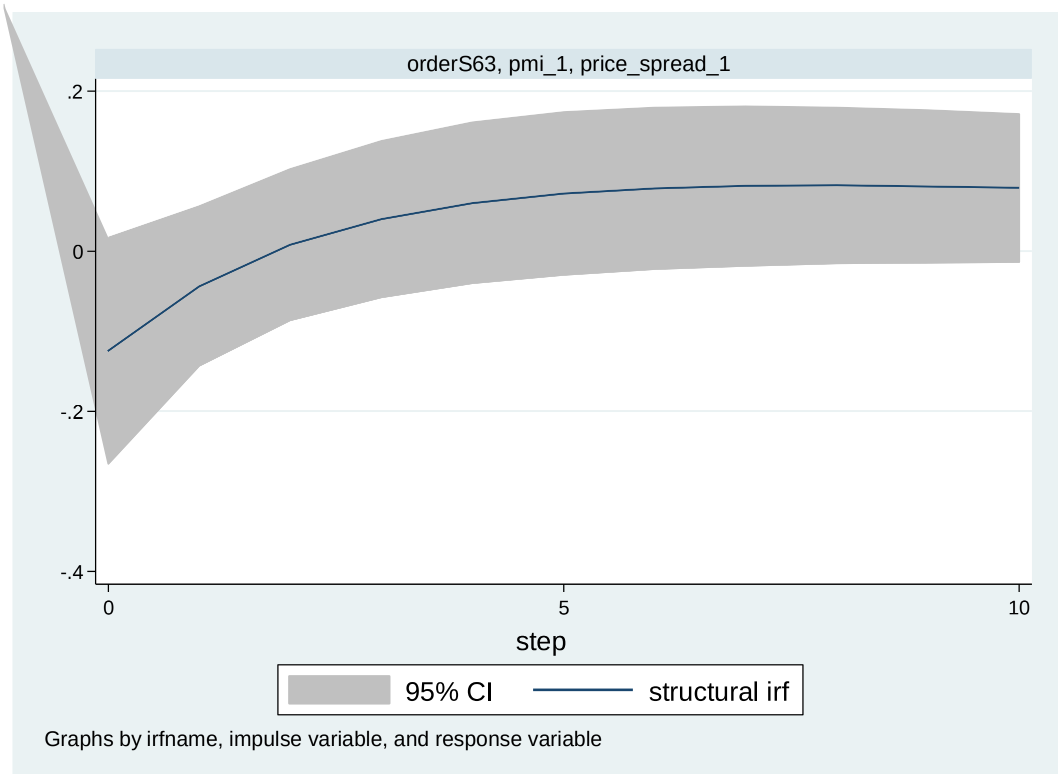


Figure 9(B): Impulse Response Function Graphs: PMI Shock (Dec 2010 - Mar 2016)

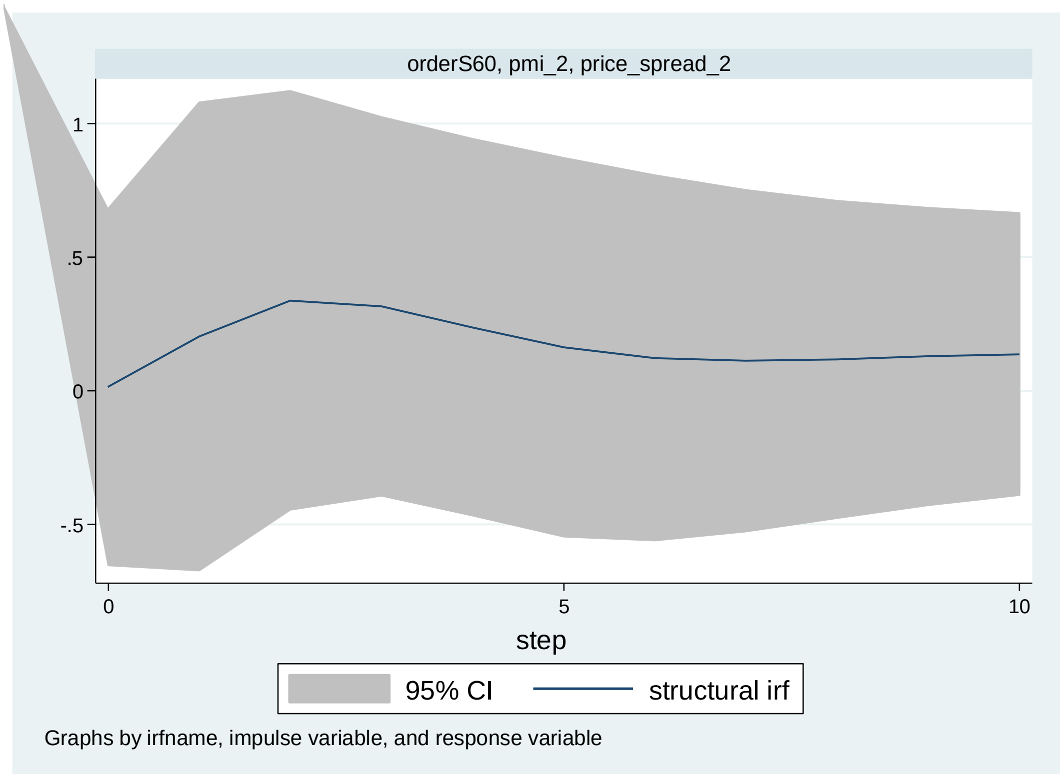


Figure 10(A): Impulse Response Function Graphs: Global Economic Activity Index Shock (Jan 1994 - Nov 2010)

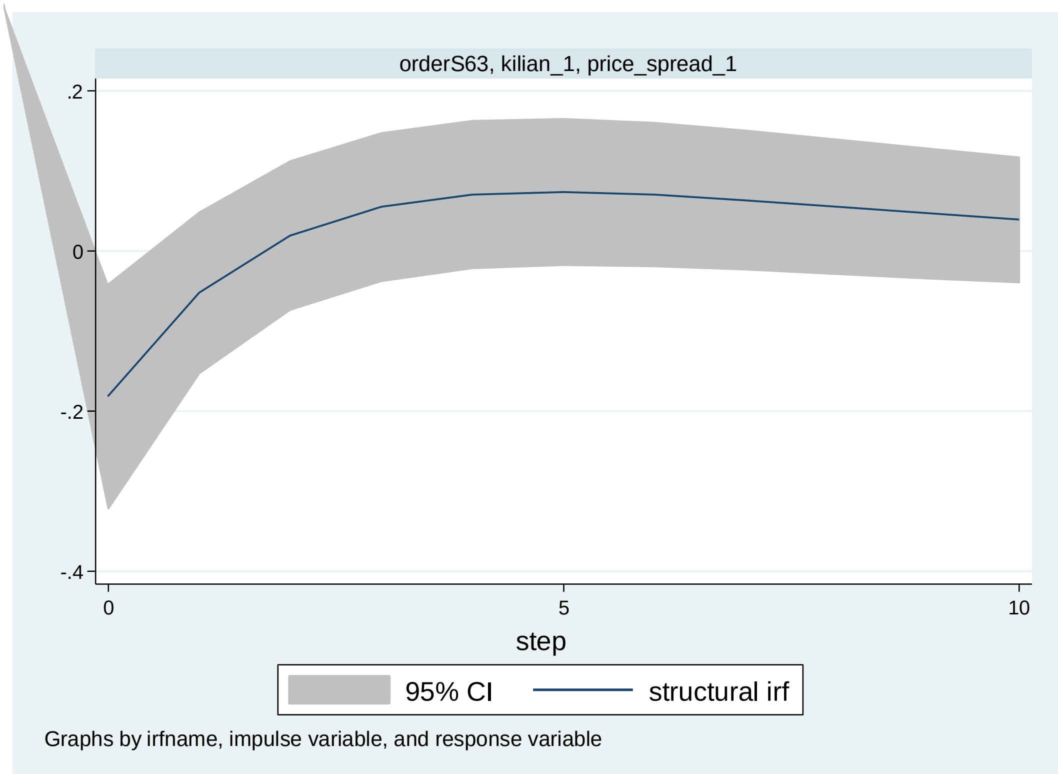


Figure 10(B): Impulse Response Function Graphs: Global Economic Activity Index Shock (Dec 2010 – Mar 2016)

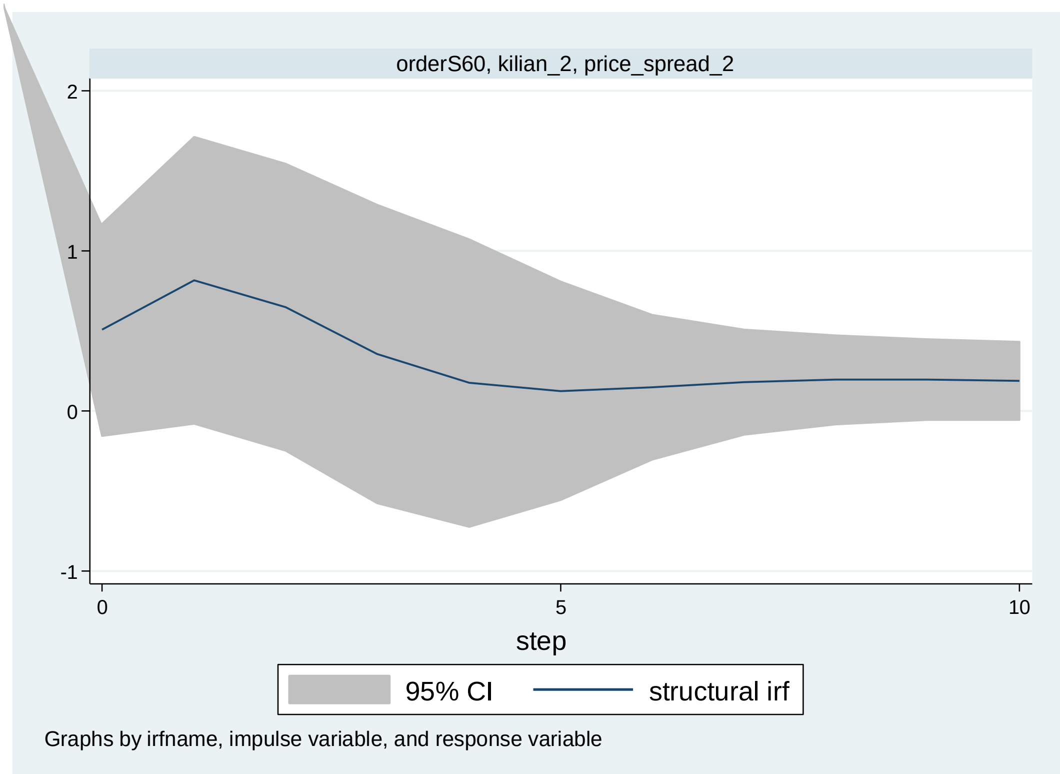


Table 1: Descriptive Statistics

	WTI Supply (Thousand of barrels)	Norway Production (Thousand of barrels)	PMI	Kilian's Index	WTI/Brent Spread
Full Sample					
Min	5113	1310	33.10	-134.04	-27.31
Max	11761	3417	61.40	66.08	6.88
Mean	7377	2483	52.23	3.49	-1.35
Standard Deviation	1460.93	622.74	4.91	30.33	6.22
Skewness	1.81	-0.27	-0.99	-0.33	-2.12
Kurtosis	2.39	-1.38	1.70	1.25	3.87
Sub-sample 1					
Min	5113	1611	33.10	-38.98	-4.23
Max	7557	3417	61.40	66.08	6.88
Mean	6738	2755	51.86	10.97	1.445
Standard Deviation	444.43	443.51	5.34	26.95	1.45
Skewness	-0.19	-0.59	-0.88	0.21	-0.79
Kurtosis	0.26	-0.72	1.04	-0.99	3.86
Sub-sample 2					
Min	6790	1310	48.00	-134.04	-27.31
Max	11761	1911	59.90	22.10	0.98
Mean	9404	1621	53.40	-20.24	-10.20

Standard Deviation	1699.44	119.34	2.90	28.34	7.22
Skewness	-0.05	0.09	0.26	-1.55	-0.46
Kurtosis	-1.45	0.80	-0.40	3.90	-0.89