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What is Driving the Crude Oil Price?

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Abstract

The unparalleled surge of the crude oil price after 2003 has triggered a heated scientific and public debate about its ultimate causes. Unexpected demand growth particularly from emerging economies appears to be the most prominently supported reason among academics. We study the price dynamics after 2003 in the global crude oil market using a structural VAR model. We account for structural breaks and approximate market expectations using a time series for media sentiment in order to contribute to the existing literature. We find that forward-looking demand activities rather than demand arising from current needs have played an important role for the run-up in the price of crude oil after 2003. We additionally find that emerging economies have not majorly contributed to the price surge.

JEL classification: Q43; Q41; C32; D8; E3

Keywords: Oil Price; Spot Market; Futures Market; Fundamentals; Speculation; Financialization

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1 Introduction

The increase in the price of crude oil in the first decade of the new millennium has caused an extended debate about its reason. Three explanations are usually outlined in this context: First, it is claimed that the rising price reveals the finiteness of crude oil and the inability to further extent production capacities ("peak oil hypothesis"). Second, it is hypothesized that the unexpectedly strong growth of emerging countries such as China and India has resulted in a strong and unexpected increase of crude oil demand, leading to squeezes in the spot delivery of crude oil and a rising price ("demand growth hypothesis"). Third, it is stated that the increasing number of speculators in the market of crude oil has considerably enforced the role of forward-looking demand activities and therewith altered the price dynamics ("speculation hypothesis").

Amongst the three hypotheses, the demand growth hypothesis has been averted most (Kilian (2009), Kilian and Murphy (2010), Kilian and Hicks (2012), Krugman (2008) and Hamilton (2008, 2009)). The peak oil hypothesis, as well as the speculation hypothesis have seen a less pronounced echo in the literature (see e.g. Kaufmann, 2011 for arguments in favor of the peak oil hypothesis and Singleton, 2011, and Hamilton and Wu, 2011, for arguments in favor of the speculation hypothesis).

The major challenge in empirically assessing which of the three hypotheses provides a better explanation for the dynamics in the crude oil market after 2003 consists in isolating the different forces in its effect on the price. While price effects arising from supply are identifiable due to the ability of observing extracted quantities of crude oil, a differentiation between the role of the demand growth hypothesis and the speculation hypothesis for the price increase requires a careful decomposition of observed total crude oil demand into two "un-observable" parts: fundamental crude oil demand, i.e. demand for crude oil today that arises as a result of today's real economic needs for the commodity, and non-fundamental demand which is triggered/driven by the expectation of changes in the market of crude oil taking place in the future.[1] Both types of demand need to

[1]As crude oil is storable, it is possible to buy or sell units of crude oil in the future or spot market in

be approximated by suitable data. As changes in the fundamental demand for crude oil mainly arise due to up- and downturns of the business cycle, it can be represented by appropriate business cycle indicators. However, an approximation of non-fundamental demand for crude oil is far less straightforward. For example, expectations which form the basis for non-fundamental demand activities are not observable. Inventories as one form of non-fundamental demand, in contrast, is observable but data are generally considered not reliable. Thus, approximating non-fundamental demand in empirical models on the oil market is still an open issue.

Several approaches have been taken in the literature to proxy for non-fundamental demand. While Kilian (2009) relegated all forward-looking demand activities into the residuum, subsequent papers in this strand of literature have tried to find explicit proxies for this variable. Kilian and Murphy (2011) consider shocks to OECD crude oil inventories as a mean of capturing changes in market expectations.[2] This approach, however, requires that OECD inventories data are correct, provided in a timely fashion and that they resemble activities of all market participants, including investment banks and growing economies such as China and India (see e.g. Singleton, 2011 on the limits of inventory data). Kilian and Hicks (2012) use revisions of forecasts of real GDP growth to approximate forward-looking demand activities.

In this paper, we contribute to the question of what has driven the price of crude oil after 2003 by considering a new means of representing non-fundamental demand. In order to proxy for non-fundamental crude oil demand, we use a time series of all news items with reference to the crude oil market that have appeared on news tickers of one of the world's largest news suppliers. The qualification of such a time series to be used as a proxy for non-fundamental demand is rooted in the principles of economic theory according to which information serves as foundation for expectation formation (see e.g. Muth, 1961). As this time series reconstructs the continuous flow of information to the crude oil market, it is indicative of market expectations and consequently of forward-looking demand activities. Our approach extends Kilian and Hicks (2012) as our time

expectation of future market conditions. Thus, the price reflects current conditions as well as expectations of future market conditions.

[2]The rational is that "any expectation of a shortfall of future oil supply relative to future oil demand not already captured by flow demand and flow supply shocks necessarily causes an increase in the demand for above-ground oil inventories and hence the price of crude oil" (pg. 2).

series for non-fundamental demand captures the entire flow of relevant information for the crude oil market rather than only particular aspects.

With this new proxy for non-fundamental demand for crude oil at hand, we undertake a structural decomposition of the crude oil price in a VAR model. The methodology follows Kilian (2009).

Results of the structural VAR model indicate that non-fundamental demand for crude oil has played an important role for the price increase. As these results stand in sharp contrast to previous contributions on this topic, we provide an extended sensitivity analysis in which we discuss possible triggers of our results, such as structural breaks in the time series, variations in the proxy for fundamental demand and the role of emerging economies for the global crude oil demand. In particular, we find evidence that structural breaks have occurred in the global crude oil market in 2003 which is crucial for the estimation results. Furthermore, we find no empirical support that demand growth from major emerging economies have driven the price surge after 2003. This belief forms the backbone of the demand growth hypothesis.

2 The Empirical Model

In the following section, we propose a four-dimensional structural VAR (SVAR) model for the time period of 2003-2010. The model incorporates an explicit differentiation between fundamental and non-fundamental demand.

2.1 Model Description and Identification

The price of crude oil is set in the global market and is therefore simultaneously determined with other macroeconomic aggregates which complicates the identification process of the model's parameters. SVAR models provide a suitable approach in this context as they consist of endogenous variables only and, thus, do not require exogenous variables for identification. In return, the identifying strategy relies on restrictions imposed on the interplay of the variables under consideration. These restrictions typically cannot be tested and should therefore rely on a sound theoretical fundament. The empirical results are derived by modeling and analyzing unobserved structural shocks using impulse-response functions and cumulative effects of these shocks on the variables of interest.

Starting point for the estimation of an SVAR model is the estimation of its reduced form, i.e. a conventional VAR model, using OLS estimation methodology. The VAR model is based on monthly data for

$$\mathbf{y_t} = (prod_t, econact_t, sentiment_t, price_t)'$$

where $prod_t$ is the percentage change in global crude oil production, $econact_t$ refers to the economic activity index, $sentiment_t$ denotes the time series of news sentiment reflecting expectation based market activities and $price_t$ is the real price of crude oil. The number of lags, p, is chosen to be nine.[3] The VAR representation is

$$\mathbf{y_t} = \sum_{i=1}^{9} \mathbf{A_i y_{t-i}} + \mathbf{e_t}. \tag{1}$$

The underlying SVAR models the contemporaneous effects between the variables $\mathbf{y_t}$

$$\mathbf{A_0 y_t} = \sum_{i=1}^{9} \mathbf{A_i^* y_{t-i}} + \varepsilon_\mathbf{t} \tag{2}$$

with $\mathbf{A_i} = \mathbf{A_0^{-1} A_i^*}$ and $\mathbf{e_t} = \mathbf{A_0^{-1}} \varepsilon_\mathbf{t}$.

The structural parameters cannot be identified without imposing restrictions on the model. While there are in general several techniques of how to impose such restrictions, we apply a parametric approach which is based on a recursive system.[4] We reduce the number of free parameters by imposing a triangular structure on the matrix $\mathbf{A_0}$. We impose the following restrictions:[5]

$$\mathbf{e_t} = \begin{pmatrix} e_t^{prod} \\ e_t^{econact} \\ e_t^{sentiment} \\ e_t^{price} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\text{flow supply shock}} \\ \varepsilon_t^{\text{flow demand shock}} \\ \varepsilon_t^{\text{news shock}} \\ \varepsilon_t^{\text{residual shock}} \end{pmatrix}. \tag{3}$$

In contrast to the reduced form disturbances $\mathbf{e_t}$ from the VAR model which are only linear

[3]See Section 2.6 for a justification of the choice of the number of lags.

[4]Recursivity typically requires two types of assumptions: First, the structural shocks are assumed to be uncorrelated, i.e. the variance-covariance matrix Σ_ε is diagonal. The underlying economic interpretation is that the structural shocks do not have a common cause. Second, restrictions on the contemporaneous relationships of variables are imposed. Further methods for recovering structural parameters are long-run restrictions or sign restrictions. For more details on identifying restrictions see Fry and Pagan (2009).

[5]With the model being four-dimensional ($K = 4$), we set $\frac{K(K-1)}{2} = 6$ elements of matrix $\mathbf{A_0}$ equal to zero. The restrictions described in Equation (3) follow the justifications given in Kilian (2009).

combinations of the unidentified structural innovations $\varepsilon_{\mathbf{t}}$, residual shocks from the structural model can now be interpreted in a meaningful economic way. Flow demand and flow supply shocks represent unexpected changes in fundamental market forces whereas the news shock depicts changes in the forward-looking, non-fundamental demand-component. The SVAR-parameters are determined using Maximum-Likelihood methodology. All estimations are conducted in R, version 2.12.2 (R Development Core Team, 2011).

2.2 News Sentiment as Estimate for Non-Fundamental Demand

While current needs of crude oil contribute to total crude oil demand and thus to the price formation, the ability to store crude oil allows agents to act today to tomorrow's expected changes in the market of crude oil.[6] [7] Thus, the spot price of crude oil contains views held in the market place regarding the future conditions of supply and demand in addition to current supply and demand conditions. Such expectation-based demand activities need to be explicitly modeled to correctly represent the relative contribution of each force to the price development.

A direct way of capturing expectations held in the market place consists of going to the roots of the expectation formation process. What affects the formation of expectations in the market? According to economic theory, the process is based on information that market participants receive over the course of time (Muth, 1961). Thus, a time series that captures in a continuous way all pieces of information that are relevant for the crude oil market is indicative for the expectations of market participants regarding the future development of supply and demand.[8]

[6] Expectations regarding the future development of supply and demand impact the price of crude oil through two channels: On the one hand, the price for a future delivery of crude oil can be agreed upon today on futures markets. On the other hand, crude oil is storable so that market participants can buy units today in anticipation of future market conditions. Thus, if an individual, for example, holds the expectation of a rising crude oil demand in the nearer future, she may take precautionary steps to avoid having to pay a high price in the future. She can either decide to buy a futures contract today (if the current futures price is still less than what she expects the spot price to be in the future) or buy crude oil today and store it. In both cases, her expectation of the future conditions of demand and supply will have an impact on the price of crude oil today, either via the futures market (and consequently, via the no-arbitrage condition also on the spot price) or via the spot market, directly.

[7] Note that expectation based demand activities are inclusive of but not limited to speculation activities. While speculation is primarily undertaken with view on profit maximization in the first place, non-fundamental demand activities include also demand activities not primarily seeking profit maximization (e.g. hedging activities).

[8] News have been used to model the formation of expectations in other contexts as well, see e.g. Lamla and Sarferaz (2012).

The Thomson Reuters News Analytics Database allows a re-construction of the continuous flow of information to the market. It contains all news items that have run over tickers in trading rooms. Time stamps characterizing the exact time of appearance of the news item as well as topic codes describing topics mentioned in the text allow for a selection of relevant news articles for the crude oil market and a construction of a continuous time series of news items. Due to the broad coverage the database is representative of the timely, public information available at least to professional investors, i.e. public news. The language used to describe the content, i.e. news sentiment, helps in quantifying the otherwise not quantifiable information of the news article.

Quantifying the content of a news article based on its language is a relatively new approach and has become possible through the advent of automated linguistic programs. The idea behind the program is that the overall tone of the language provides an indication of the expected movement of the underlying economic variable. For example, news articles reporting about an increase (decrease) of the economic variable referred to in the text naturally use more positive (negative) words. Thus, an article reporting about an increase (decrease) in supply or demand of crude oil can be expected to have been ascribed a positive (negative) sentiment. Articles reporting about an increase in supply or demand include news about an increase in OPEC supply, the finding of additional oil fields or an increase in world economic growth. In contrast, news articles reporting about a reduction in supply or a decrease in demand include articles on a war in resource rich countries, a reduction in the supply from OPEC countries, riots or strikes on oil platforms or upcoming economic recessions.

The sentiment attached to each news item is based on the tone of the language in each individual news article: On the basis of large dictionaries, the program counts the number of positive, negative and neutral words in each article and attaches a "1" ("-1"; "0") if the number of positive (negative/neutral) words outweighs the negative or neutral ones. Additional information on the likelihood of whether the sentiment variable correctly represents the tonus in the news article is given in form of probabilities ($prob_{pos}$ and $prob_{neg}$). The number of positive, negative and neutral articles on a specific day is given as n_{pos}, n_{neg} and n_{neut}. The time series of daily sentiment is computed in the first step as

$$sents = \sum(1) \times prob_{pos} + \sum(-1) \times prob_{neg}. \tag{4}$$

A time series of monthly sentiment is given as the sum of daily news sentiments.

While the tone contains a signal regarding the expected change in supply or demand of crude oil, news items lack a reference to which economic variable they correspond to in particular. Thus, we cannot observe a time series of news sentiment for supply and demand separately. This constitutes a major drawback for the empirical estimations: estimated coefficients will only reveal the average marginal effect of supply and demand-related expectations on the price of crude oil. Still, we can derive some conclusions regarding the relative importance of supply- and demand-related news from descriptive statistics. As we can observe whether news within a certain time period have been overly positive, negative or neutral and as we can observe the direction of the price, it is possible to ex-post infer the dominating type of news. Figure 1 illustrates this point.

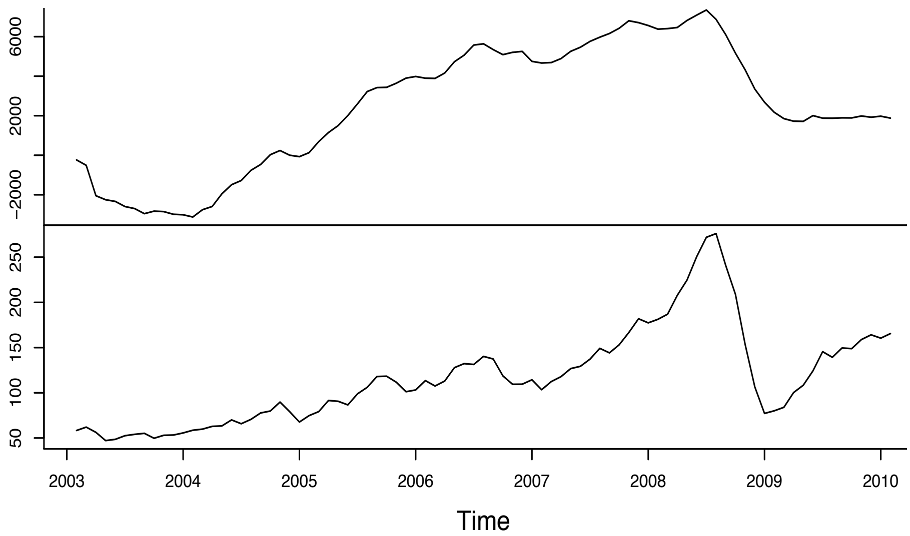

Figure 1: Development of crude oil price in comparison to news sentiment

Since 2003 the price of crude oil and the news sentiment have shown a high degree of co-movement: both, the time series of sentiment and the time series of the crude oil price, are increasing until the outbreak of the financial crisis and abruptly decreasing at the beginning of 2009. The years afterwards are characterized by a raising sentiment and price. The synchronous development of the two time series manifests itself in a high, positive correlation (0.815) which indicates that the majority of news contained a reference to demand.

Based on the development of the sentiment and price time series, the question remains whether these news articles rather describe current conditions of the market or whether the news have resulted in the formation of certain expectations that were not accompanied by a corresponding shift in flow demand or flow supply. The structural VAR decomposition where we account for fundamental supply and demand will allow for such a separation of effects.

2.3 Motivation & Implications of Restrictions

The restrictions imposed on the contemporaneous relationships of the four variables in Section 2.1 are explained in the following section.

Restrictions on Crude Oil Production

While wars within crude oil producing countries or strikes on oil platforms immediately reduce the amount of crude oil produced, adjustments of the production plan due to developments in the business cycle or the price of crude oil take place over a longer time horizon. As a consequence, we restrict production to be influenced in the *same* month by no other variable than a flow supply shock, itself ($a_{12} = a_{13} = a_{14} = 0$). The supply curve results to be vertical in the short run.

Restrictions on Fundamental Crude Oil Demand

Fundamental crude oil demand associated with the business cycle development is affected in the same month by only a shock to the supply of crude oil or via a shock to the business cycle itself ($a_{23} = a_{24} = 0$). This can be rationalized on the basis that industrial production plans by firms need to instantaneously adjust if supply of crude oil is interrupted or if demand for the firm's products suddenly decline. In contrast, production plans will not react in an immediate fashion to changes in the price of crude oil. Thus, shocks to the real price of oil are restricted to have an effect on fundamental crude oil demand in the same month. Similarly, the world economy is assumed to be too inert to react to a news shock in the very same month.[9]

[9] Note that it will clearly depend on the size of the news shock whether the assumption is fulfilled or not. Small news shocks will not affect fundamental crude oil demand immediately while large shocks might be able to alter the behavior within 30 days. Lamla and Sarferaz (2012) show that the propensity

Restrictions on Sentiment

Market sentiment, which forms the basis for the formation of expectations regarding future supply and demand conditions and thus for non-fundamental crude oil demand, is assumed to be reactive to a flow supply shock, a flow demand shock as well as to a news shock in the same month. That is, we assume that market participants are capable of adjusting precautionary demand activities within 30 days after having learned about the outbreak of a war in resource producing countries or an upcoming economic crisis. However, movements in the price of crude oil that are not explained by a flow supply, flow demand or news shock itself are not likely to influence the market's expectation regarding the future status of fundamental supply and demand conditions. As these residual shocks cannot have an obvious origin immediately at its occurrence, the market will need time to understand the reason behind the price movement and its implication for the future. The residual shocks are thus restricted from having an impact on sentiment within the same month ($a_{34} = 0$).

The Price of Crude Oil

Last, the price of crude oil is the most reactive variable within the system as it responds instantaneously (i.e. within the same month) to flow supply, flow demand, news shocks and shocks that are not captured by any of the other three types of shocks (residual shocks).

2.4 Data

We use monthly global crude oil production taken from the Energy Information Administration (EIA) as measure of crude oil supply. The refiner acquisition cost of imported crude oil, deflated by the US CPI and expressed in logs, is taken as proxy for the real price of oil. We employ the index of industrial production as provided in the MEI database of the OECD as measure of business-cycle related crude oil demand. Last, we use the sentiment time series for the crude oil market as obtained from the Thomson Reuters News

to update expectations changes over time and depends on the quality and quantity of the news signal.

Analytics database, expressed in logs, as explicit measure for precautionary demand activities. The data run from February 2003 until February 2010. As the time series of the OECD production indicator as well as the one for crude oil production contain a unit root (see Table 2 in the Appendix), we transform the time series from levels into growth rates in order to achieve stationarity. While the crude oil price also exhibits a unit root, we restrain from any further transformation to preserve the information contained in the levels of the time series.

2.5 Results

Figure 2 represents the responses of the price to a unit shock from each of the four variables.[10] They allow four conclusions.

First, the responses of the crude oil price to a shock from flow supply and flow demand exhibit economically plausible patterns: A flow supply shock has a negative (not significant) impact on the price of crude oil after around nine months. A flow demand shock leads to a positive and significant increase in the price of crude oil, peaking after about eight months.

Second, a news shock has a highly significant and positive impact on the price of crude oil. The effect is significant from the impact period onwards and lasts for the following five months. A positive shock from news accordingly represents the expectation of higher demand in the future. This indicates that forward-looking demand activities have taken place, resulting in an increase in the price of crude oil. Note that a news shock does not have a reverting behavior of the price of crude oil. It remains positive over the course of the following 18 months.

Third, the results also indicate a reasonable difference in speed in the adjustment of the price of crude oil to flow demand and news shocks: while flow demand shocks arising from the business cycle need more than half a year to fully unfold their impact, news shocks have a rather short term impact on the price of crude oil with no significant influence after half a year.[11]

[10] The impulse response functions for the response variables supply, demand and news are shown in the Appendix (Figure 11 to 13).

[11] Adjustments to shocks from fundamental demand are clearly more sticky than adjustments to expectation shocks. While the latter does include costs from adjusting positions in the futures markets or adjusting inventories, the first incurs other costs, such as capacity adjustments.

Last, residual shocks do also impact the price of crude oil significantly but show signs of self-reverting behavior. While a residual shock increases the price of crude oil significantly during the first two to three months, the shock turns negative over the following months.

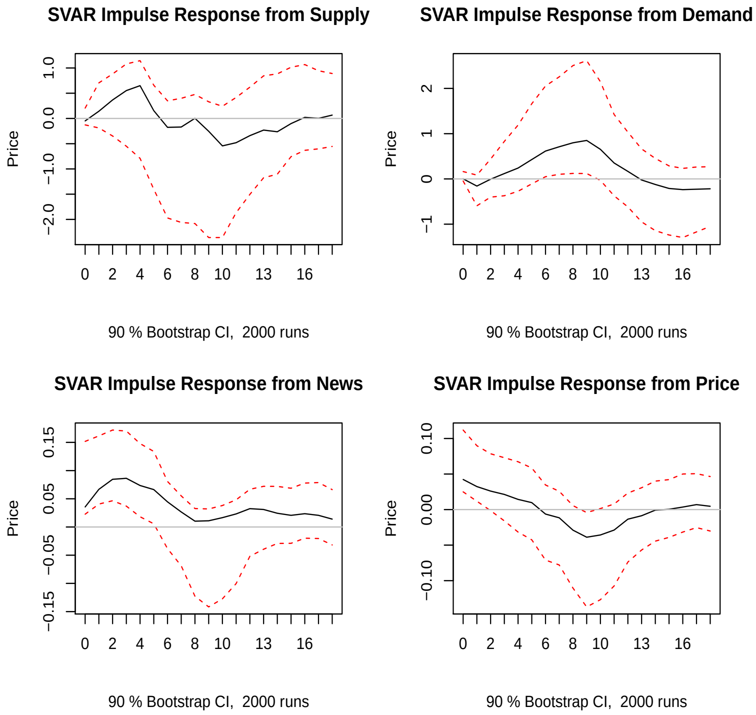

Figure 2: Impulse response function for the Crude Oil Price

In accordance with the results from the impulse response functions, the historical decomposition of the price of crude oil in Figure 3 attributes most of the price development to news shocks. Especially around the year 2008, precautionary demand activities have influenced the price of crude oil in a notable way. While shocks from flow demand can explain some swings in the price of crude oil, they did not contribute in a systematic way. Flow supply shocks did not contribute to the price development, at all.

Last, cumulative effects from residual shocks are rather volatile but do not show a systematic pattern. This is in line with the overshooting pattern found in the impulse response function according to which the shocks did not have a persistent effect on the price of crude oil.

All in all, the results from our SVAR model do not support the often claimed hypothesis that fundamental demand has caused the increase in the price of crude oil after

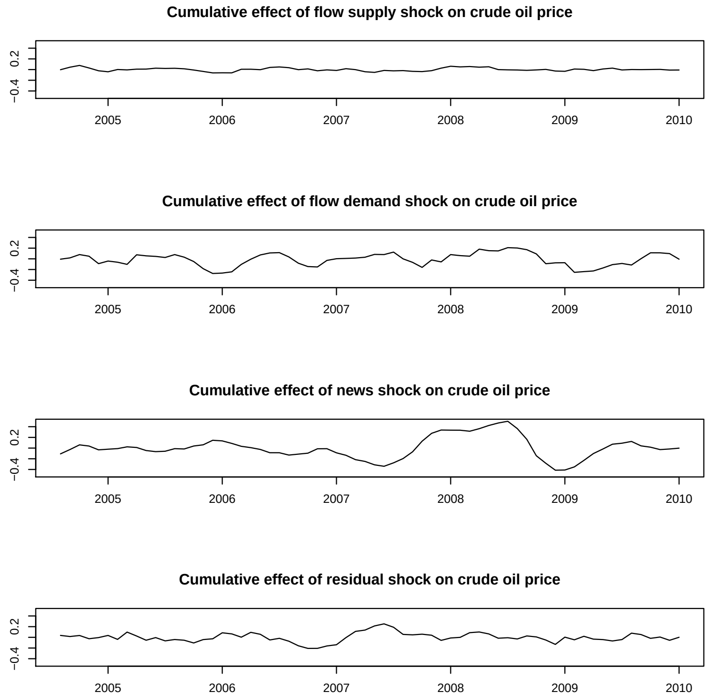

Figure 3: Historical decomposition of crude oil price in four variables model

2003. Rather, they suggest that the price surge in 2008 was mainly based on expectations regarding future market conditions. In fact, expectations remained partly unrealized by the actual fundamental development.

2.6 Diagnostic testing

The results of an SVAR model do not only depend on the choice of the identifying assumptions but also on the specification of the underlying reduced-form model. Whereas the assumptions are imposed on the model on a priori grounds and cannot be tested directly, there are various statistical procedures for examining whether the reduced-form specification adequately represents the data generating process (DGP). In this section, following Breitung, Brüggemann, and Lütkepohl (2004) or Pfaff (2008), we apply some well established diagnostic procedures.

Figure 14 to 16 in the Appendix display the diagram of fit and the residual for every variable in the VAR model - flow supply, flow demand, news and crude oil price. Based on visual assessments, the plots of the residuals do not indicate any noticeable specification problems. In addition, the estimated autocorrelation function (ACF) as well as the partial autocorrelation function (PACF) for each single residual does not exhibit any significant deviation from zero at any lag.

In the following we apply multivariate tests to the model residuals. In a first step we test for the absence of autocorrelation. Two different procedures are considered: we perform a test based on an adjusted portmanteau statistic in order to check the null hypothesis of no autocorrelation against the alternative that at least one autocovariance is nonzero.[12] Secondly, as described in Godfrey (1978), we apply the Breusch-Godfrey LM (BP) statistic in order to test for hth order autocorrelation. As we can see from Table 1 both tests reject the null hypothesis of no autocorrelation in the model residuals. While a higher number of lags may reduce autocorrelation, the number of observations in our dataset imposes a severe trade-off in terms of asymptotic properties of the estimated parameters. Tests on optimal lag length (i.e. the Akaike information criterion (AIC), the Hannan-Quinn criterion (HQ) and the Schwarz criterion (SC)) indicate only little informational gain for lag three and beyond (see Table 1). In order to find a compromise between the optimal lag length, the autocorrelation patterns and the suggestion in previous papers of including long lag orders (e.g. Hamilton and Herrera (2004) and Kilian (2009)), we increase the corresponding number up to nine in order to adequately represent the dynamics of the global crude oil market.

In a further step, we test for conditional heteroskedasticity in the error term by applying a multivariate extension of the univariate ARCH-LM test as described in Engle (1982). The corresponding p-value from Table 1 indicates that no ARCH effects are present.

Finally, we test for nonnormality in the error term. The test is based on the skewness and kurtosis properties and is constructed by generalizing the Lomnicki-Jarque-Bera (JB) test (Jarque, Bera; 1987). As we can see from Table 1 the null hypothesis of the residuals being normally distributed cannot be rejected. Based on the test results we conclude that the reduced-form model performs in a satisfactory manner, providing an adequate basis for the structural identification.

[12]For a more detailed description of the following test statistics see Lütkepohl (2004).

Table 1: Model Checking: the VAR Specification

Diagnostic Tests							
Q_h	p-value	BG	p-value	ARCH	p-value	JB	p-value
164.029	0.001	147.866	$\leq$ 2.2e-03	512.845	0.336	2.250	0.972

Lag Length Selection					
AIC	lag length	HQ	lag length	SC	lag length
-28.416	2	-28.002	1	-27.634	1

3 Discussion

What has caused our results to differ so dramatically from those obtained in the reference literature? In the following section, we provide a discussion about possible factors causing the difference, e.g. the time period of estimation and the choice of the fundamental demand indicator. Last, we examine whether we can find empirical support for the hypothesis of demand from emerging economies triggering the price increase as it provides the backbone of the demand growth hypothesis.

3.1 Fundamental Changes and Structural Breaks

The first difference of our model in comparison to the estimations in the reference literature arises from the estimation horizon. We use data starting in 2003 due to the limited availability of the Thomson Reuters News Sentiment time series while many empirical assessments of the crude oil market use data over several decades. While longer time series are usually preferred as asymptotic properties of estimators increase with the number of observations, the likelihood of encountering structural breaks in the time series rises with the number of observations, as well. Ignoring the presence of such discontinuities when estimating a structural VAR model renders wrong parameter estimates and thus results. The finding of structural breaks occurring around 2003 would justify the concentration of our estimations on the shorter time horizon.

Various contributions have documented an altered functioning of the market for crude oil after 2003, indicating the likelihood of altered properties of the underlying time series (see e.g. Tang and Xiong (2011), Hamilton and Wu (2011)).

In order to find out whether central variables related to the market for crude oil have indeed experienced structural breaks within recent decades, we have applied a three-step test procedure to data most often used in the reference literature on oil price decompositions, i.e. Drewry's shipping index as proxy for business-cycle related demand, crude oil supply and the spot price of crude oil.

In the first step, we investigate for the three time series whether the mean differs significantly for sub-periods of the sample.[13] We compute an F-statistic in order to compare the unsegmented model against a possible break for each point in time. Following Andrews and Ploberger (1994), we reject the null hypothesis of structural stability if the supremum of these statistics is too large. We reject the null hypothesis of no structural change for the mean of shipping and the mean of the price at the 5% level. In order to see at which points in time the null hypothesis is rejected, we draw the process of the F-statistics for shipping and pricing (Figure 4), where the peaks roughly indicate the timing of possible structural shifts. The straight line illustrates the threshold for rejecting the null hypothesis. The process for shipping has three peaks: at the beginning in 1973, around 1982, and around 2004. The F-statistics for the price variable exhibit one peak around 1985 and one around 2003.

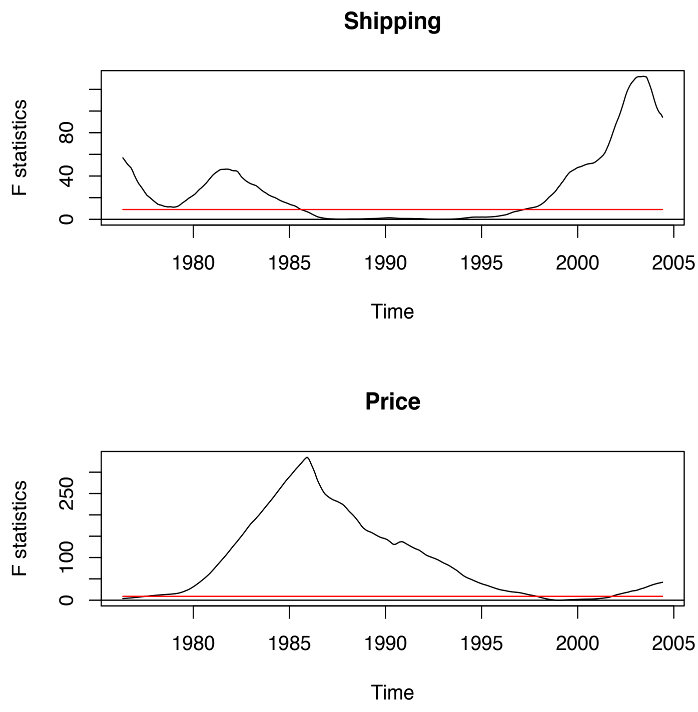

Figure 4: The process of the F-statistic

[13]The data start in January 1973 and end in November 2007. For a detailed description of the data see Kilian (2009).

Given the evidence for structural instability for two time series, we assess the timing of the structural break following the procedure described in Bai and Perron (2003) in the next step. We assume a three-segment partition with two breaking points for both means based on the behavior of the F-statistics described above. The mean of the shipping variable contains breaking points in November 1981 and February 2003. The mean of the price variable occurs several months later, i.e. December 1982 and May 2003. Figure 5 illustrates the timing of the structural breaks and the mean for each sub-period for the time series of economic activity (”shipping”) and the real price of oil.

In a last step we find that the null hypothesis of no structural break in May 2003 is clearly rejected (test-value=932.910, p-value $\leq$ 2.2e-03) by applying a Chow test for structural breaks to the VAR model including the three variables under examination.[14]

In summary, we find that the single time series of the spot crude oil price and of the economic activity indicator, as well as the structural VAR model representing the global crude oil market, exhibit a structural break in 2003.

This finding implies the need to focus on sub-periods for estimations that coincide with our chosen estimation period.[15]

The importance of acknowledging the presence of structural breaks in the estimations can be highlighted when re-estimating Kilian (2009) for the estimation period of 2003-2010. Focussing on this sub-period, results change dramatically: Not business-cycle related demand as in Kilian (2009), but non-fundamental demand activities seem to have been the main driver of the price development of crude oil after 2003 (see Section 5.1 of the Appendix). Thus, the consideration of structural instability seem important in an empirical assessment of the crude oil market.

[14] For a detailed description see Lütkepohl (2004).

[15] Similar conclusions with respect to the occurrence of structural breaks are drawn in a variety of other contributions. Fan and Xu (2011) find three structural breaks which have occurred since the start of the new millennium: a ”relatively calm market” period (January 07, 2000, to March 12, 2004); the ”bubble accumulation” period (March 19, 2004, to June 06, 2008,); and the ”global economic crisis” period (June 13, 2008, to September 11, 2009). Further evidence of a change in the dynamics of the crude oil market is provided by Kaufmann (2011) who documents a structural break in the series on U.S. private crude oil inventories.

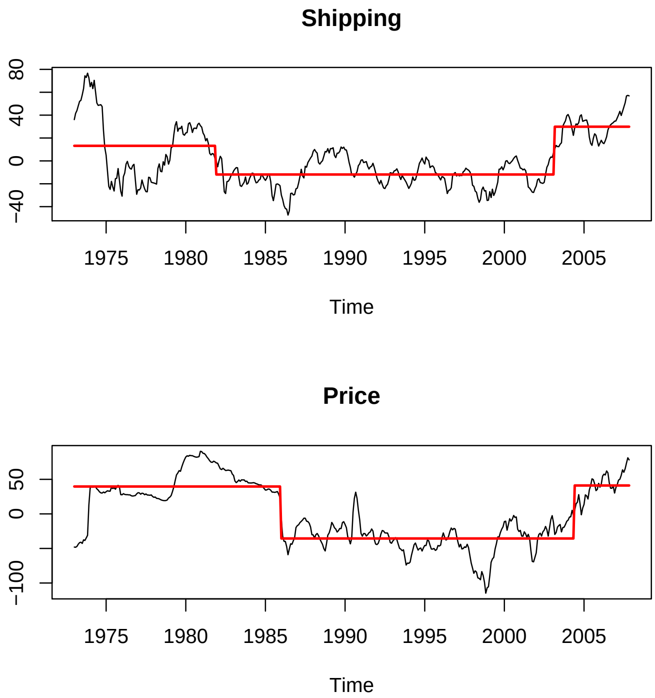

Figure 5: Breakingpoints and mean of sub-seriods

3.2 The Indicator for Business-Cycle Related Crude Oil Demand

A second source of variation of our model in contrast to the reference literature consists in the choice of the proxy for business-cycle related crude oil demand.[16] The reference literature has mainly used fundamental demand proxies that are based on shipping activities, i.e. the Baltic Dry Exchange Index or Drewry's shipping index. However, while one would expect an estimate of business-cycle related crude oil demand to be correlated with either total crude oil demand or other indicators of the business cycle, we do not find a significant correlation with the commonly used estimators for the time period of 2003-2010: The correlation between the Baltic Dry Exchange and two alternative business cycle indicators, the index of industrial production (IIP) provided in the MEI database of the OECD and the Composite Leading Indicator (CLI) provided by the OECD, is -0.028 and 0.21, respectively, and not significant. In addition, the shipping indicator does not

[16]It has become common practice to identify fundamental crude oil demand with the help of business cycle indicators. Such indicators are capable of indicating changes in the demand for crude oil that are purely based on an expansion or contraction of current world economic activity and thus demand for crude oil for today's use. Note that there are some crude-oil intensive activities that are not closely related to industrial production, e.g private traveling. However, such activities can be assumed to be highly correlated with the overall business cycle.

show any relation to figures on total crude oil demand, either (0.045, not significant).[17] Due to these obvious shortcomings, we have used the index of industrial production which is positively and significantly correlated with total crude oil demand (0.381).

The reference literature has refrained from using indices based on industrial production as proxy for fundamental crude oil demand due to several, presumed shortcomings. We argue, however, that they are not severe in the context of our estimations: First, the link between fundamental crude oil demand and industrial production figures has been argued to be influenced by structural changes of economies and the development of new technologies. While this argument applies in particular to estimations conducted over several decades, it may be less problematic when investigating only a period of several years. Second, it has been argued that data on industrial production are only available for a fraction of countries in the world. For example, industrial production of major emerging economies are not yet contained in standardly available indices. Still, we find that countries for which data on industrial production is provided contribute on average by 77% to total world GDP between 2003 and 2010. China and India only contribute by 8% to world GDP.[18]

Replacing the shipping index in the estimations of Kilian (2009) by the index of industrial production as provided by the OECD for the time period of 2003-2010, we find that the industrial production indicator provided by the OECD provides a better explanatory power for the price than the shipping indicator.[19] The results of the estimation are shown in Figure 9 and Figure 10 in Appendix 5.2.

The overall conclusion from the structural decomposition remains the same: Non-fundamental demand shocks have mainly contributed to the price increase after 2003 (Figure 10). Thus the results obtained in Section 3.1 are robust to the choice of the demand indicator.

[17] The correlation-coefficients for all relevant variables are listed in Table 3 in the Appendix.

[18] However, looking at GDP increase only, emerging countries play a more prominent role: between 2003 and 2010 China and India contribute to global increase in GDP by an average of 30%, whereas the contribution from the OECD is 42%.

[19] The shocks from the industrial production indicator on the price appear to be partly significant in contrast to shocks from the shipping indicator. As in Section 3.1, the industrial production indicator is considered in growth rates rather than levels.

3.3 The "China-Effect" - The Role of Emerging Economies for the Development of the Crude Oil Price

As a last sensitivity analysis, we investigate the backbone of the demand growth hypothesis, i.e. the claim that demand from emerging economies such as China and India has driven the price increase in 2003.

We re-run the model in Section 2 but replace the industrial production indicator for OECD countries by two sorts of leading indicators: the first composes of only OECD countries, the second additionally includes major non-member economies (MNEs), including China, India, Russia, South Africa and Indonesia.

Note that due to the characteristics of a leading indicator these results will be only informative with respect to a *comparison* of cumulative effects of flow demand shocks. The results cannot be used as a comparison of the role of fundamental versus non-fundamental demand for the price development as the leading indicators contains expectations regarding the development of the business cycle. The leading indicators therefore capture part of the information contained in the news sentiment time series.

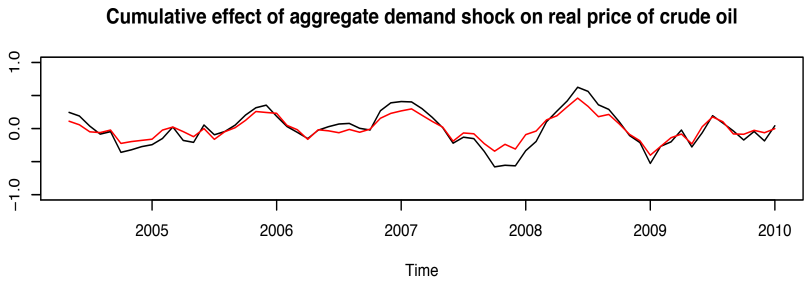

Figure 6: Comparison of cumulative effects for OECD and OECD plus major emerging economies in four variables model

Figure 6 shows the cumulative effects from fundamental demand on the price of crude oil, using the CLI for OECD countries and the CLI for OECD plus major non-member economies (MNE). The red line refers to the estimation based on the CLI of OECD countries (=benchmark case) whereas the black line refers to the CLI including major non-member economies. The graphs do not show a huge difference for the role played by fundamental demand in the run up of the price. The most notable difference arises in 2008, during the price peak, when cumulative flow demand shocks from OECD plus MNE countries on the price are slightly higher than those for only OECD countries. Still, considering the entire time period, emerging economies have not contributed to a large extent to the run up in the price of crude oil. Thus, we cannot find empirical support for the claim that the growth in emerging economies have majorly contributed to the price rise, a backbone of the demand growth hypothesis.

4 Conclusion

What has caused the increase in the price of crude oil after 2003? This highly discussed question has been at the heart of this paper. While competing explanations have been put forward by the academic society, the hypothesis of aggregate demand increases due to strong economic growth of emerging economies has been supported most prominently (Hamilton, Kilian, Krugman). Despite the clear econometric analysis favoring the hypothesis, doubts remain as such a conclusion implies that the market must have been constantly shocked by increases in fundamental demand without being capable of adjusting expectations over a time period of several years.

The major challenge in empirical assessing the relative contribution of supply, fundamental and non-fundamental demand consists in finding appropriate time series approximating the three essential components of the price. While this task is comparably straightforward for supply and business-cycle related demand, finding an appropriate proxy for non-fundamental demand has remained a rather unsolved issue in the empirical literature on oil market modeling: as non-fundamental demand activities are driven by expectations and as inventory data only draw a partial picture of all forward-looking demand activities in the world, the contribution of non-fundamental demand to the price formation can be characterized as not directly observable.

This paper proposes a new proxy for non-fundamental (forward looking) demand activities for a structural decomposition of the crude oil price after 2003. We use a time series of all news items relevant for the crude oil market that have appeared on news tickers of one of the world's largest news providers. This time series is indicative of market expectations held at any point in time. The subsequent structural decomposition show that non-fundamental demand activities have played an important role for the price development: the results indicate that the market has been adapting an expected increase in demand (probably from emerging economies) but with little actual contribution from fundamental crude oil demand. Thus, the results from the structural VAR model do not support the demand growth hypothesis but rather the hypothesis that expectation based activities have driven the crude oil price after 2003.

As this result stands in sharp contrast to the reference literature (Hamilton, Kilian, Krugman), we provide an extended discussion about possible factors driving the result. First, we find that most commonly used time series in empirical assessments of the crude oil market as well as the corresponding empirical model exhibit a structural break in 2003 which most studies have not accounted for, so far. We can show that accounting for such instabilities in the time series have a decisive effect on the estimation results: A re-estimation of Kilian (2009) for the structural break free time period from 2003-2010 yield results in line with our results. The second part of the discussion illustrates the robustness of our results to the choice of the fundamental demand proxy. Last, we investigate whether we can find empirical support for the commonly held view that demand from emerging economies has contributed most to the price development. Through appropriate choices of fundamental demand estimators, we can separate between fundamental demand effects arising from OECD countries and those arising from OECD countries and major emerging economies such as China and India. The estimations cannot find strong support for the backbone of the demand growth hypothesis: There is no systematic fundamental demand effect attributable to emerging economies. Thus, this paper concludes that expectation-based demand activities, rather than business-cycle related demand activities have majorly contributed to the price rise.

5 Appendix

5.1 Re-Estimation of 3-Variables SVAR

We re-estimate Kilian (2009) for the sub-period of 2003-2010.[20] The VAR model is based on monthly data for

$$\mathbf{y_t} = (prod_t, econact_t, price_t)'$$

where $prod_t$ is the percentage change in global crude oil production, $econact_t$ refers to the economic activity index and $price_t$ is the real price of crude oil. The VAR representation is

$$\mathbf{y_t} = \sum_{i=1}^{9} \mathbf{A_i y_{t-i}} + \mathbf{e_t}.^{21} \tag{5}$$

The underlying SVAR allows to model the contemporaneous effects between the variables $\mathbf{y_t}$:

$$\mathbf{A_0 y_t} = \sum_{i=1}^{9} \mathbf{A_i^* y_{t-i}} + \varepsilon_\mathbf{t} \tag{6}$$

with $\mathbf{A_i} = \mathbf{A_0^{-1} A_i^*}$ and $\mathbf{e_t} = \mathbf{A_0^{-1}} \varepsilon_\mathbf{t}$. We impose the restriction matrix as in Kilian (2009) as

$$\mathbf{e_t} = \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{econact} \\ e_t^{price} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{pmatrix} \varepsilon_t^{\text{flow supply shock}} \\ \varepsilon_t^{\text{flow demand shock}} \\ \varepsilon_t^{\text{residual shock}} \end{pmatrix} \tag{7}$$

As in Kilian (2009), we use monthly percentage changes of global crude oil production taken from the Energy Information Administration (EIA) as measure of crude oil supply. The refiner acquisition cost of imported crude oil, deflated by the US CPI, is used as proxy for the real price of oil. While Kilian (2009) uses a self-composed shipping index based on single cargo freight rates provided by Drewry's, the follow-up paper by Kilian and Murphy (2010) use the Baltic Dry Exchange Shipping index which is "essentially identical" (Kilian and Murphy, pg. 6) to the index used in Kilian (2009). As the latter is readily available on data providing platforms, such as Datastream, we also use it here. The shipping index appears to be non-stationary in levels and is thus investigated in

[20]For a more detailed description of the model see Section 2.

[21]Note that we include only nine lags instead of 24 as in Kilian (2009). This is due to the shorter time series used for the estimations.

growth rates.[22] As in Kilian (2009), we use the the refiner acquisition cost of imported crude oil, deflated by the US CPI, as proxy for the real price of oil. It is expressed in logs. Our data start in February 2003 and range until February 2010.

Figure 7 displays the impulse response functions on the price of crude oil for the re-estimated model of Kilian (2009).[23] Neither a flow supply shock nor a flow demand shock lead to a significant increase in the price of crude oil. We find significant effects in the autoregressive part in the price of crude oil.

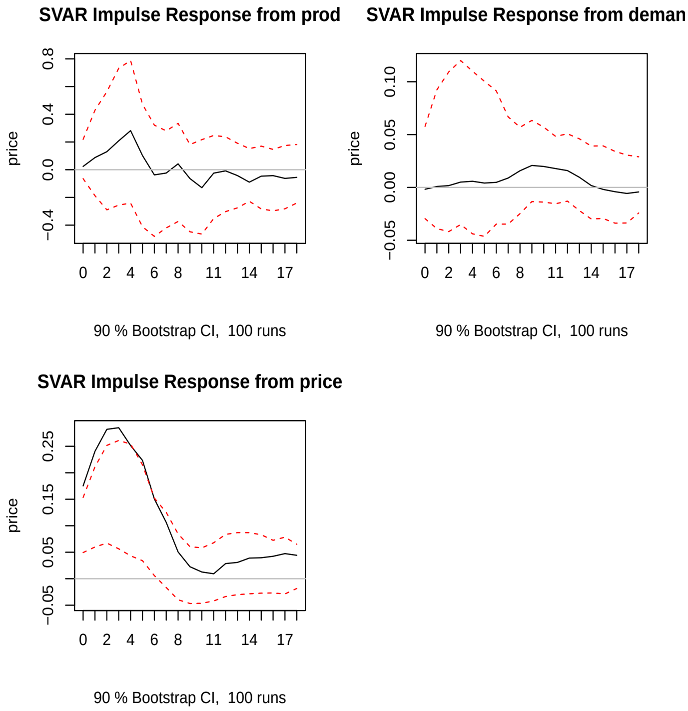

Figure 7: Impulse response function of the price for re-estimated Kilian Model

Figure 8 displays the historical decomposition of the crude oil price according to this three-variable model. As to be expected from the impulse response functions, the main driver of the price development seems to come from the residual which is interpreted as precautionary demand in Kilian (2009). Neither cumulative effects from flow supply nor from flow demand contribute in a visible way to the development of the crude oil price. This result stands in contrast to Kilian (2009) and illustrates that the results are sensitive

[22]Note that Kilian (2009) uses a different operation in order to make the series stationary. The series is detrended and expressed in deviations from trend. Both manipulations yield the same results.

[23]The bootstrap-confidence-interval from price to price appears to be biased. According to Philips and Spencer (2010) this bias is due to the bootstrap OLS estimate of the error covariance matrix in the reduced form VAR which is biased downwards.

to the selection of the sample period.

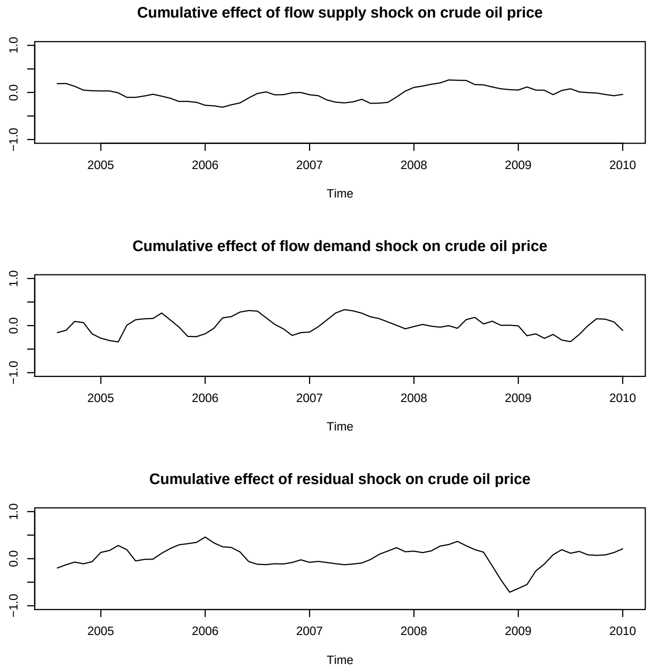

Figure 8: Decomposition of crude oil price in three variables model

5.2 Re-Estimation of 3-Variables SVAR with OECD Production Indicator

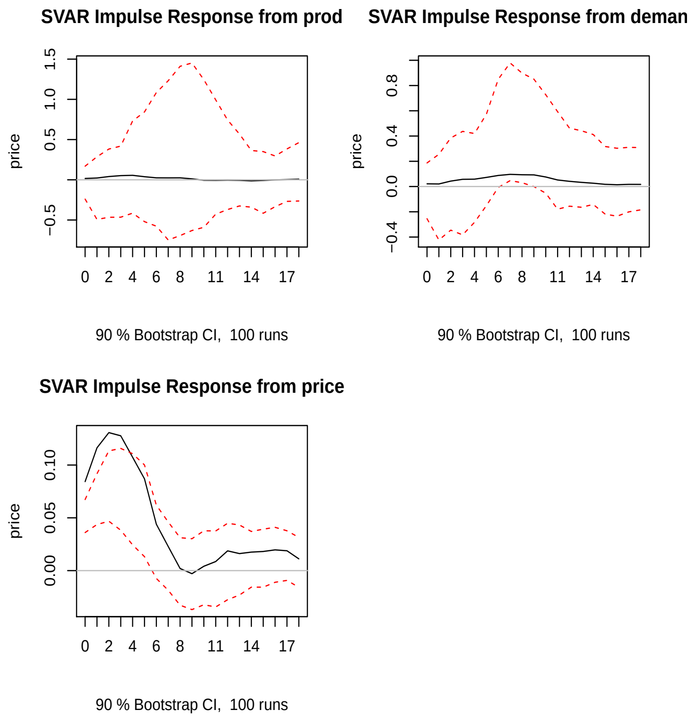

Figure 9: Impulse response function of crude oil price with alternative aggregate demand measure

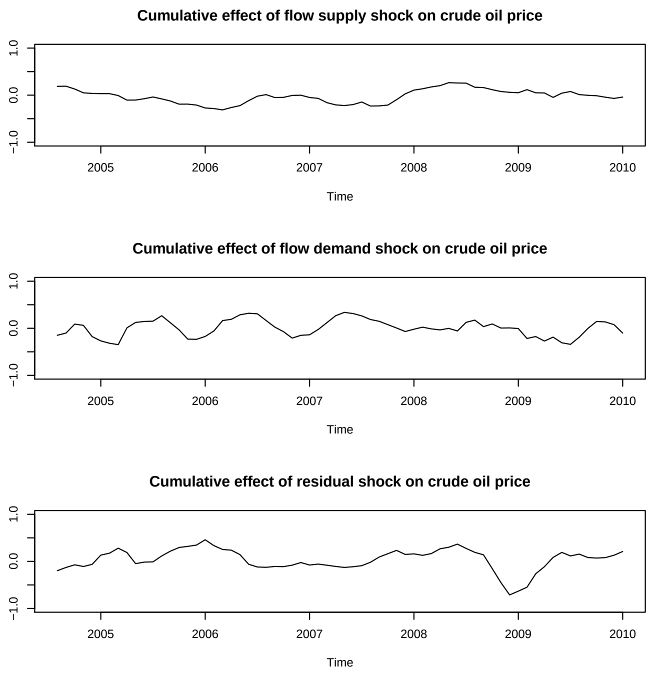

Figure 10: Decomposition of Crude Oil Price with alternative aggregate demand measure

5.3 Test for Unit Roots

Table 2: Test for unit roots / stationarity tests

	ADF test (k=4)	ADF test (k=3)	PP test	KPPS test
Crude oil price	non stationary	non stationary	non stationary	non stationary
Crude oil production	stationary	stationary	stationary	non stationary
Shipping index	non stationary	non stationary	non stationary	non stationary
OECD production	non stationary	non stationary	non stationary	non stationary
Media sentiment	stationary	stationary	stationary	non stationary
CLI	non stationary*	stationary	non stationary	non stationary

Notes:

*stationary at 15 % level
ADF test: Augmented Dickey-Fuller test, see Dickey and Fuller (1981)
PP test: Philips-Perron test, see Philips and Perron (1988)
KPPS test: see Kwiatkowski *et al.* (1992)

5.4 Impulse Response Function of 4-Variable System

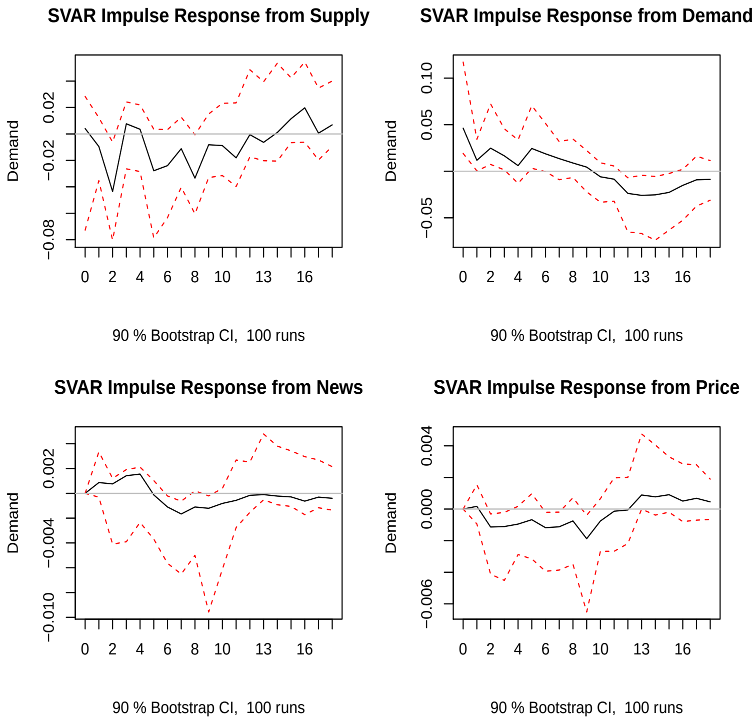

Figure 11: Impulse response function for supply

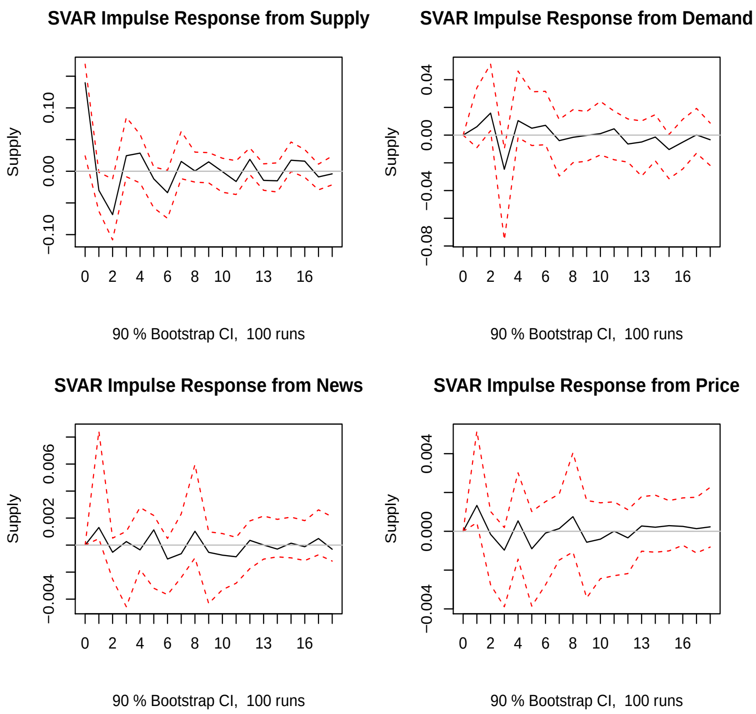

Figure 12: Impulse response function for demand

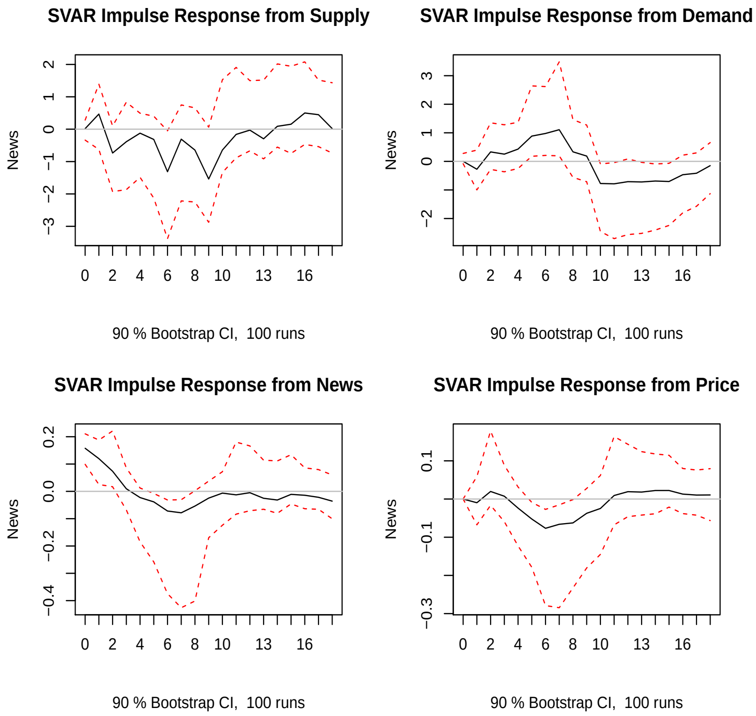

Figure 13: Impulse response function for news

5.5 Diagram of Fit

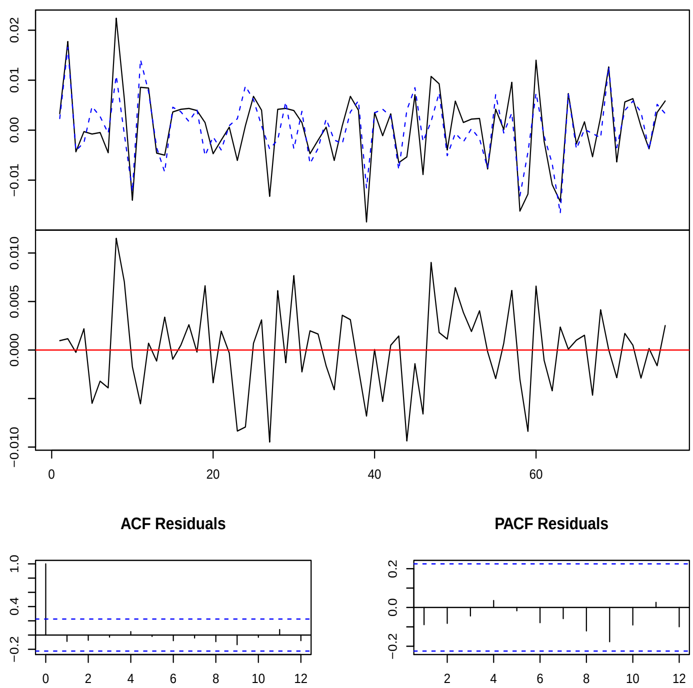

Figure 14: Diagram of fit and residual for supply

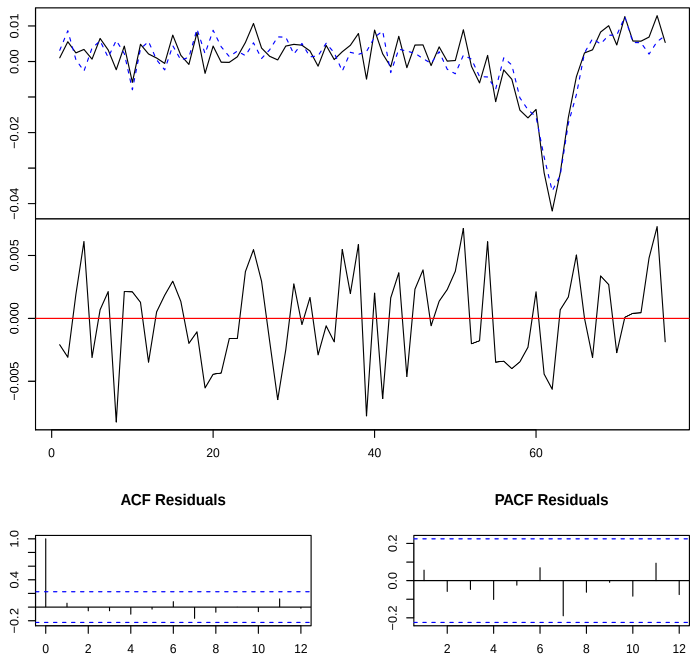

Figure 15: Diagram of fit and residual for demand

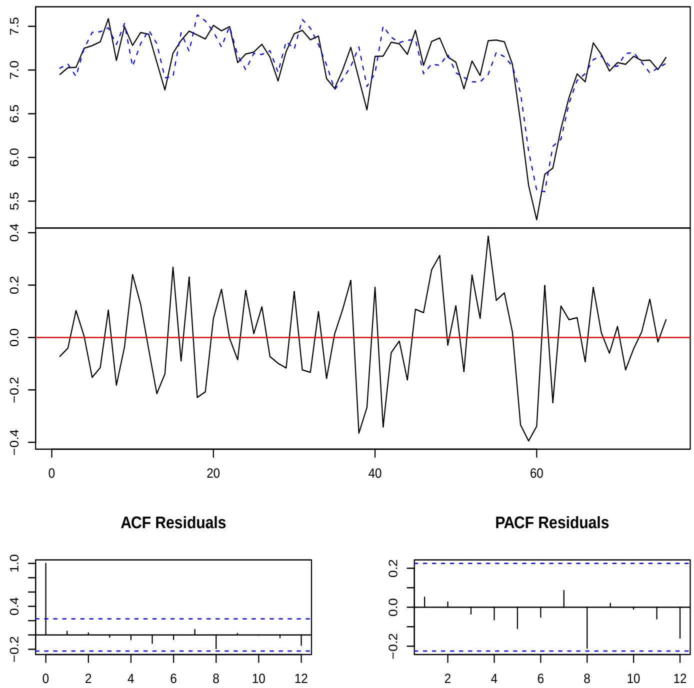

Figure 16: Diagram of fit and residual for news

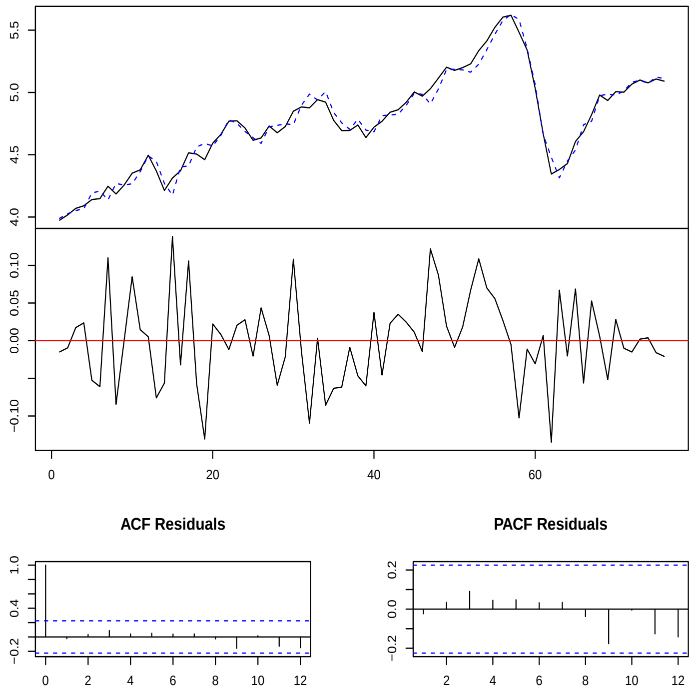

Figure 17: Diagram of fit and residual for price

5.6 Correlations

Table 3: Correlations

	Shipping index	OECD prod	CLI	Petr. cons	Net sent	Cumul. sent	Oil price
Shipping index	1.000	-0.028	0.210	0.045	0.226*	-0.067	-0-052
OECD prod	-	1.000	0.648**	0.381**	0.195	0.765**	0.644**
CLI	-	-	1.000	0.522**	0.531**	0.160	0.177
Petr. cons	-	-	-	1.000	0.217*	-0-056	-0.256*
Net sent	-	-	-	-	1.000	-0-031	0.086
Cumul. sent	-	-	-	-	-	1.000	0.815**
Oil price	-	-	-	-	-	-	1.000

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