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Clostermann, Jörg; Keis, Nikolaus; Seitz, Franz

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Short-term oil models before and during the financial market crisis

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Jörg Clostermann, Nikolaus Keis and Franz Seitz

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Jörg Clostermann, Nikolaus Keis and Franz Seitz

Prof. Dr. Jörg Clostermann
University of Applied Sciences Ingolstadt
Department of Economics
Esplanade 10
D-85049 Ingolstadt
e-mail: clostermann@fh-ingolstadt.de

Dipl.-Vw. Nikolaus Keis
UniCredit Bank AG
Economics & Commodity Research
Arabellastr. 12
D-81925 München
e-mail: nikolaus.keis@unicreditgroup.de

Prof. Dr. Franz Seitz
University of Applied Sciences Weiden
Department of Business and Economics
Hetzenrichter Weg 15
D-92637 Weiden
e-mail: f.seitz@haw-aw.de
and
WSB Poznan
(Poznan School of Banking)
al.Niepodleglosci 2
61-874 Poznan, Poland

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Build. 23.32.01.63, D-40225 Duesseldorf, Germany
Tel.: ++49(0)-211-81-15372
Fax: ++49(0)-211-81-10434
E-mail: helpdesk@rome-net.org
michler@uni-duesseldorf.de

Abstract
The present paper presents three different short-term oil models on a weekly basis. With these models we try to forecast oil prices out-of-sample up to three months. Two of the models are based on the VAR methodology and consider fundamental factors like the net long position and oil inventories. The third variant is a pure futures model. It is shown that the first two fundamental models perform better until mid/end 2007 and since mid 2009. During the financial market crisis from end 2007 until mid 2009, the futures model clearly has better forecasting quality than the other models.

JEL-Classification: C53, E37, Q43

Keywords: Oil, VAR, futures, forecast

1. Introduction

Due to the oil price hikes since the beginning oft he century, the oil market has gained increased attention from different perspectives, but especially from banks.[1] This process not only had consequences for the development of new products (e.g. Exchange Traded Funds in the commodities sector), but also for the necessity of quantitative models to explain oil price movements. The latter trend was amplified further by the price slumps with the onset of the financial market crisis in 2007 and the renewed rise in the oil price from the turn of 2008/09.

Weekly and monthly models are prime candidates for those interested primarily in short-term oil price forecasts (up to at most one quarter). The academic literature differentiates here between pure financial models, which use only information from spot and futures prices, and structural models (fundamental models), which factor in the special characteristics of the oil market (specifically, the supply and demand situation and its determinants). Longo et al. (2007) provide a good overview here, including further differentiations above all of the empirical-econometric approach. In what follows, we present three different weekly models from both categories for the West Texas Intermediate (WTI) oil price. Our primary interest is the performance of the models in quiet versus turbulent phases (as during the recent financial market crisis). In section 2, we describe the models, the econometric methodology and the data used. Subsequently, in chapter 3, we discuss in detail the results and the performance of the models since mid-2007. The final section concludes and summarizes.

2. Models and Data

2.1 Econometric methodology

In principle, there are two alternatives available to explain and predict the oil price. The first is a single-equation approach. This has the advantage that it is easy to model and that the results are, as a rule, easier to interpret and more plausible for the user. If, however, the primary focus is on forecasting, single-equation models have the drawback that the exogenous variables also have to be predicted, thereby

[1] For a long-run and detailed analysis of oil price developments see Breitenfellenr et al. (2009), Hamilton (2009) and Lehman Brothers (2007).

creating an additional area of uncertainty.[2] For that reason, the state-of-the-art procedure now is the use Vector Auto-Regressive (VAR) models, in which all variables are endogenous (see with respect to oil prices, for example, Akram, 2009; Kaufmann et al., 2004; Miller and Ratti, 2009).[3] Within this framework, each variable from the VAR model is itself forecasted within the model for every forecasting horizon chosen. It was possible to demonstrate that an unrestricted VAR is a good approximation for every data-generating process, provided sufficient lags are of the variables are considered (Canova, 1995).

A VAR takes the following form:

(1) $$X_t = \Phi + A_1 X_{t-1} + \ldots + A_p X_{t-p} + \varepsilon_t ,$$

where X_t represents the vector of the endogenous variables, Φ represents the matrix of the deterministic terms, specifically the constant and a linear deterministic trend, A_1 to A_p are the symmetric coefficient matrices, p represents the selected lag length and ε_t is the vector of the residuals. If the variables used are non-stationary but cointegrated, it is possible to recast the VAR model into a so-called Vector Error Correction (VEC) model (for details, see Johansen, 1995). To this end, (1) is modified to

(2) $$\Delta X_t = \Phi + \Pi X_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta X_{t-i} + \varepsilon_t$$
$$\text{mit } \Pi = \sum_{i=1}^{p} A_i - I,\ \Gamma_i = -\sum_{j=i+1}^{p} A_j$$

In (2), X_t is the vector of the k non-stationary I(1) variables. If the matrix Π has reduced ranking *(r-k)*, there are, according to Granger's representation theorem, *(kxr)* matrices α and *ß* with rank *r* such that $\Pi = \alpha\beta'$ and $ß'X_t \sim I(0)$; r is the number of cointegration relationships and each column of *ß* includes one cointegration vector. The α-coefficients are the so-called adjustment coefficients or error correction terms of the VEC model. The number of cointegration relationships is determined, as usual, by the trace and maximum eigenvalue statistics.

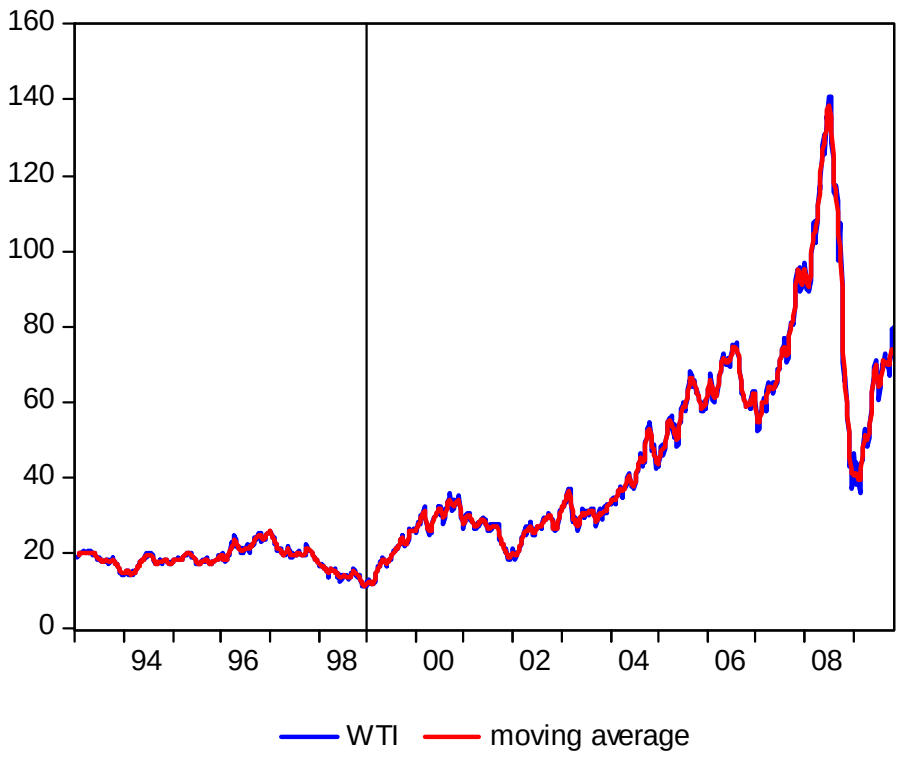
[2] We cross-checked our results with a single-equation model. Within this model, we forecasted the exogenous variables with the help of autoregressive models. The results were significantly worse than those of the VAR models presented below.

[3] An approach which combines econometric models, neural networks, expert systems and narrative evidence may be found in Shouyang et al. (2005).

2.2 Used data and estimation approaches

The objective of the model is to explain and forecast the oil price in US dollars per barrel.[4] As is customary, we use the respective "nearest future" contract. Its development is shown in the following chart 1 on a weekly basis (in each case the Friday reading) since the beginning of 1993. To eliminate erratic fluctuations due to the fixing day, we calculate moving 4-week averages. The rather moderate development up to the beginning of the 21st century is clearly evident; the price increases that subsequently ensued emerge clearly from the end of 2006 to the beginning of 2008 and resulted in an oil price of over USD 140 per barrel. Subsequently, the oil price fell to below USD 40 by the beginning of 2009, only to rise to levels of up to USD 80 again by the end of 2009. The graphic representation of the oil price suggests that we have been in a new regime since 1999. Because of these developments, we decided to start our investigation only in 1999. It ends in October 2009. Overall, therefore, we have 565 observations. We use a weekly model so as to be able to analyze forecasting horizons of one week up to three months.

Chart 1: Oil price WTI



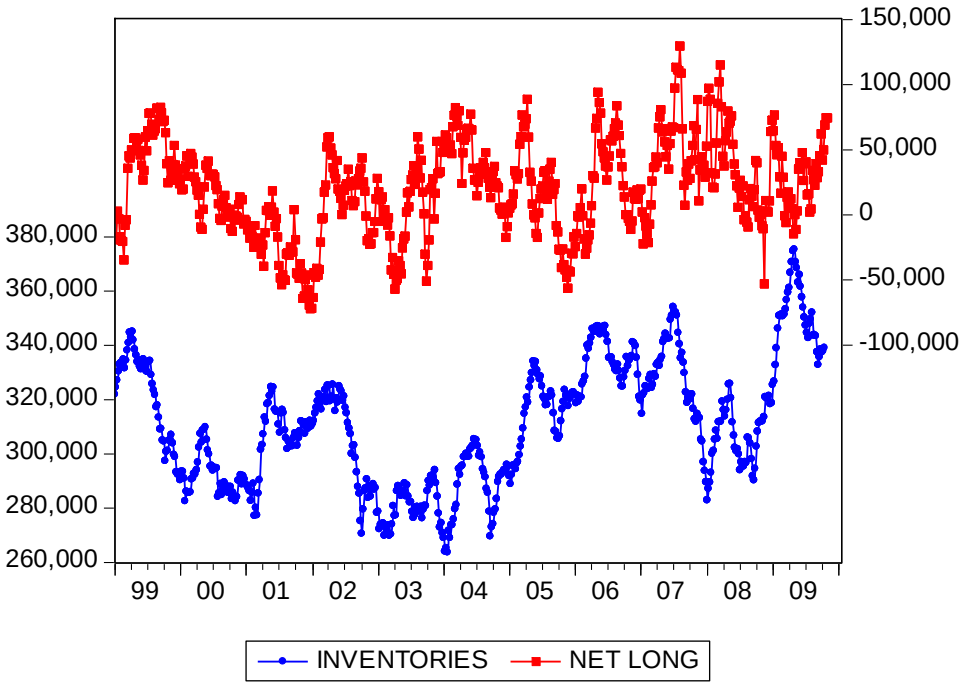
[4] An alternative would be Brent oil. However, the WTI is more commonly used internationally. A comparison of both and one further price is presented in Kang et al. (2009).

Because of the selection of a weekly oil price, the explanatory variables should also be available at least in this frequency. As a fundamental factor in this context, crude oil inventories are traditionally analyzed as a "summary statistic" for the supply and demand situation (see, for example, Chevillon and Rifflart, 2009; Kaufmann et al., 2004; Ye at al., 2005; Zamani, 2004). In the following, we use the industrial inventories of the US, since these are the only consistent data available on a weekly basis. They constitute the bulk of the OECD inventories. The theoretical relation between inventories and the oil price is, however, ambiguous. A negative influence is based on the view that rising inventories indicate a supply surplus, which has a dampening effect on the oil price. In contrast, strategic considerations argue for a positive correlation: The expectation of rising oil prices could, for example, prompt the industrialized countries to increase their inventories. Security considerations could also play a role in this respect.

We augment this model with further variables that are available on a weekly basis. First, we include the net long position of non-commercial traders to check for the role of speculation in driving oil prices (see, for example, also Merino and Ortiz, 2005).[5] Rising net long positions suggest that the oil price will increase. However, interdependencies between the net long position and inventories must also be taken into account. Under certain circumstances, changing inventories impact on investor behavior, and vice versa. This is, for example, suggested by the positive correlation between the net long position and inventories (see chart 2). Depending on the period observed and the time lags considered, the correlation coefficient between both time series was in some cases up to 50% in the past.

[5] Reitz and Slopek (2009) show in a model with heterogeneous speculators that trend-extrapolating chartists tend to destabilize the market, whereas fundamentalists exercise a stabilizing effect on price dynamics.

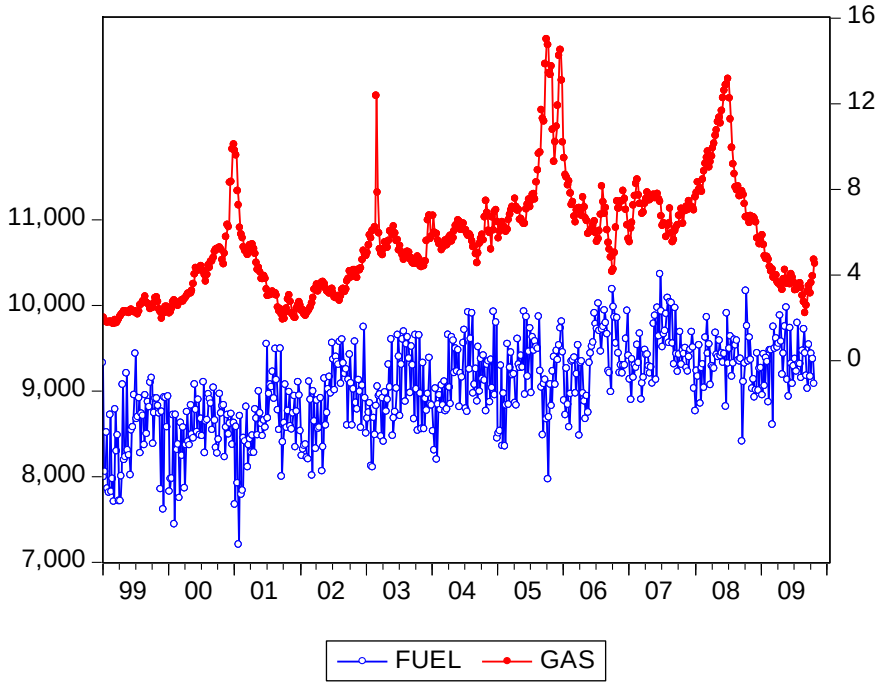
Chart 2: Net long position (left scale) and US industrial crude oil inventories (right scale)



Note: inventories: in 1,000 barrels.

As further variables, we factor in the Henry-Hub natural gas price in US dollars per MMBTU ("million British thermal units") and gasoline consumption in thousands of barrels per day. Since natural gas is a substitute for crude oil, there should be a positive relationship between the natural gas price and the oil price. Equally, rising demand for gasoline should drive up the price of crude oil. Both variables are illustrated in the following chart 3. It is apparent that gasoline consumption has increased only marginally since 1999, albeit with clear fluctuations from week to week. These volatilities do not appear to have changed. The natural gas price shows a pronounced persistent pattern, albeit with significant short-term fluctuations.

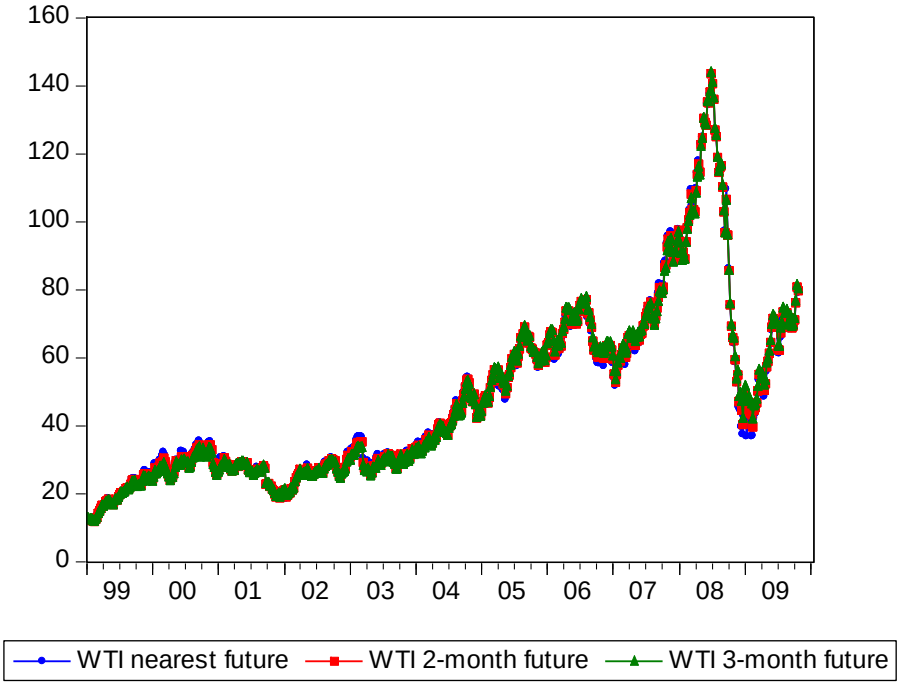
Chart 3: Natural gas prices (right scale) and gasoline consumption (left scale)



With these variables, we specify an unrestricted VAR model and a Vector Error Correction model. Alongside these fundamental VAR models, we have also estimated a purely financial market model, which exploits only the relationships between oil futures of various maturities and the spot price. Coppola (2008), for example, found evidence supporting a cointegration relationship between the oil spot price and the futures prices and a high explanatory power of futures prices for spot prices (see also Abosedra, 2005; Dées et al., 2008; Huang et al., 2009; Pagano and Pisani, 2009).[6] If price innovations become evident in spot prices first, market fundamentals are probably decisive for crude oil price developments. If, in contrast, futures prices react first, speculators should play an important role (Kaufmann and Ulmann, 2009). Alongside the spot price or the "nearest future" price, respectively, we also include the 2-month and the 3-month future. All of them are shown in the following chart 4. Arbitrage processes lead to the extreme parallel movement of the three time series. Furthermore, statistical tests reveal that they are highly non-stationary.

[6] Geman and Ohana (2009) show that the pattern of the futures (or forward) curve is a good indicator for oil (and gas) inventories. We do not consider further financial market prices like exchange rates or interest rates in any model (see in this direction Akram, 2009 and Krichene, 2005).

Chart 4: Oil price futures ($ per barrel)



The theoretical basis of the relationships between the different futures prices is the expectations theory, which is based on this time series characteristic. If the various oil prices follow a stochastic trend, they must all follow the same trend irrespective of their maturity, i.e. the price differences between (arbitrarily selected) price pairs are stationary. In our case, the expectations theory states specifically that in an arbitrage equilibrium the "long-term" price – for example measured by the 3-month future – must be equal to the expected price from revolving short-term transactions – for example, three consecutive transactions with a one month maturity. With P_t as the 3-month future, p_t as the 1-month future, this yields ("*e*" denotes expectations)

(3) $$P_t = \tfrac{1}{3} \cdot (p_t + p^e_{t+1} + p^e_{t+2})$$

Subtracting p_t on both sides, one obtains

(4) $$P_t - p_t = \tfrac{2}{3} \cdot \Delta p^e_{t+1} + \tfrac{1}{3} \cdot \Delta p^e_{t+2},$$

with $\Delta p_{t+1} = p_{t+1} - p_t$ as the one-period price change. The spread $P_t - p_t$ is, therefore, a weighted mean of the changes expected in the 1-month futures over the next two months, whereby the price changes expected further in the future get a smaller weight. This illustrates the information content, which according to the expectations theory is incorporated in the difference between a long-term and short-term "price". Moreover, it is apparent from (4) that the long-term and the short-term prices follow a

common trend, i.e. the spread between the 3-month and the 1-month future is stationary. On the right side of (4) there are only (expected) changes of the short-term future. Since the futures follow a stochastic trend, the price difference and therefore also the right side of (4) are consequently stationary. In fact, multivariate cointegration tests show this to be the case.[7] In our sample, the spreads we observe become greater as the maturity difference increases. That also means that spot prices are, in general, lower than the future prices, which is commonly referred to as the contango effect. In this case, the marginal "convenience yields" are then probably relatively high. The so-called backwardation, spot prices above futures prices, a standard result in the literature (e.g. French, 2005) does not, therefore, hold generally for our data set.[8] Huang et al. (2009) also find this result for the period from September 11, 2001 to April 30, 2007, which covers the largest part of our sample. Kaufmann et al. (2008) conclude that the strong rise in the price of oil from 2005 to 2007 went hand in hand with a change in the futures markets from backwardation to contango.

Except the net long position, all variables are in logarithms. To reduce the impact of individual outliers on the results and in order to better model the relationships, we calculate moving 4-week averages for all variables. The lag length of the VAR models is selected to maintain forecasting quality despite parsimony. The final models include only those variables that are required in each case on forecasting considerations. That also means that even if an additional variable or an additional lag is significant but does not improve the forecasting results, it is not included in the approach. In this respect, we proceed according to the so-called "general-to-specific" methodology. The estimation period extends at most from the first week of 1999 to October 26, 2009. Our primary interest here is how the quality of the models change during the financial market crisis since mid/end 2007.

2.3 Forecasting exercises

For out-of-sample forecasts, the respective forecasting period is shortened by one year, and the "missing" year is used as the forecasting period. The estimates and forecasts are conducted recursively, where the base period used is extended step by

[7] The results of these tests are available from the authors upon request.

[8] This conventional term structure on oil futures markets (backwardation) may be explained with inventory-theoretic behaviour and option-pricing related considerations, see, e.g. Pindyck (2001) or Litzenberger et al. (1995).

step by one week. The forecasting horizons extend from one week to three months (12 weeks).

The forecasting quality of our three models (VAR, VEC, Futures) is assessed using several forecast evaluation criteria. The benchmarks used in any case are a random walk with/without drift and an optimized ARIMA model. For each of these models, the oil price was estimated from the beginning of 1999 to point *t* and forecasted up to *h* (*h* = 1,…12) weeks into the future based on data available in *t* (= $wti_{t+h,t}$)). The forecast error (= $e_{t+h,t}$) is consequently the difference between the actual value at *t+h* (= wti_{t+h}) and its forecasted value:

(5) $$e_{t+h,t} = wti_{t+h} - wti_{t+h,t}$$

The comparison of the forecasted values with the actual values is the basis for the calculation of the Root Mean Squared Error (*RMSE*). It is defined as

$$RMSE_h = \sqrt{\frac{1}{T}\sum_{t=1}^{T} e_{t+h,t}^2}$$

The second criterion used is the so-called Hit Ratio (*HR*). To this end, an indicator variable *J* is defined with the following characteristics

(6) $$\begin{aligned} &if\ \ sign\left(wti_{t+h}^l - wti_t^l\right) = sign\left(wti_{t+h,t}^l - wti_t^l\right) \Leftrightarrow J = 1 \\ &if\ \ sign\left(wti_{t+h}^l - wti_t^l\right) \neq sign\left(wti_{t+h,t}^l - wti_t^l\right) \Leftrightarrow J = 0 \end{aligned}$$

Thus, *HR* reads as

$$HR_h = \left(\frac{1}{T}\sum_{t=1}^{T} J_t\right) \cdot 100\% .$$

The higher the hit ratio, the greater the frequency that the direction of change of the oil price is predicted correctly. For example, a hit ratio of 70% indicates that in 70% of the cases the model correctly predicted the direction of change. Both evaluation criteria– *RMSE* and *HR* – are discussed in Cheung et al. (2005).

Furthermore, we use a rather unusual measure which we call the "Mean Weighted Hit Ratio" (*MWHR*). It also refers to the indicator function (6); with the only difference that false hits are now assigned the value "-1". *MWHR* is defined as follows

$$MWHR = mean\left(\underset{+}{(1}, \underset{-}{-1)} \cdot \left|\Delta wti\right|\right)$$

The higher the values of *MWHR*, the better the forecasting quality. *MWHR* weights the hit ratio with the absolute change of the oil price at the corresponding point in time. Extremely positive is factored in if big changes are predicted correctly. On the other side, extremely negative is a situation in which major changes are not predicted correctly.

3. Results

3.1 Performance until end 2007

The models were optimized for the period up to the financial market crisis at mid/end 2007 (the detailed estimation results may be found in the annex). Alongside the oil price, the only variables included (in levels) in the two fundamental models are the natural gas price and the net long position (with lags). The net long position is included as an exogenous, non-modeled variable, since, in contrast to the other variables, it is already stationary in levels. For the out-of-sample forecast exercises, it is modeled as a univariate process. In the VEC model, there is one cointegration relationship between the oil price and the natural gas price. The Futures VEC model includes – according to the theoretical considerations discussed in the preceding section - two cointegration relationships between the three oil prices. All models include three lags in levels. It was not necessary to model seasonal effects in any of the models, since no pronounced and systemic seasonal patterns were observable (see, for example, Zamani, 2004).

Tables 1-3 show the results for the three forecast evaluation criteria (*RMSE*, *HR*, *MWHR*), the four models (VAR, VEC, Futures, Random Walk (RW)) and for the 12 forecast horizons.[9] It is apparent that the Random Walk is beaten by all three models, irrespective of the forecasting measure.[10] With respect to futures prices, this result is also confirmed by Abosedra (2005) as well as Murat and Tokat (2009). In terms of comparison with the actual value, measured by the *RMSE*, the VAR, the VEC and the futures model perform equal on forecasting horizons of up to two months. For the medium term, the VAR model is the best, whereas for the two longest forecast horizons, the VAR and VEC models are equally good and superior to the futures

[9] For the *RW* model we only present the results for a random walk with drift. Qualitatively and relative to the other models the results do not differ from those of a random walk without drift or the optimised ARIMA model.

[10] Reitz et al. (2009) show in their analysis that oil price forecasts on the basis of survey data from Consensus Economics never beat a random walk in a sample from 1989 until 2008 and are systematically biased in that they underestimate future oil price changes.

model. The quality of the forecast results generally declines with the forecast horizon. In the case of the *HR*, the VEC fundamental model performs best on the two longest forecast horizons. However, for maturities up to six weeks, the futures model correctly predicts up to 80% of the oil price changes and yields better results than all other models. This finding is also confirmed by Table 3, which shows the *MWHR*. The comparatively higher forecasting quality of the fundamental error correction model for the longer horizons underlines the validity of the assumed cointegration relationship.[11]

Table 1: RMSE

forecast period	VAR	VEC	RW	Futures
1 week(s)	0.9	0.9	1.9	0.9
2 week(s)	2.2	2.2	3.6	2.2
3 week(s)	3.7	3.7	5.2	3.7
4 week(s)	5.3	5.4	6.5	5.3
5 week(s)	6.5	6.7	7.6	6.6
6 week(s)	7.5	7.8	8.5	7.6
7 week(s)	8.2	8.5	9.1	8.4
8 week(s)	8.7	9.1	9.7	9.0
9 week(s)	9.1	9.5	10.3	9.5
10 week(s)	9.6	9.9	10.7	10.1
11 week(s)	10.2	10.3	11.2	10.7
12 week(s)	10.9	10.9	11.7	11.3

Table 2: Hit ratio

forecast period	VAR	VEC	RW	Futures
1 week(s)	78.8	78.8	38.5	78.8
2 week(s)	75.0	73.1	32.7	75.0
3 week(s)	76.9	76.9	36.5	78.8
4 week(s)	71.2	69.2	26.9	78.8
5 week(s)	65.4	61.5	28.8	76.9
6 week(s)	63.5	63.5	25.0	80.8
7 week(s)	63.5	63.5	26.9	75.0
8 week(s)	63.5	67.3	28.8	73.1
9 week(s)	61.5	67.3	30.8	69.2
10 week(s)	59.6	67.3	30.8	69.2
11 week(s)	63.5	69.2	32.7	63.5
12 week(s)	63.5	71.2	34.6	61.5

[11] See in this respect also Chinn et al. (2005)

Table 3: MWHR

forecast period	VAR	VEC	RW	Futures
1 week(s)	1.3	1.3	-0.4	1.3
2 week(s)	2.3	2.4	-0.9	2.4
3 week(s)	3.0	3.0	-1.5	3.4
4 week(s)	3.1	2.8	-2.2	3.9
5 week(s)	3.0	2.4	-2.9	4.0
6 week(s)	3.4	2.4	-3.6	4.2
7 week(s)	3.2	2.2	-4.0	4.1
8 week(s)	3.3	2.6	-4.4	4.1
9 week(s)	3.1	3.6	-4.6	4.7
10 week(s)	2.7	3.8	-4.9	4.5
11 week(s)	3.2	4.7	-5.2	4.3
12 week(s)	2.3	5.0	-5.5	4.1

Overall, this analysis suggests that up to the end of 2007 the two fundamental models, specifically the VEC model, produce pretty good results, especially for the longer forecast horizons, and are clearly superior to a random walk, but also to the futures model. However, the ranking of the models might have changed with the onset of the structural break triggered by the financial market crisis. For that reason, the focus in the following is on the performance of the various models from 2008 to the end of 2009.

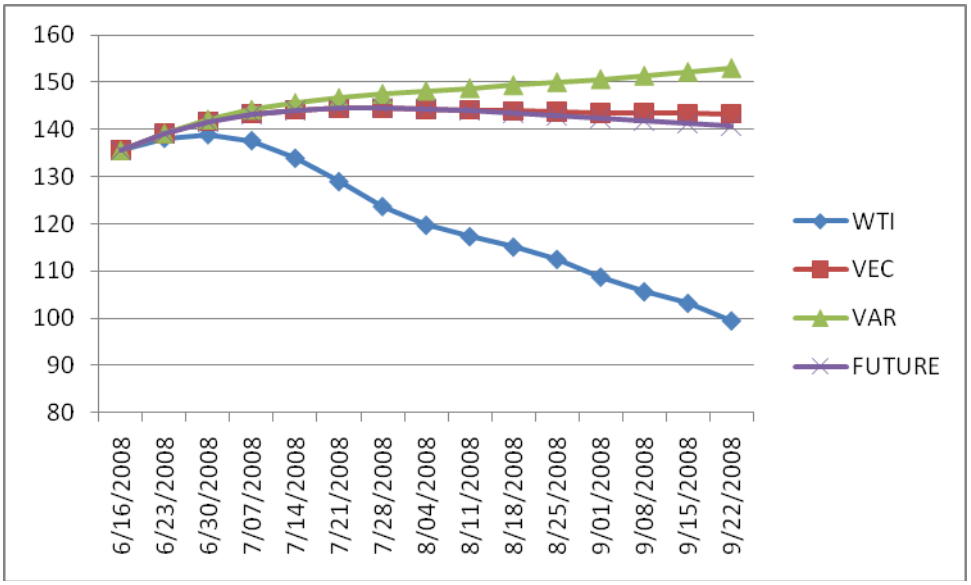
3.2 Performance during the financial market crisis

The following chart 5 compares the forecasts produced by our three models for a 3-month period with the actual development of the oil price for selected periods from mid-2008. The turning points are the main focus of interest (mid-2008, beginning of 2009). The forecast evaluation process is once again done recursively, and the estimation base period is extended successively to the current edge (end of October 2009). It is obvious that the futures model clearly dominates up to mid-2009, but that from the second half of 2009 the two fundamental models again come out on top. Even though the sharp decrease in oil prices in 2008 (sample up to week 26, 2008) is predicted only to a small extent by the futures, the VAR and VEC model would still have signaled rising prices. The renewed rise from February 2009 is, however, signaled early on by the futures model (sample up to week 52, 2008). While this ranking persists until mid-2009 (sample up to week 26, 2009), the superiority of the two fundamental models is evident again after the gradual calming of the situation on

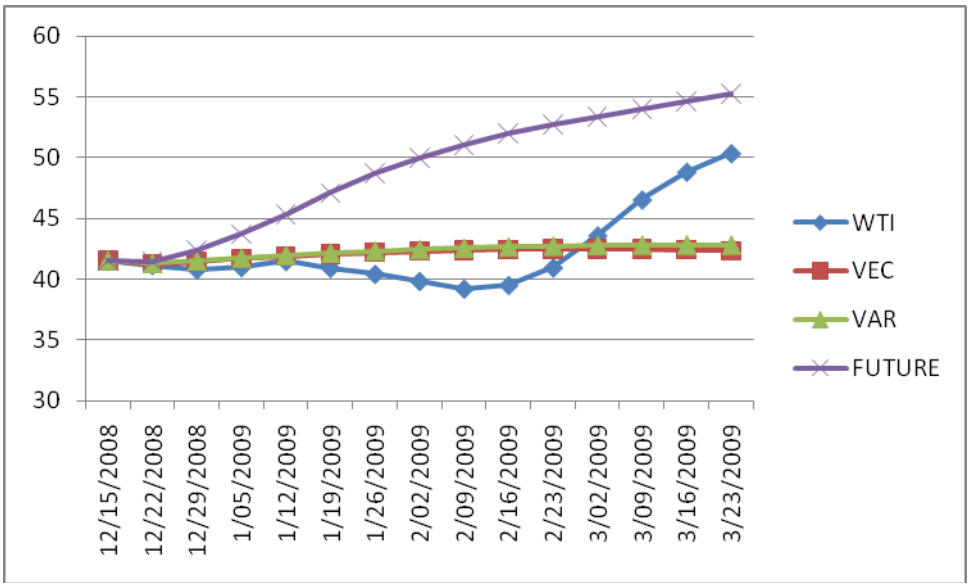
financial markets (sample up to week 30, 2009). If the estimation period is extended up to the end of October (sample: total period observed), the futures model would predict only marginally rising oil prices until the end of January 2010, while the two other models suggest prices rising to over US-$ 90.

Chart 5: Model forecasts during the financial market crisis

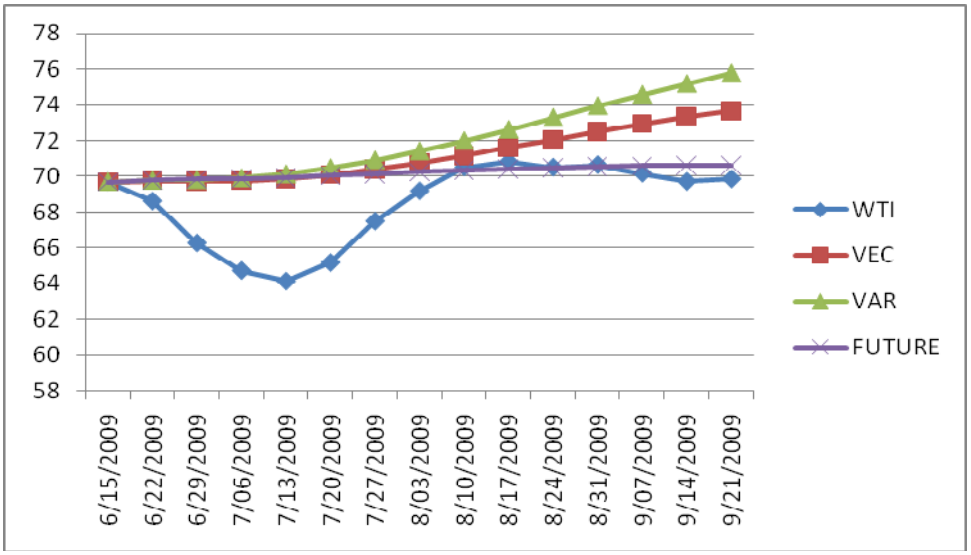
2008.26



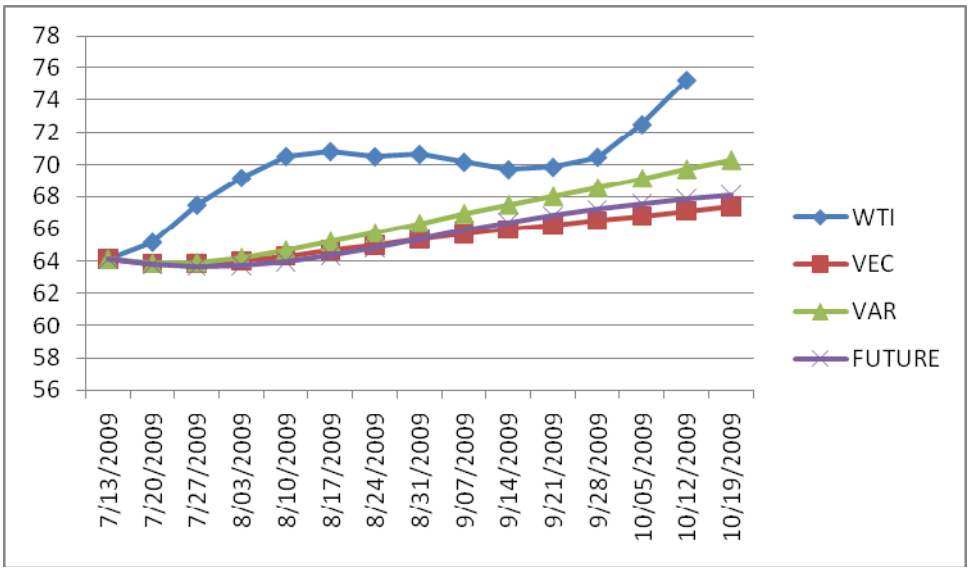
2008.52



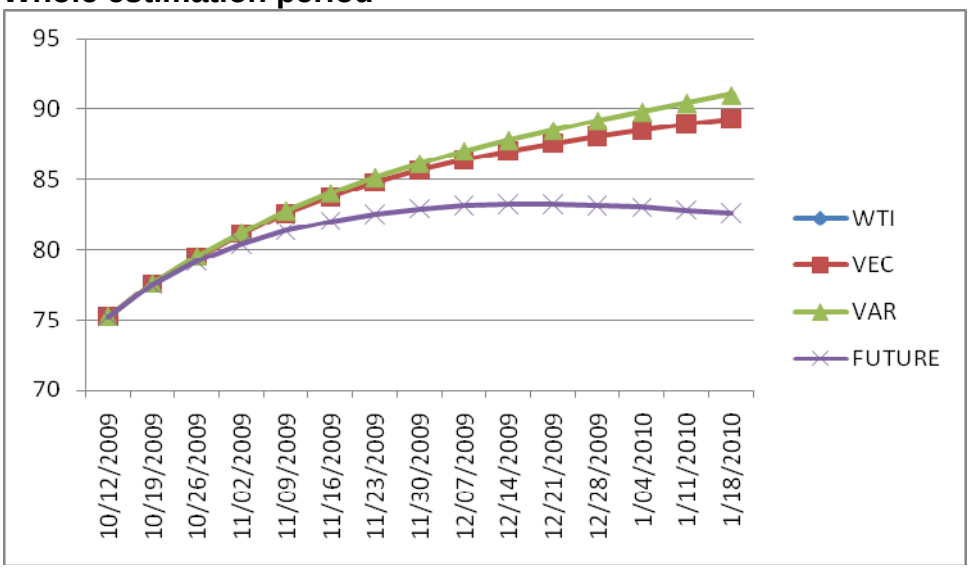
2009.26



2009.30



Whole estimation period



Note: Above the corresponding figures is the end of the respective estimation period. Shown are the 4-week moving averages.

Overall, these observations permit the conclusion that during strong upheavals on markets, characterized by extreme shocks, preference should be given to the futures model over the two other models. In quiet phases, in contrast, the fundamental VAR and VEC models are more reliable. The models also appear to be still valid; the financial market crisis probably did not trigger any long-term changes or instabilities. Only the short-term performance was affected.

4. Summary and outlook

In this analysis, we have presented three different short-term forecasting models for the oil price. Model selection was based on a purely forecast-oriented approach. Accordingly, VAR models formed the methodological econometric basis. On the one hand, we considered fundamental determinants on a weekly basis, such as the net long position, oil inventories and the natural gas price. This was, on the other hand, compared with a pure financial market model based on futures prices.

It was evident that a VAR or VEC model based on fundamental variables produces good forecasting results in quiet market phases and is clearly superior to a random walk model and also to the futures model. In turbulent market phases, such as triggered by the financial market crisis, investors should however tend to rely more on the futures model. It is, therefore and in general, advantageous to monitor both variants and focus on a specific model depending on the market situation.

It was astonishing that oil inventories had no significant influence and were not included in the preferred fundamental models. This could have to do with the weekly data used, but also with the fact that only US industrial inventories are available on a weekly basis and that we also included the net long position. In the literature, a significant influence of inventories is usually established if these assumptions are abandoned (see, for example, the overview in Longo et al., 2007, ch. 2.2). Some authors do, however, find that it is not the inventories per se but their position relative to a normal level that is the decisive variable (Ye et al., 2005; Zamani, 2004). The oil price inventories nexus could also depend on whether the market is in a phase of rising or falling prices (Ye et al, 2005). Moreover, Geman and Ohana (2009) find that the information in futures prices is a good proxy for inventories. The inventories would, therefore, be implicitly included in the futures model.

Further research will have to determine whether the relations discovered are also to be found in models with monthly or quarterly frequency. Furthermore, it is interesting

to investigate to what extent models with lower data frequency are more stable in turbulent market phases, and whether they are also suitable as valid approaches for longer-term forecasts.

Appendix

Futures model

$$\Delta wti = \underset{(+0.10)}{+0.01}\cdot\left(wti_{-1} - \underset{(-58.81)}{0.95}\cdot wti_f2_{-1} - \underset{(-2.97)}{0.18}\right) - \underset{(-0.63)}{0.14}\cdot\left(wti_f2_{-1} - \underset{(-141.45)}{0.98}\cdot wti_f3_{-1} - \underset{(-3.27)}{0.09}\right)$$
$$+\underset{(+4.48)}{1.19}\cdot\Delta wti_{-1} - \underset{(-2.12)}{0.61}\cdot\Delta wti_{-2} + \underset{(+0.66)}{0.52}\cdot\Delta wti_f2_{-1} - \underset{(-0.01)}{0.01}\cdot\Delta wti_f2_{-2} - \underset{(-1.28)}{0.79}\cdot\Delta wti_f3_{-1} + \underset{(+0.77)}{0.48}\cdot\Delta wti_f3_{-2}$$

Adj. R^2: 0.69; standard error: 0.014; F-statistic: 178.79; sample: 1st week 1999 until 43rd week 2009.

$$\Delta wti_f2 = \underset{(+1.73)}{+0.15}\cdot\left(wti_{-1} - \underset{(-58.81)}{0.95}\cdot wti_f2_{-1} - \underset{(-2.97)}{0.18}\right) - \underset{(-2.20)}{0.45}\cdot\left(wti_f2_{-1} - .\underset{(-141.45)}{0.98}\cdot wti_f3_{-1} - \underset{(-3.27)}{0.09}\right)$$
$$+\underset{(+2.15)}{0.53}\cdot\Delta wti_{-1} - \underset{(-2.04)}{0.54}\cdot\Delta wti_{-2} + \underset{(+1.23)}{0.90}\cdot\Delta wti_f2_{-1} - \underset{(-0.04)}{0.03}\cdot\Delta wti_f2_{-2} - \underset{(-0.86)}{0.49}\cdot\Delta wti_f3_{-1} + \underset{(+0.74)}{0.44}\cdot\Delta wti_f3_{-2}$$

Adj. R^2: 0.69; standard error: 0.013; F-statistic: 183.19; sample: 1st week 1999 until 43rd week 2009.

$$\Delta wti_f3 = \underset{(+1.90)}{+0.16}\cdot\left(wti_{-1} - \underset{(-58.81)}{0.95}\cdot wti_f2_{-1} - \underset{(-2.97)}{0.18}\right) - \underset{(-2.31)}{0.45}\cdot\left(wti_f2_{-1} - \underset{(-141,45)}{0.98}\cdot wti_f3_{-1} - \underset{(-3,27)}{0.09}\right)$$
$$+\underset{(+2.24)}{0.52}\cdot\Delta wti_{-1} - \underset{(-2.01)}{0.51}\cdot\Delta wti_{-2} - \underset{(-0.18)}{0.13}\cdot\Delta wti_f2_{-1} + \underset{(+0.34)}{0.25}\cdot\Delta wti_f2_{-2} + \underset{(+1.03)}{0.56}\cdot\Delta wti_f3_{-1} + \underset{(+0.19)}{0.11}\cdot\Delta wti_f3_{-2}$$

Adj. R^2: 0.69; standard error: 0.012; F-statistic: 183.58; sample: 1st week 1999 until 43rd week 2009.

VEC-Modell

$$\Delta wti = \underset{(+0.77)}{+0.00}\cdot\left(wti_{-1} - \underset{(-5.64)}{1.59}\cdot pgas_{-1} - \underset{(-2.41)}{1.12}\right) + \underset{(+22.44)}{1.01}\cdot\Delta wti_{-1} - \underset{(-4.85)}{0.22}\cdot\Delta wti_{-2}$$
$$+\underset{(+1.07)}{0.02}\cdot\Delta pgas_{-1} - \underset{(-0.24)}{0.01}\cdot\Delta pgas_{-2} - \underset{(-1.41)}{0.00}\cdot netlong + \underset{(+0.94)}{0.00}\cdot netlong_{-1} - \underset{(-0.37)}{0.00}\cdot netlong_{-2}$$

Adj. R^2: 0.68; standard error: 0.014; F-statistic: 171.57; sample: 1st week 1999 until 43rd week 2009.

$$\Delta pgas = \underset{(+3.49)}{+0.01}\cdot\left(wti_{-1} - \underset{(-5.64)}{1.59}\cdot pgas_{-1} - \underset{(-2.41)}{1.12}\right) + \underset{(+3.37)}{0.27}\cdot\Delta wti_{-1} - \underset{(-3.49)}{0.29}\cdot\Delta wti_{-2}$$
$$+\underset{(+25.42)}{1.01}\cdot\Delta pgas_{-1} - \underset{(-7.52)}{0.30}\cdot\Delta pgas_{-2} - \underset{(-2.37)}{0.00}\cdot netlong + \underset{(+2.66)}{0.00}\cdot netlong_{-1} - \underset{(-2.53)}{0.00}\cdot netlong_{-2}$$

Adj. R^2: 0.66; standard error: 0.026; F-statistic: 153.60; sample: 1st week 1999 until 43rd week 2009.

VAR-Modell

$$wti = + \underset{(+44.19)}{2.00} \cdot wti_{-1} - \underset{(-14.28)}{1.22} \cdot wti_{-2} + \underset{(+4.78)}{0.22} \cdot wti_{-3} + \underset{(+1.03)}{0.02} \cdot pgas_{-1} - \underset{(-0.75)}{0.03} \cdot pgas_{-2} + \underset{(+0.33)}{0.01} \cdot pgas_{-3}$$
$$- \underset{(-1.40)}{0.00} \cdot netlong + \underset{(+0.94)}{0.00} \cdot netlong_{-1} - \underset{(-0.38)}{0.00} \cdot netlong_{-2} + \underset{(+1.60)}{0.01}$$

Adj. R^2: 0.99; standard error: 0.014; F-statistic: 85596.79; sample: 1st week 1999 until 43rd week 2009.

$$pgas = + \underset{(+3.47)}{0.28} \cdot wti_{-1} - \underset{(-3.63)}{0.57} \cdot wti_{-2} + \underset{(+3.49)}{0.29} \cdot wti_{-3} + \underset{(+49.56)}{1.99} \cdot pgas_{-1} - \underset{(-17.42)}{1.31} \cdot pgas_{-2} + \underset{(+7.49)}{0.30} \cdot pgas_{-3}$$
$$- \underset{(-2.33)}{0.00} \cdot netlong + \underset{(+2.63)}{0.00} \cdot netlong_{-1} - \underset{(-2.49)}{0.00} \cdot netlong_{-2} - \underset{(-1.16)}{0.01}$$

Adj. R^2: 0.99; standard error: 0.026; F-statistic: 21019.31; sample: 1st week 1999 until 43rd week 2009.

wti: 4-week moving average of WTI oil price (nearest future) (in logarithm)

wti_f2: 4-week moving average of 2-month WTI future (in logarithm)

wti_f3: 4-week moving average of 3-month WTI future (in logarithm)

pgas: 4-week moving average of natural gas price (in logarithm)

netlong: net long position of non-commercial traders

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