

Oil Shocks and Real GDP Growth in Germany: Looking for a Needle in a Haystack

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Abstract

This paper investigates the relationship between real GDP growth and oil price shocks in Germany using a number of VAR models. Various non-linear oil price specifications are considered, the use of which is now widespread in the relevant literature. As a contribution to this discussion a new specification based on a Markov regime switching approach is introduced. Furthermore, a number of structural break and specification tests are applied. The key findings are: (1) the new oil price specification is appropriate in both empirical and theoretical terms and allows for a non-arbitrary, data driven distinction between “large” and “normal” oil price movements. (2) The observed impact of oil price shocks can essentially be explained by a small number of large oil price increases. (3) The relationship has changed considerably over time, with strong evidence of a structural break in 1986.

Keywords: Oil price shocks, vector autoregression, Granger causality, impulse responses, Markov-switching models, non-linear models, structural breaks

JEL-Classification: C22, C32, E32

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1 Introduction

A vast quantity of literature has considered the relationship between oil price movements and real GDP. Manifold methodical approaches have been applied and it is a widely held view that a strong negative relationship between the two forementioned variables certainly appears to have existed in the 1970s and 1980s, with the structural properties of this relationship changing over time. While most of the research thus far has considered the US economy, some papers have widened the perspective and looked at different OECD countries. In periods of rising oil prices, in particular, questions concerning this relationship arise once again, ensuring that this field of research continues to grow in importance.

This paper focusses on the German economy. In order to examine the relationship between oil price movements and real GDP growth, the three following issues are analysed: is it fruitful to apply a Markov-switching model on the real oil price? Is the use of non-linear methods justified, and what is the effect of a small number of very large oil price shocks on real GDP compared to the effect of “normal” oil price increases? And does the relationship have the same properties over the sample period or is there evidence of structural breaks?

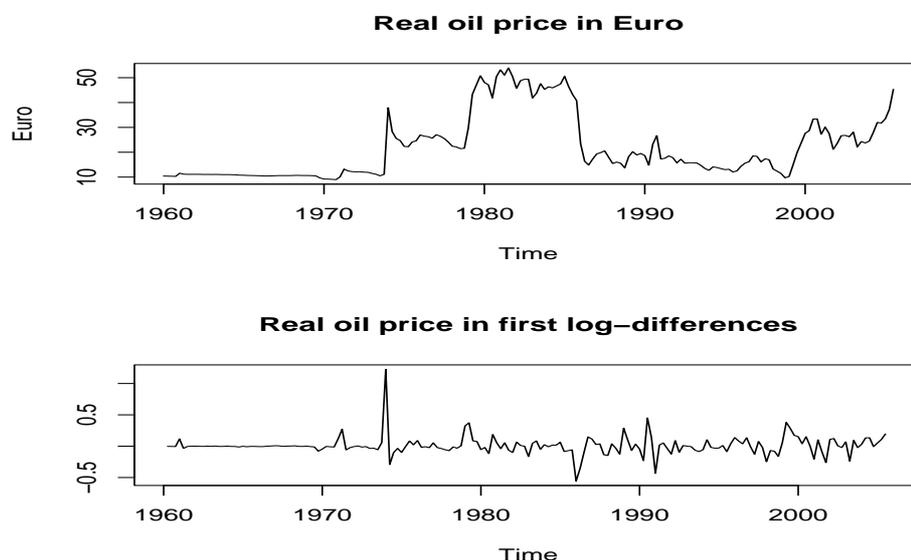
In order to explore these issues, a number of linear VAR models with different oil price specifications, different dimensions and different sample periods are considered. Furthermore, a new non-linear oil price specification is introduced by applying a Markov-switching approach. This procedure leads to a data driven distinction between large and normal oil price increases. Finally, a variety of tests are performed in order to check whether the use of non-linear methods in this context is justified.

The task of identifying a significant oil price-GDP relationship has come close to the search for a needle in a haystack, in that the relationship is not as clear-cut as one would expect.¹ There are sufficient grounds for concluding, first, that the observed impact of oil price shocks on real GDP in Germany can essentially be explained by a small number of large oil price increases - in particular those associated with incidents such as the first and the second oil crisis - which permeate through the whole analysis and, second, that a significant relationship can be found only in the subperiod from 1970 to the mid 1980s. In particular, this first finding appears to have been overlooked in previous research. To illustrate this, Figure 1 contains plots of the real oil price both in levels and first log-differences over time.² The prominent role

¹This is particularly true when one considers the recent contribution by Jiminez-Rodriguez and Sanchez (2005).

²The real oil price is calculated as follows: the price of an international traded variety

Figure 1: The real oil price both in levels and first log-differences



of a small number of large oil price shocks is clearly visible.

By way of a brief overview of the existing literature it should be noted that research on this question was already underway in the mid 1980s. Gisser and Goodwin (1986) and Loungani (1986) typify these early contributions; Burbidge and Harrison (1984) and Hamilton (1983) had already made use of VAR models at this time. Subsequently in the late 1980s and early 1990s researchers have been confronted with the finding that oil price declines affected real GDP to a lesser extent than that predicted by the models of that time. Therefore the question arose of whether the impact of oil price movements on real GDP was symmetric or not [see, for example, Mork (1989), Mory (1993) or Hooker (1996a)]. In response to this they began proposing non-linear oil price specifications [see Mork (1989), Hamilton (1996) and Lee et al. (1995)]. These proposals have been motivated by both empirical and theoretical considerations, see in particular Hooker (1996a). Furthermore, authors such as Hooker (1996a) or Hamilton (1996) raised the question of whether the relationship between real GDP growth and the oil price is characterized by structural stability or whether there is evidence of structural breaks. Hooker (1999) and Hamilton (2003) summarize this debate. Recent contributions to this research field include Kilian (2005), Roeger (2005) and Jiminez-Rodriguez and Sanchez (2005). The latter employ a similar model-

of crude (UK Brent) in US Dollars is converted to German Marks and EURO respectively and deflated using the German producer price index.

ing strategy to that used here. Barsky and Kilian (2004) offer an interesting retrospective view on this oil price-real GDP growth discussion.

The outline of this paper reflects the evolution of this research field. Section 2 explains the general modeling strategy and considers models using the linear oil price. Section 3 summarizes the discussion on non-linear oil price specifications and introduces a new non-linear specification. By applying a variety of specification and diagnostic tests, in addition to those procedures commonly used in the literature, the justification for using non-linear methods is assessed. In Section 4 three non-linear specifications are included in the basic modeling approach of this paper. Section 5 can be distinguished from the other sections as it does not deal with the full sample from 1960 to 2005. It investigates the issue of structural breaks and demonstrates to what extent the properties of this relationship have changed over time. Section 6 concludes.

2 Models with linear oil price

In order to investigate the oil price-GDP relationship a small scale model consisting of just real GDP growth and real oil price changes is initially used. This model will be referred to as the basic model. Both variables in this model are taken in first log-differences.³ The ordering of the VAR is real GDP followed by the real oil price. Thus this paper concentrates on the impact of oil shocks on real GDP growth. The method used here is a linear VAR model; the period of observation is 1960:1 to 2005:3 and quarterly data is used.⁴ The issue of lag length is tackled as follows: the AIC suggests to use 4 lags of the variables while both the SC and the HQ criteria suggest to use just 1. Since both the Portmanteau and the LM test for autocorrelation in the residuals do not reject the null hypothesis of no autocorrelation for 4 lags for the first time and since quarterly data is used 4 lags of the variables are included in the model.⁵

Since the use of VAR models consisting of more than two variables is prominent in this research field, as an excursus a six variable VAR model is also considered. This model follows that of Jiminez-Rodriguez and Sanchez

³For both variables standard unit root tests indicate clearly that they have a unit root in levels but no unit root in first differences. The issue of cointegration has been considered by applying both the Engle and Granger (1987) methodology and the Johansen (1991, 1995) procedure. The results indicate that there is no cointegration relationship at the usual significance levels. Detailed results can be obtained from the author on request.

⁴Details on the data can be found in Appendix A.1.

⁵The null is rejected for lags 1,2, and 3. The results of the tests on residual autocorrelation are provided in Appendix A.2.

(2005) and will be referred to as the extended model. In addition to the variables of the basic model it contains both short and long term interest rates, the consumer price index, and real wages. The first three variables are taken in first differences while the latter variable is first log-differenced.⁶ The ordering in the VAR has been chosen following Jiminez-Rodriguez and Sanchez (2005): real GDP, real oil price, short term interest rate, long term interest rate, consumer price index, and real wages.⁷ Both the lag length criteria and the tests on residual autocorrelation clearly call for the use of five lags of the variables in the VAR model.⁸

The relationship between real GDP growth and the oil price is investigated using standard procedures such as Granger causality tests and impulse response analysis. Since the latter are merely point estimators their statistical reliability has to be assessed. A number of approaches have been considered in the literature and here the approach suggested by Sims and Zha (1999) is used. They provide a comprehensive treatise of the features of this approach. Further discussion can be found in Canova (2005). The mechanism makes use of a particular Monte Carlo method. Sims and Zha (1999) suggest to use the 0.025 and 0.975 fractiles taken from the outcome of the Monte Carlo procedure instead of two standard error bands. Since this procedure is used here, this paper differs from Jiminez-Rodriguez and Sanchez (2005) who make use of two standard error bands based on Lütkepohl (1990). The results obtained from both the basic and the extended model using the linear oil price variable are now presented.

Over the sample period from 1960:1 to 2005:3 the oil price-GDP relationship has been found to be weak. Table 1 summarizes Granger causality tests and Figure 2 displays impulse response functions.⁹ The oil price is not found to be significant in the respective GDP equation. This finding is confirmed by examining the impulse response functions. The error bands clearly indicate that the obtained results are not significant. Moreover, the forecast error variance decompositions reported in Table 2 lead one to conclude that oil price shocks do not affect real GDP growth to a large extent.

⁶For all variables standard unit root tests show that the variables have unit roots in levels but not in first differences. The cointegration analysis does not yield clear results. But since this is an excursus this finding is not taken into account.

⁷As a check of robustness an alternative ordering has been used: short term interest rate, long term interest rate, real GDP, real wage, real oil price and consumer price index. The results are essentially unchanged. See appendix A.3 for the results.

⁸The detailed results can be obtained from the author on request.

⁹The impact of impulses on variables like the short term interest rate and the consumer price index in the extended model is investigated in the context of models with non-linear oil price specifications in Section 4.

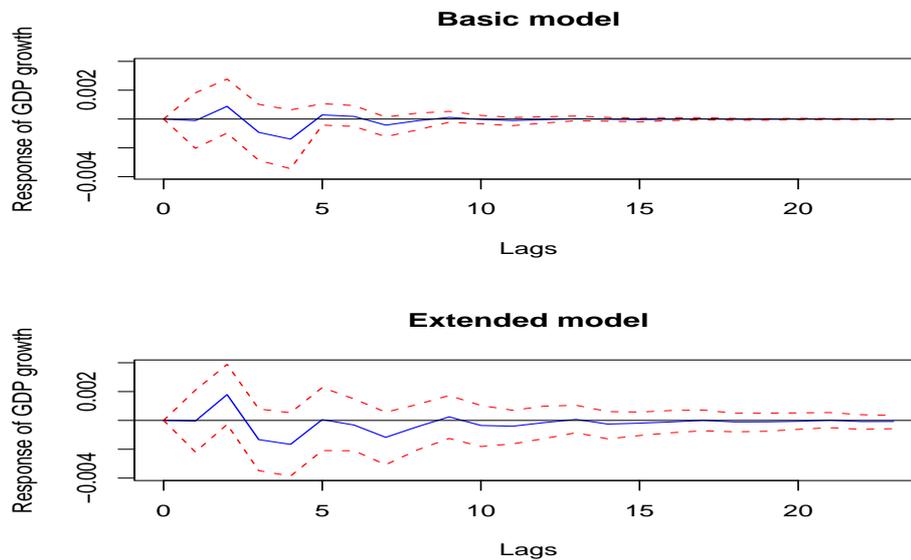
Table 1: F-Statistics for Granger causality tests, basic and extended model, full sample

Basic model			Extended model		
GDP equation	Test statistic	p-value	GDP equation	Test statistic	p-value
GDP	5.719	0.0001	GDP	6.6654	0.0001
Oil price	0.972	0.4250	Oil price	0.8409	0.5228
Oil equation	Test statistic	p-value	Oil equation	Test statistic	p-value
GDP	0.291	0.8835	GDP	0.3565	0.8774
Oil price	1.887	0.1148	Oil price	3.6281	0.0040

Table 2: Decomposition of the forecast error variance of GDP, basic and extended model, full sample

Basic model			Extended model			
Periods	GDP	Oil price	Periods	GDP	Oil price	Other variables
4	99.0422	0.9578	4	91.9818	2.6943	5.3239
8	97.9221	2.0779	8	86.0736	4.2602	9.6662
12	97.9130	2.0871	12	84.9727	4.3856	10.6417
24	97.9124	2.0876	24	84.6939	4.4311	10.8750

Figure 2: Response of real GDP growth to impulse in linear oil price, basic and extended model, full sample



The model diagnostics displayed in Table 3 exhibit some further problems. The normality tests indicate clearly that the residuals are not normal.

Furthermore, tests such as the BDS- and the RESET test lead one to conclude that the linear approach is not the appropriate one.

Table 3: Testing for general misspecification of the basic model, full sample

	Test statistic	p-value
Jarque-Bera(ϵ_1)	46.6124	0.0001
Jarque-Bera(ϵ_2)	3309.05	0.0001
Jarque-Bera(joint)	3355.67	0.0001
Doornik-Hansen(ϵ_1)	48.0143	0.0001
Doornik-Hansen(ϵ_2)	110.5528	0.0001
Doornik-Hansen(joint)	158.3161	0.0001
Anderson-Darling(ϵ_1)	1.4831	0.1742
Anderson-Darling(ϵ_2)	8.7601	0.0001
Triples(ϵ_1)	1.19726	0.2312
Triples(ϵ_2)	0.6422	0.5208
BDS(2)-(ϵ_1)	0.0351	0.0001
BDS(4)-(ϵ_1)	0.0677	0.0001
BDS(2)-(ϵ_2)	0.0297	0.0001
BDS(4)-(ϵ_2)	0.0697	0.0001
RESET(1)	0.5526	0.4583
RESET(2)	2.6546	0.0733
RESET(3)	1.7688	0.1551
ARCH-LM(1)	36.5502	0.0001
ARCH-LM(2)	18.1694	0.0001
ARCH-LM(3)	12.2375	0.0001

Notes: ϵ_1 and ϵ_2 denote the residuals from the GDP- and oil equation in the basic model; Doornik-Hansen: Doornik and Hansen (1994) multivariate omnibus normality test; Anderson-Darling: Anderson and Darling test for normality; Triples: asymmetry test, see Randles et al. (1980); BDS(m)-(ϵ_i): portmanteau test for time-based independence in a series where m is the so-called embedding dimension, see Brock et al. (1996). The RESET- and the ARCH-LM-Test are performed for a univariate regression of GDP_t on four lagged own and four lagged oil price values (analogous to the GDP equation in the VAR model). The numbers in parentheses denote the number of included expressions in terms of each test, see Ramsey (1969) and Engle (1982). These results are in general confirmed by the extended model.

The results obtained from both models can be attributed to the neglect on the modeling strategy's part of two important features: firstly, the changing behavior of the oil price since the mid 1980s, as widely discussed in the literature; and secondly, the considerable decrease in dependence of production on the input factor, oil, over the same time period.

In light of these considerations, two approaches have been adopted in the literature [see, in particular, Hooker (1996a)]. One approach suggests using a variety of non-linear oil price specifications in order to capture the phenomenon that not every oil price movement has the same impact on real GDP growth. One purpose for doing this has been to maintain a significant relationship for periods ending after the mid 1980s. From the non-significance obtained in this section this step appears to be justified. Furthermore, the non-normalities and non-linearities detected in this paper clearly justify the decision to employ non-linear methods. The other approach involves testing for structural breaks and constructing subsamples. These two approaches are discussed in detail in the coming Sections 3-5.

3 Discussion of non-linear oil price specifications

In the initial stages of the oil price-GDP discussion researchers assumed a linear relationship between the oil price and real GDP. However, from the mid 1980s the positive effects of oil price declines on net oil importing countries, as predicted by the models available at the time, have been larger than those actually observed. Therefore this relationship has been found to be asymmetric, a finding which has motivated the use of a number of non-linear oil price specifications. Furthermore, the use of these specifications finds both empirical and theoretical support: first, for periods of observation ending after the mid 1980s, linear oil price specifications have ceased finding significant impacts on real GDP growth. This has led many to conclude that the linear oil price is not the appropriate measure to reflect the given economic mechanisms, and a number of proposals for the use of the forementioned non-linear oil price specifications have subsequently emerged [see Hooker (1996a), Hamilton (1996) and Hooker (1996b)]. Second, on the theoretical front, three lines of thought can be identified. Lilien (1982) argues that, in general, economic shocks lead to expensive labor and capital reallocations across sectors, with these sectors being affected to different degrees. Therefore contractionary effects can not merely be ascribed to oil price increases. Authors such as Bernanke (1983) and Pindyck (1991) emphasize the inverse relationship between investment and uncertainty caused by the option value of waiting for a better time to invest. Ferderer (1992) argues in a similar manner and includes a volatility measure for the oil price in his VAR framework. The very recent contribution by Guo and Kliesen (2005) takes up this idea and finds further evidence of the implications of volatility. Hamilton (2003)

presents further statistical arguments for the asymmetric characteristics of the relationship between the oil price and real GDP growth. Hooker (1999, 2002) provides summaries of this discussion, Jimenez-Rodriguez and Sanchez (2005) can be regarded as an example of how to include these specifications in a VAR approach. The three most prominent specifications to emerge from this research effort, the *asymmetric*, *net*, and *scaled* specifications, are now considered.

It has been concluded by Mork (1989) that oil price increases and decreases do not have the same impact on real GDP. Based on this finding he proposes the very simple *asymmetric* specification and simply divides oil price movements in increases and decreases:

$$o_t^+ = \begin{cases} o_t & o_t > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$o_t^- = \begin{cases} o_t & o_t < 0 \\ 0 & \text{otherwise,} \end{cases}$$

where o_t denotes the oil price in first differences. The *net* specification has been introduced by Hamilton (1996). It takes into account the fact that oil price movements after a long period of stability may have different effects than those in a more volatile environment. In light of the asymmetry mentioned above this specification is divided into net oil price increases (*NOPI*) and decreases (*NOPD*). *NOPI* is defined as the amount by which the oil price in period t exceeds the maximum value over the previous 4 periods and 0 otherwise:

$$NOPI_t = \max \{0, p_t - \max \{p_{t-1}, p_{t-2}, p_{t-3}, p_{t-4}\}\},$$

where p_t denotes the oil price in levels. The most sophisticated specification thus far is called *scaled* specification and can be traced back to Lee et al. (1995). It is designed to address the same volatility issue as the net specification and is based on an *AR(4) – GARCH(1, 1)* representation of the oil price. It is defined as follows:

$$o_t = \alpha_0 + \alpha_1 o_{t-1} + \alpha_2 o_{t-2} + \alpha_3 o_{t-3} + \alpha_4 o_{t-4} + e_t$$

$$e_t | I_{t-1} \sim N(0, h_t)$$

$$h_t = \gamma_0 + \gamma_1 e_{t-1}^2 + \gamma_2 h_{t-1}$$

$$SOPI_t = \max \left(0, \frac{\hat{e}_t}{\sqrt{\hat{h}_t}} \right)$$

$$SOPD_t = \min \left(0, \frac{\hat{e}_t}{\sqrt{\hat{h}_t}} \right),$$

where *SOP*I means scaled oil price increases and *SOP*D scaled oil price decreases. The residual analysis from the basic model performed in the previous section can be seen as additional evidence justifying the use of non-linear methods.

The new non-linear oil price specification introduced here is based on a Markov-switching autoregressive representation of the real oil prices in first differences.¹⁰ By way of a short overview of the theory of MS-processes, consider a usual AR(*p*)-process:¹¹

$$X_t = \mu + a_1 X_{t-1} + \dots + a_p X_{t-p} + u_t \quad (1)$$

where X_t , $t \in 1, \dots, T$, is a one-dimensional random variable and $u_t \sim IID(0, \sigma^2)$ is a disturbance term. This process is described by the time-invariant parameters $\mu, \alpha_1, \dots, \alpha_p$ and σ^2 . In contrast to this, a MSAR-process allows one to capture the feature that the relationship between the observations changes over time - thus the parameters mentioned above are time varying. Expressed formally, the parameters of the underlying data generating process of the observed time series X_t depend on an unobservable regime variable s_t . Again, s_t is governed by a discrete time discrete state Markov process so that

$$s_t \in \{1, \dots, M\}, P_{ij} = P(s_{t+1} = j | s_t = i) \text{ and } \sum_{j=1}^M P_{ij} = 1 \forall i, j \in \{1, \dots, M\},$$

where P_{ij} denotes a transition probability. Then, equation (1) becomes

$$X_t = \mu(s_t) + a_1(s_t)X_{t-1} + \dots + a_p(s_t)X_{t-p} + u_t \quad (2)$$

with $u_t \sim IID(0, \sigma^2(s_t))$. A process from this class is characterized by either MS autoregressive parameters, $\alpha_1, \dots, \alpha_p$, a MS intercept term, μ , or MS heteroscedasticity, σ^2 , or particular combinations.

The data generating process of the real oil price in first differences is assumed to be well described with this MS process, an assumption which is deemed to be reasonable in light of this section's subsequent findings. But determining the appropriate model is in general more complicated - it requires more than just deciding on the order p : the number of regimes and the type of process must also be considered. For this reason three decision criteria are adhered to: first, classic information criteria are used here. The second criterion demands that the regime probabilities that are estimated

¹⁰Henceforth the following abbreviations are used: MS denotes Markov-switching while a MSAR process is a Markov-switching autoregressive process.

¹¹For a comprehensive treatise see Krolzig (1997).

for every $t \in 1, \dots, T$ and every $s_t \in 1, \dots, M$ should yield clearly separable regimes. The third criterion calls for an economic interpretation of the regimes. A classic example of this is the different phases of a business cycle [see, for example, Artis et al. (2004)]. Hamilton (2005) performs a similar analysis of the short term interest rate and obtains regimes that can clearly be interpreted as high or low volatility regimes.

From Figure 1 it can be seen that a small number of large oil price increases is clearly visible. Therefore the question of examining the role of this small number of shocks which permeate through the entire analysis certainly arises. One should bear in mind that these shocks dominate the whole series and that the statistical methods applied in the literature may be sensitive to these large shocks. One way to tackle this is to apply a Markov-switching heteroscedasticity approach on the linear oil price; abbreviated as MSH process hereafter. It allows one to capture the feature that shocks may have different magnitudes at different periods of time. Since severe shocks such as those associated with incidents such as the two oil crises or the Gulf War in the beginning of the 1990s clearly differ from oil price movements in different periods, the MSH approach appears to be useful. Therefore the following model is estimated:

$$o_t = \mu + a_1 o_{t-1} + a_2 o_{t-2} + a_3 o_{t-3} + a_4 o_{t-4} + u_t$$

where o_t is the linear oil price in first log-differences and $u_t \sim IID(0, \sigma^2(s_t))$.¹² Table 4 summarizes estimation results. The number of regimes in the estimated model is $M = 3$.¹³ It can be seen from Table 4 that this approach performs better than a linear approach. Moreover, Figure 3 displays the estimated filtered regime probabilities together with the plot of the oil price against time. This specification also clearly fulfills the decision criteria outlined above. It is evident that the regimes should be interpreted as regimes with no volatility (regime 1), with high volatility (regime 3) and, in a manner of speaking, “normal” volatility (regime 2) in the oil price movements.¹⁴ This ex-post classification illustrates vividly that recent oil price increases cannot be considered large when compared with the oil price increases of the 1970s and 1980s.

¹²The use of four lags in this model is suggested by both classic information criteria and by the fact that quarterly data is used.

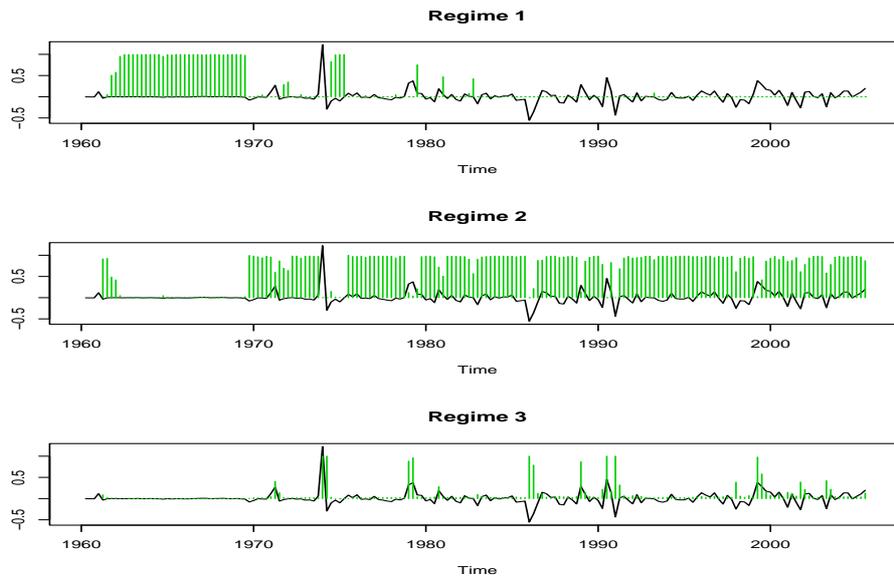
¹³The choice of $M = 2$ regimes did not yield both clearly separable and interpretable regimes.

¹⁴Clements and Krolzig (2002) and Raymond and Rich (1999) have already used MS models in this research field, but they have focused on regimes that can be interpreted as business cycle phases.

Table 4: MSH(3)-AR(4) model of linear oil price: estimation results

Coefficients	Estimate	Standard error	
μ	-0.0014	0.0008	
a_1	0.2548	0.0269	
a_2	-0.0233	0.0070	
a_3	-0.0075	0.0048	
a_4	-0.0751	0.0043	
$\sigma^2(s_t = 1)$	0.0046	-	
$\sigma^2(s_t = 2)$	0.0900	-	
$\sigma^2(s_t = 3)$	0.4235	-	
Matrix of transition probabilities			
	Regime 1	Regime 2	Regime 3
Regime 1	0.9357	0.0642	0.0001
Regime 2	0.0003	0.9209	0.0789
Regime 3	0.1304	0.4465	0.4231
Comparison to linear model		MSH(3)-AR(4)	Linear model
Log-likelihood		221.6704	86.4066
AIC		-2.3334	-0.9034
HQ		-2.2319	-0.8600
SC		-2.0831	-0.7962

Figure 3: Estimated filtered regime probabilities for the MSH(3)-AR(4) model of the linear oil price



Since this approach yields models with abrupt regime switches the question arises as to whether this approach is appropriate, or whether models with smooth regime switching behavior are preferable. For this reason tests for the presence of LSTAR or ESTAR characteristics in the real oil price following Teräsvirta (1994) are performed. From the tests no clear-cut indications of those features can be found. The null of a linear AR(4) against the alternative of LSTAR is rejected at the 5% level, with the delay on the threshold variable d set equal to 1. But for $d > 1$ the null cannot be rejected at usual significance levels. Furthermore, the null of a linear AR(4) against the alternative of ESTAR cannot be rejected for any value of d at any usual significance level. In addition, the procedure based on Inclan and Tiao (1994) to detect changes in the variance of a variable clearly supports the decision to use the MSH(3)-AR(4) model proposed here. It detects changes in the variance of the oil price in 1973:4, 1974:2, 1985:4 and 1991:1 and therefore captures the most prominent observations already discussed here and identified by the MSH(3)-AR(4) approach.¹⁵ With these results, and bearing in mind that this approach also explicitly makes use of the volatility argument, this appears to be the pertinent way to proceed.

In light of these findings a new non-linear oil price specification is constructed and introduced below. Since large oil price shocks are of greatest interest here, the new oil price specification is defined as follows:

$$VOLA+ = \begin{cases} o_t & \hat{P}_t(s_t = 3) \geq 0.5 \quad \text{and} \quad o_t > 0 \\ 0 & \text{otherwise.} \end{cases}$$

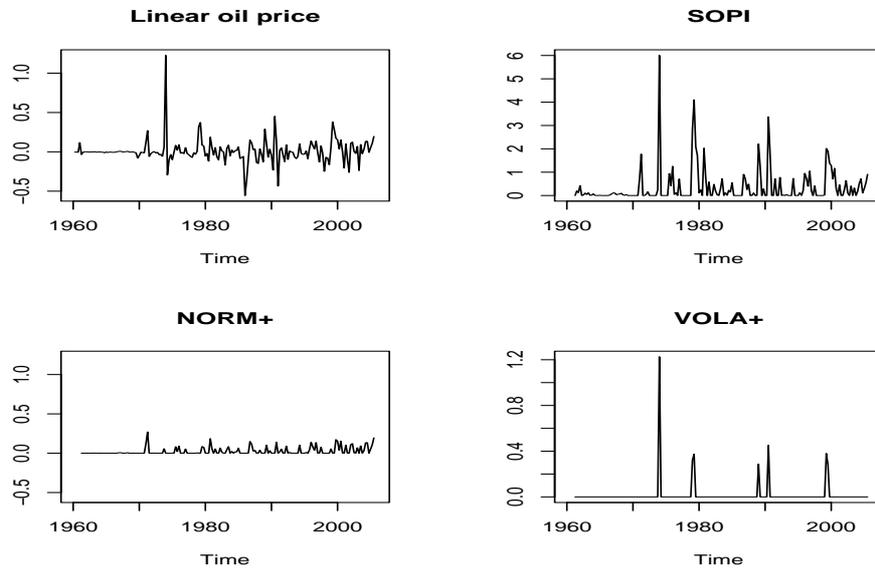
$\hat{P}_t(s_t = 3)$ denotes the estimated filtered probability for the third regime - the regime of large oil price movements. If this probability is above 0.5 this regime is most likely to prevail. Therefore this variable captures only the large oil price increases. Furthermore, the following variable describes normal oil price increases:

$$NORM+ = \begin{cases} o_t & \hat{P}_t(s_t = 2) \geq 0.5 \quad \text{and} \quad o_t > 0 \\ 0 & \text{otherwise.} \end{cases}$$

Thus, $NORM+$ contains just normal oil price increases in the sense of the identified regime 2. To state it differently, $NORM+$ is the linear real oil price in first differences corrected by large oil price increases (regime 3), small or non-existent oil price increases (regime 1) and every single oil price decline. To allow for comparison Figure 4 contains plots of $SOPI$ and $VOLA+$. It can

¹⁵Further breaks in the variance of the linear oil price are detected in 1961:2, 1969:3 and 1997:4. The two former ones are caused by movements of the exchange rate.

Figure 4: Comparison of different oil price specifications



be seen that *VOLA+* captures only those five largest oil price increases that resulted in the five largest peaks in *SOPI*. Moreover, Figure 4 also graphs the linear oil price and *NORM+* respectively. These new oil price specifications allow one to analyze the impact of these large shocks and normal increases on real GDP separately. While the scaled specification considers current oil price movements compared to previous ones, the MS specification proposed here evaluates the whole series. Nevertheless, this distinction does not have any impact on the validity of this approach, as the results reported later illustrate. The advantage is that the distinction in the three regimes obtained from this applied MS-approach is data driven and therefore not arbitrary. One should keep in mind that impulse response functions are based on the vector moving average representation of the VAR process and clearly such a representation is substantially influenced by large shocks.

4 Models with non-linear oil price specifications

The basic and extended models used in Section 2 are now expanded upon. While they retain the same number of variables, the oil price specifications outlined in the previous section are now incorporated into the models; in addition to the linear oil price, *SOPI*, *VOLA+* and *NORM+* are now

present. This procedure highlights the way in which these different oil price specifications affect real GDP growth. Moreover, by comparing these effects a number of interesting findings about the role of the large and normal oil price increases captured in *VOLA+* and *NORM+* can be derived. The analysis of the basic model with the different oil price specifications is analogous to Section 2, while for the extended model the focus is directed towards impulse response analysis.

The estimation results obtained from the basic model are summarized in Tables 5 and 6 and Figure 5. The responses of real GDP growth, the short term interest rate, and the consumer price index to impulses in the different oil price specifications in the extended model can be found in the Figures 6 to 8.

First of all, it can be seen from the basic model that only *SOPI* is significant in the GDP equation, indicated by both the Granger causality test (at the 10% level) and the impulse response function.¹⁶

Table 5: F-Statistics for Granger causality tests, comparison of oil price specifications, basic model, full sample

Model with linear oil price			Model with SOPI		
GDP equation	Test statistic	p-value	GDP equation	Test statistic	p-value
GDP	5.719	0.0001	GDP	6.7881	0.0001
Oil price	0.972	0.4245	SOPI	2.4070	0.0515
Oil equation	Test statistic	p-value	Oil equation	Test statistic	p-value
GDP	0.2910	0.8835	GDP	0.4446	0.7762
Oil price	1.8874	0.1148	SOPI	4.6183	0.0015
Model with VOLA+			Model with NORM+		
GDP equation	Test statistic	p-value	GDP equation	Test statistic	p-value
GDP	6.3061	0.0001	GDP	5.6382	0.0003
VOLA+	1.6232	0.1708	NORM+	0.6488	0.6285
Oil equation	Test statistic	p-value	Oil equation	Test statistic	p-value
GDP	0.6816	0.6053	GDP	0.5873	0.6723
VOLA+	0.5340	0.7109	NORM+	3.2138	0.0143

The forecast error variance decomposition indicates that shocks in *SOPI* exhibit an increase in the explained portion of the forecast error variance of real GDP growth. Moreover, distinguishing between large and normal oil

¹⁶Kilian (2005) decomposes oil price movements in endogenous and exogenous ones and tries to assess the effects of exogenous shocks on the US economy. He concludes that not every large oil price increase can be treated as exogenous as done in Bernanke et al. (1997). However, the exogenous oil shocks in the sense of Kilian (2005) do yield a similar pattern in their effect on real GDP growth as those obtained here for the German economy.

price movements shows that the portion explained by large oil price shocks exceeds that explained by linear oil prices, while *NORM+* displays a clear drop in this portion. This distinction becomes more valuable and insightful in the context of Section 5's consideration of two subsamples.

Figure 5: Response of real GDP growth to impulse in different oil price specifications, basic model, full sample

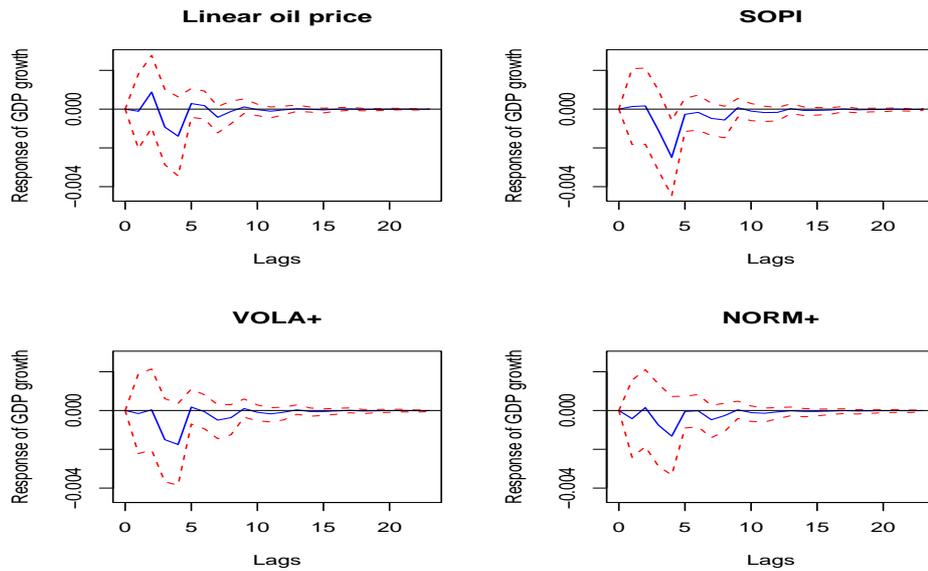


Table 6: Decomposition of the forecast error variance of GDP, comparison of oil price specifications, basic model, full sample

Periods	Model with linear oil price		Model with SOPI	
	GDP	Oil price	GDP	SOPI
4	99.0422	0.9578	99.2389	0.7611
8	97.9221	2.0779	95.8913	4.1087
12	97.9130	2.0871	95.7536	4.2464
24	97.9124	2.0876	95.7441	4.2559
Periods	Model with VOLA+		Model with NORM+	
	GDP	VOLA+	GDP	NORM+
4	98.6802	1.3198	99.5365	0.4635
8	97.0647	2.9353	98.5568	1.4432
12	96.9994	3.0005	98.4903	1.5097
24	96.9963	3.0036	98.4859	1.5141

The analysis of the extended model confirms in general the results of its basic counterpart. The most notable result is the similarity of the responses

Figure 6: Response of real GDP growth to impulse in different oil price specifications, extended model, full sample

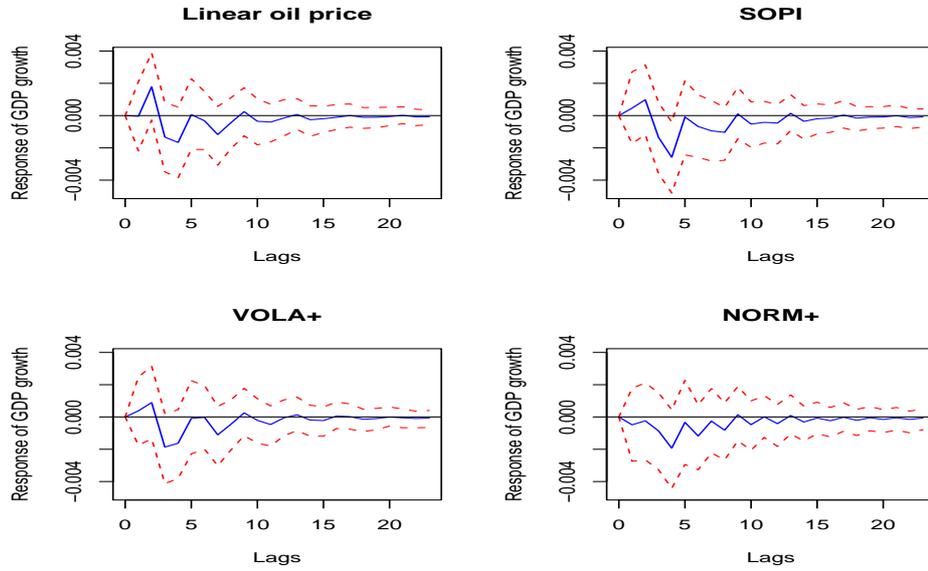


Figure 7: Response of short term interest rate to impulse in different oil price specifications, extended model, full sample

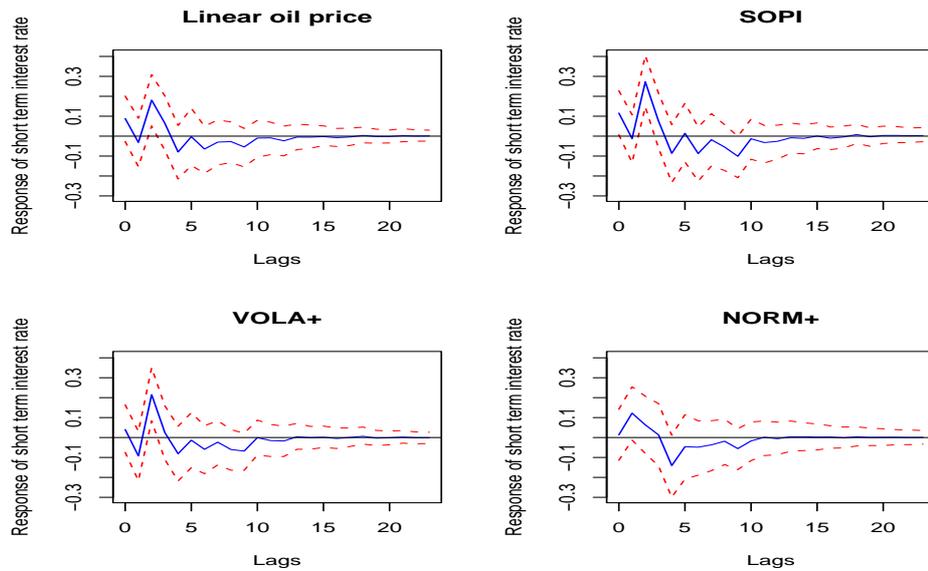
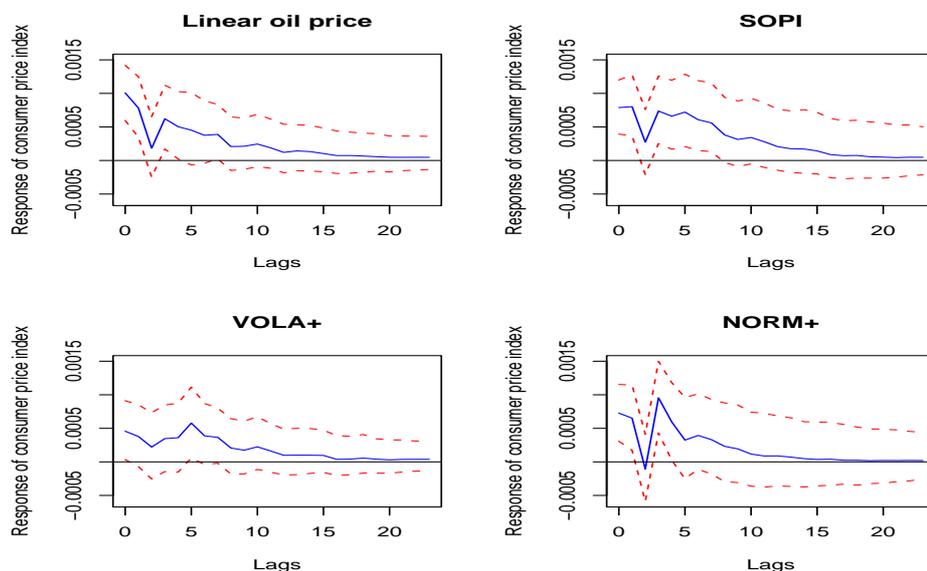


Figure 8: Response of consumer price index to impulse in different oil price specifications, extended model, full sample

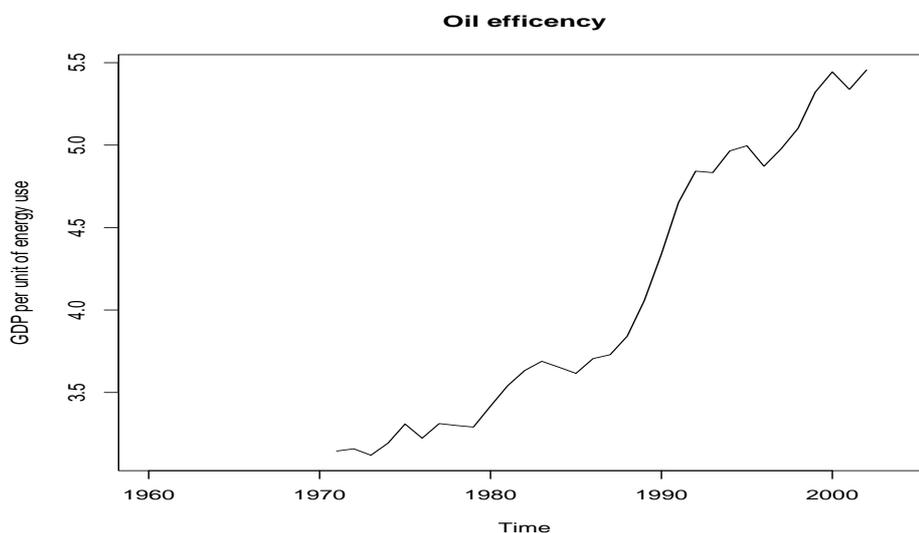


of the short term interest rate to impulses in the linear oil price, *SOPI* and *VOLA+*. The short term interest rate, therefore, appears to be very sensitive to the large oil price increases captured in *VOLA+*. The response to an impulse in *NORM+* differs considerably from the response witnessed in the other specifications. The dissimilarities of the responses of the consumer price index to the different impulses are even more conspicuous. In this case the linear oil price, *SOPI* and *NORM+* exhibit statistically significant responses.

5 Structural breaks and sample splitting

As asserted in Section 2, since the mid1980s both the behavior of the oil price and the structure of the economy with respect to oil as input factor has changed considerably. Mork (1989) and Lee et al. (1995), among others, discuss this behavioral feature. The latter, in particular, emphasize that prior to 1985:4 large oil price decreases appeared to offset previous increases. After 1986:1 this behavior of the oil price changed to an unsystematic sequence of increases and decreases. This is illustrated in the plot of the linear oil price in Figure 1. Figure 9, which illustrates GDP per unit of energy use, examines the structural feature in greater detail. This measure clearly increased after

Figure 9: GDP per unit of energy use (constant 2000 PPP \$ per kg of oil equivalent)



the mid 1980s; a feature confirmed by OECD (2004), who emphasize that the oil intensity of production has fallen continuously in the OECD area. The downward trend they find begins in the early 1970s with the strongest decline between 1980 and 1985, leaving this measure a full 50% lower than its 1970 level.

The question pursued in this section is whether these incidents bring about a structural break detectable by particular tests, and if so, do the features of two subsamples derived from the results of the tests differ substantially?

With this in mind three tests are applied: Bai and Perron multiple breakpoint, Chow breakpoint, and Hansen stability tests. The distinction between the first two tests is that for the Bai and Perron (2003) test just the number of breakpoints has to be chosen exogenously while for the Chow test the breakpoints itself are exogenous. Nevertheless, both tests yield very similar results, see Table 7. Both tests show strong evidence of a structural break in 1986:4. The Hansen (1980) test for structural stability confirms these results.

The breakpoints can be explained as follows: Figure 1 shows that large oil shocks occur unsystematically over the whole sample period. Since the structure of the economy has changed since the mid 1980s it can be concluded that shocks at the beginning of the 1990s did not had the same effect on real GDP growth as comparable shocks in the 1970s and 1980s. Incorporating similar shocks with different impacts leads to a deterioration of the fit of the

model. This again explains the results of the structural break tests.

Table 7: Structural break testing, basic model, full sample

Chow breakpoint test		
Breakpoint in	Test statistic	p-value
1986:2	1.1000	0.3657
1986:3	1.4691	0.1636
1986:4	1.4935	0.1544
1987:1	1.4278	0.1802
1986:4	0.7482	0.6643
1986:4, 1990:4	1.6613	0.0523
1986:4, 1991:1	1.5773	0.0725
Hansen structural stability test		
	Test statistic	p-value
Hansen(joint)	2.723	0.02
Bai-Perron multiple breaks test		
Best 1 breakpoint	1986:3	
Best 2 breakpoints	1986:4, 1991:1	
Best 3 breakpoints	1975:4, 1986:3, 1990:3	

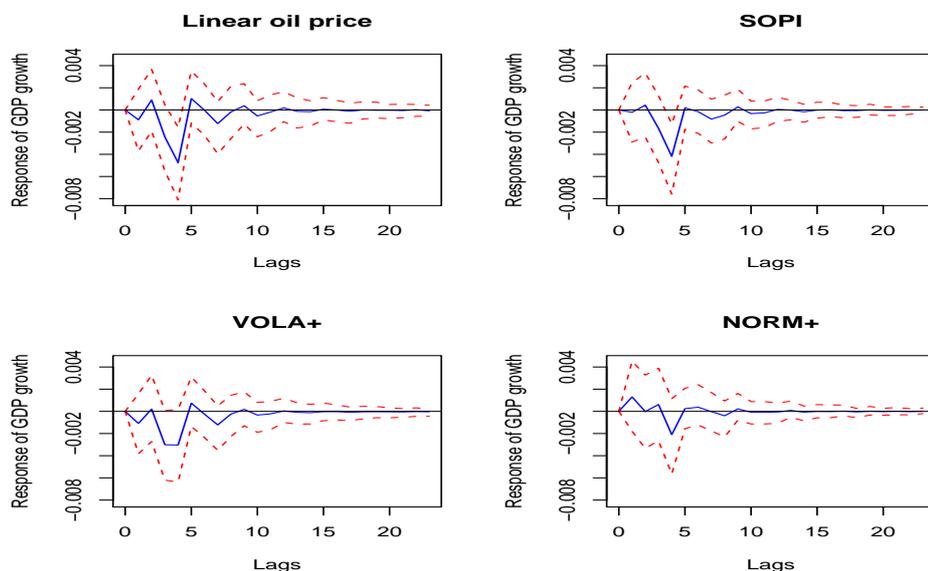
Note: For these tests the real GDP growth has been again regressed on four of its own lagged values and four lagged values of the linear oil price.

To demonstrate the extent of the change in the relationship between real GDP growth and the oil price, two illustrative subsamples for the basic model are considered now, using statistical methods equivalent to those applied to the full sample in the Sections 2 and 4. As 1986:4 has been identified as a breakpoint in the Chow and Bai-Perron tests above, subsamples from 1970:1 to 1986:4 and from 1987:1 to 2005:3 respectively are investigated. Since the MS analysis of the oil price performed in Section 3 showed that no relevant oil price movements occurred prior to 1970 this date has been chosen as starting point of the early subsample. It is clearly illustrated in the following analysis that the relationship between oil price shocks and real GDP is completely different in the two subsamples.¹⁷

Figure 10 shows that in the early subsample impulses in the linear oil price, *SOPI* and *VOLA+* lead to significant responses in real GDP growth. The general pattern of the impulse responses is quite similar to that of the full

¹⁷For both subsamples the residuals have been checked for autocorrelation, see the corresponding Tables in Appendix A.2. Again four lags of each variable are used in the model. Replacing the linear oil price by the non-linear specifications does not yield different results of the residual autocorrelation analysis.

Figure 10: Response of real GDP growth to impulse in different oil price specifications, basic model, sample 1970:1 to 1986:4.



sample. It can be concluded, therefore, that the results for this subsample have a dominant influence on the results of the full sample. This conclusion is also supported by the second subsample. Moreover, *NORM+* is still insignificant. The most remarkable result is that impulses in both the linear oil price and *SOPI* lead to very similar patterns in the response of real GDP growth, and furthermore the *VOLA+* responses capture, to a large extent, the negative impact arising from an impulse in both the linear oil price and *SOPI* - although it consists of just two peaks for this subsample. This distinction between large and normal oil price increases, therefore, allows one to conclude that these two types of shocks have very different impacts on real GDP growth. Supported by the Granger causality test these results gain importance; see Table 8. The linear oil price is significant at the 1% level; *SOPI* and *VOLA+* are significant at the 5% level and *NORM+* is insignificant even in this subsample.¹⁸ The forecast error variance decomposition (see Table 9) leads one also to conclude that the oil price is much more influential here than in the full sample. The pattern observed for the full sample is not apparent for this subsample. A considerably larger portion of the cor-

¹⁸To take this argument further, even when one takes just the oil shock associated with the first oil crisis as the oil price variable omits the other shocks a significant impact on real GDP growth in both the basic and extended model is apparent even in the full sample, both in terms of Granger causality and impulse response analysis.

responding variance can be attributed to the linear oil price than to *SOPI* and *VOLA+*. Their influences are similar to each other and larger now than in the full sample; while the smallest portion is observed again for *NORM+*.

Table 8: F-Statistics for Granger causality tests, comparison of oil price specifications, sample 1970:1-1986:4

Model with linear oil price			Model with SOPI		
GDP equation	Test statistic	p-value	GDP equation	Test statistic	p-value
GDP	3.7718	0.0085	GDP	3.8891	0.0072
Oil price	3.8260	0.0079	SOPI	3.4061	0.0142
Oil equation	Test statistic	p-value	Oil equation	Test statistic	p-value
GDP	0.7523	0.5605	GDP	0.6740	0.6127
Oil price	0.4587	0.7657	SOPI	1.3500	0.2623
Model with VOLA+			Model with NORM+		
GDP equation	Test statistic	p-value	GDP equation	Test statistic	p-value
GDP	3.5222	0.0121	GDP	2.4832	0.0533
VOLA+	3.1227	0.0213	NORM+	0.7671	0.5509
Oil equation	Test statistic	p-value	Oil equation	Test statistic	p-value
GDP	0.5975	0.6659	GDP	0.1528	0.9610
VOLA+	0.1884	0.9436	NORM+	0.7365	0.5708

Table 9: Decomposition of the forecast error variance of GDP, comparison of oil price specifications, sample 1970:1 - 1986:4

Periods	Model with linear oil price		Model with SOPI	
	GDP	Oil price	GDP	SOPI
4	93.9940	6.0060	97.5580	2.4420
8	78.9090	21.0910	85.6950	14.3050
12	78.7356	21.2644	85.5039	14.4961
24	78.6682	21.3318	85.4841	14.5159
Periods	Model with VOLA+		Model with NORM+	
	GDP	VOLA+	GDP	NORM+
4	92.3253	7.6747	98.5457	1.4543
8	85.7930	14.2070	95.6746	4.3254
12	85.6750	14.3250	95.5876	4.4124
24	85.6612	14.3389	95.5844	4.4156

The specification analysis displayed in Table 10 provides clear evidence that the residuals from the GDP equation do not contain non-normalities or non-linearities. Furthermore, the RESET test and the ARCH-LM test do not indicate that the problem of misspecification is present, and the Hansen

structural stability test indicates that there is no structural change. Therefore in the subsample 1970:1 to 1986:4 the use of linear methods is preferable to non-linear ones. This conclusion is in line with the literature, where it is the commonly held view that serious problems within the relationship between real GDP growth and oil prices have only appeared after the mid 1980s.

Table 10: General specification testing, basic model, sample 1970:1 - 1986:4

	Test statistic	p-value
Jarque-Bera(ϵ_1)	0.5353	0.7652
Jarque-Bera(ϵ_2)	1040.62	0.0001
Jarque-Bera(joint)	1041.16	0.0001
Doornik-Hansen(ϵ_1)	0.2451	0.8847
Doornik-Hansen(ϵ_2)	40.9885	0.0001
Doornik-Hansen(joint)	41.0774	0.0001
Anderson-Darling(ϵ_1)	0.1034	0.9999
Anderson-Darling(ϵ_2)	5.2022	0.0024
Triples(ϵ_1)	0.4341	0.6642
Triples(ϵ_2)	0.2823	0.7777
BDS(2)-(ϵ_1)	-0.0062	0.4184
BDS(4)-(ϵ_1)	-0.0176	0.2317
BDS(2)-(ϵ_2)	0.0470	0.0016
BDS(4)-(ϵ_2)	0.0403	0.1660
RESET(1)	0.3090	0.5805
RESET(2)	0.6869	0.5073
RESET(3)	0.9477	0.4239
ARCH-LM(1)	0.2597	0.6121
ARCH-LM(2)	0.8661	0.4255
ARCH-LM(3)	0.9704	0.4126
Hansen(joint)	1.319	1.0000

For the subsample 1987:1 to 2005:3 virtually all of the properties of the relationship observed earlier vanish. The impulse response functions in Figure 11 show very different patterns to those seen in both the full sample and the 1970:1 - 1986:4 sample. Furthermore, the dissimilarities within the specifications in this subsample are larger than those observed in the other samples. Besides the fact that none of the impulses leads to significant responses, no clear negative effect can be observed. These findings are confirmed by the Granger causality test; see Table 11. The forecast error variance decomposition (see Table 12) indicates that the corresponding portions obtained for the linear oil price, *SOPI* and *NORM+* are similar, while once again larger portions can be attributed to *VOLA+*. Furthermore, the linear oil price is

now significant in the oil equation and the residuals from this equation appear to be linear and normal, see Table 13.

Table 11: F-Statistics for Granger causality tests, comparison of oil price specifications, sample 1987:1 - 2005:3

Model with linear oil price			Model with SOPI		
GDP equation	Test statistic	p-value	GDP equation	Test statistic	p-value
GDP	1.8457	0.1306	GDP	1.8054	0.1383
Oil price	1.0139	0.4067	SOPI	1.0619	0.3824
Oil equation	Test statistic	p-value	Oil equation	Test statistic	p-value
GDP	1.1046	0.3618	GDP	2.3461	0.0635
Oil price	3.7337	0.0085	SOPI	4.2860	0.0038
Model with VOLA+			Model with NORM+		
GDP equation	Test statistic	p-value	GDP equation	Test statistic	p-value
GDP	2.6074	0.0434	GDP	3.0353	0.0233
VOLA+	1.5141	0.2082	NORM+	1.0838	0.3718
Oil equation	Test statistic	p-value	Oil equation	Test statistic	p-value
GDP	5.1239	0.0012	GDP	2.2261	0.0756
VOLA+	2.8133	0.0322	NORM+	2.9479	0.0265

Figure 11: Response of real GDP growth to impulse in different oil price specifications, sample 1987:1 to 2005:3.

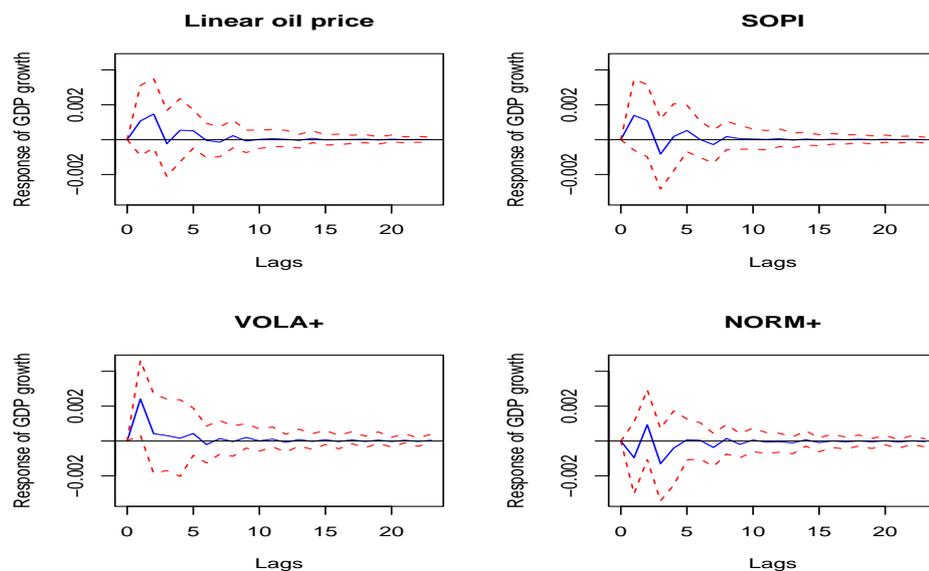


Table 12: Decomposition of the forecast error variance of GDP, comparison of oil price specifications, sample 1987:1 - 2005:3

Periods	Model with linear oil price		Model with SOPI	
	GDP	Oil price	GDP	SOPI
4	95.7412	4.2588	95.1491	4.8509
8	95.4597	4.5403	95.0647	4.9353
12	95.4371	4.5629	95.0788	4.9212
24	95.4358	4.5642	95.0825	4.9175
Periods	Model with VOLA+		Model with NORM+	
	GDP	VOLA+	GDP	NORM+
4	92.3925	7.6075	95.2526	4.7474
8	92.7329	7.2671	95.1958	4.8042
12	92.7589	7.2411	95.2003	4.7997
24	92.7633	7.2367	95.1971	4.8029

Table 13: General specification testing, basic model, sample 1987:1 - 2005:3

	Test statistic	p-value
Jarque-Bera(ϵ_1)	5.4512	0.0655
Jarque-Bera(ϵ_2)	2.0291	0.3626
Jarque-Bera(joint)	7.4803	0.1126
Doornik-Hansen(ϵ_1)	7.4902	0.0236
Doornik-Hansen(ϵ_2)	3.0537	0.2172
Doornik-Hansen(joint)	8.7285	0.0683
Anderson-Darling(ϵ_1)	1.1066	0.2927
Anderson-Darling(ϵ_2)	0.2556	0.9651
Triples(ϵ_1)	2.2088	0.0272
Triples(ϵ_2)	0.8113	0.4172
BDS(2)-(ϵ_1)	0.0071	0.4867
BDS(4)-(ϵ_1)	0.0371	0.0583
BDS(2)-(ϵ_2)	-0.0020	0.8069
BDS(4)-(ϵ_2)	0.0108	0.4976
RESET(1)	2.3703	0.1285
RESET(2)	1.2257	0.3003
RESET(3)	0.8316	0.4815
ARCH-LM(1)	0.1449	0.7046
ARCH-LM(2)	5.8957	0.0043
ARCH-LM(3)	3.4269	0.0219
Hansen(joint)	2.164	0.0800

The specification analysis in general confirms these findings. This can be seen as evidence of changing behavior in the oil price itself, a finding consistent with existing literature.

To summarize, the 1970:1-1986:4 subsample is characterized by a particularly strong relationship between oil price shocks and real GDP growth, with incidents such as the first and the second oil crises having a dominant impact in this subsample and, moreover, the full sample. Since the linear oil price performs better than the non-linear specifications in the earlier subsample, it could be concluded that, strictly speaking, the use of non-linear methods is not necessary. Nevertheless, the importance of one particular insight arising from the MS-based oil price specification should be emphasized once again: as illustrated by the distinction between large and normal oil price increases, these two types of shocks exhibit very different influences on real GDP growth.

6 Conclusions

The global economy has been persistently confronted with large oil price shocks over the last few decades. The most prominent examples are the oil crises in the 1970s and 1980s and the oil shock stemming from the Gulf War in the early 1990s. The recent oil price increases observed 2004-2005 have emerged as a result of increasing demand, especially from the United States and China.

Since the very appearance of these shocks economists have been driven by the desire to assess their impact on macroeconomic variables, in particular on real GDP growth. As these shocks never seem to vanish and appear to have numerous causal factors, and furthermore as the oil price, according to the consensus of industry forecasts, seems destined to continue its increase relentlessly, any effort invested in this research area is more than justified.

The prevailing view emanating from this stream of research is that the relationship between oil price shocks and real GDP is characterized by structural breaks and that non-linear oil price specifications both fit the data well and shed further light on those factors driving GDP growth. These findings have been confirmed here using VAR models with four oil price specifications, different dimensions and varying sample periods. In addition to the general procedure in the literature the decision to use non-linear methods in this context has been validated by manifold specification and diagnostic tests.

Among the more salient findings to emerge from this analysis are: firstly, the applied MS model has proven to be suitable for analysing the underlying oil price data, yielding valuable insights on oil price behavior and allowing for a non-arbitrary, data driven distinction between large and normal oil price movements. Secondly, including the new MS based specification constructed

in this paper based in the basic modeling approach leads to the conclusion that the observed impact of oil shocks on real GDP can be attributed, to a large extent, to a small number of oil price increases permeating through the whole analysis. This feature has not been discussed in previous literature. Finally, the detailed analysis of two illustrative subsamples (1970-1986 and 1987-2005) highlights the full extent of the change in the oil price-GDP relationship over the last 30 years.

Since significant impacts are only present in the first subperiod and since a large influence can be ascribed to a small number of large oil price increases, one can conclude that the overall results are dominated by the oil crises in the 1970s and 1980s, rather than by more recent oil price spikes - perhaps this is the elusive needle that has been sought in this paper. These same dominant incidents may also account for the decline of oil intensity in production and may have been an incentive to consider ways of increasing GDP per unit of energy use. Furthermore, this paper's newly constructed oil price specification indicates that the oil price increases witnessed in 2004-2005 cannot be regarded as large, as formalized in this specification.

Thus it appears that the good news arrives at the end: it is unlikely that the recent oil price increases will prove to be unduly harmful to the German economy.

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A Appendix

A.1 Details on the data

This sections summarizes data sources and provides some calculatory details.

Data Sources

- Oil price (UK Brent): IFS
- Nominal GDP: Statistisches Bundesamt
- GDP deflator: IFS
- Producer Price Index: Deutsche Bundesbank
- Exchange Rate: IMF
- Short term interest rate: IMF
- Long term interest rate: Deutsche Bundesbank
- Consumer Price Index: Deutsche Bundesbank
- Wages: Deutsche Bundesbank
- GDP per unit of energy us: International Energy Agency, World Bank and OECD GDP Data

Treatment of the German reunification The GDP data have been level adjusted for observations prior to 1991. The consumer price index and the wage series contain survey errors due to the German reunification as well. They have been adjusted by taking first differences and log-differences respectively and by using the average of the four previous and four subsequent values instead of the observed outlier.

Seasonally Adjustment The wages series has been seasonally adjusted by using the X12 method.

A.2 Tests on residual autocorrelation

Table 14: Testing for residual autocorrelation, basic model, full sample

Lags	LM-Statistic	p-value	Portmanteau-Statistic	p-value
1	2.5250	0.6402	0.1260	NA
2	1.7481	0.7820	0.2015	NA
3	2.1577	0.7068	0.3220	NA
4	1.0422	0.9033	0.4690	NA
5	3.6178	0.4602	4.0116	0.4044
6	0.4269	0.9802	4.4203	0.8174
7	0.3182	0.9886	4.7292	0.9664
8	2.5357	0.6383	7.1990	0.9692

Note: the Portmanteau Test for autocorrelations is valid only for lags larger than the VAR lag order. Both approaches test the null hypothesis of no residual autocorrelations up to lag h (first column).

Table 15: Testing for residual autocorrelation, basic model, sample 1970:1 - 1986:4

Lags	LM-Statistic	p-value	Portmanteau-Statistic	p-value
1	0.8113	0.9369	0.2604	NA
2	1.7697	0.7780	0.6979	NA
3	0.7258	0.9481	0.7434	NA
4	4.8091	0.3075	1.662	NA
5	4.0594	0.3980	5.169	0.2704
6	2.5357	0.6383	7.6326	0.4702
7	0.4644	0.9769	8.0832	0.7886
8	4.4816	0.3447	11.9152	0.7498

Table 16: Testing for residual autocorrelation, basic model, sample 1987:1 - 2005:3

Lags	LM-Statistic	p-value	Portmanteau-Statistic	p-value
1	4.3761	0.3575	0.8954	NA
2	4.2117	0.3781	1.7632	NA
3	9.2685	0.0547	4.9195	NA
4	5.8983	0.2069	6.2197	NA
5	3.1300	0.5363	9.1641	0.0571
6	3.6509	0.4553	12.6363	0.1250
7	2.3794	0.6664	15.0291	0.2398
8	5.3150	0.2565	20.1049	0.2155

A.3 Alternative variable ordering in the extended model

Figure 12: Response of real GDP growth to impulse in oil price variable in extended model, alternative ordering of variables.

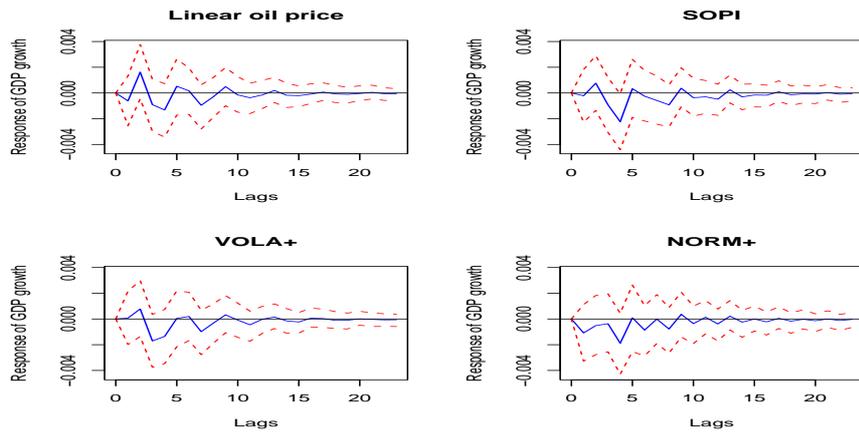


Figure 13: Response of short term interest rate to impulse in oil price variable in extended model, alternative ordering of variables.

