THE EFFECT OF OIL PRICE SHOCKS ON THE MACROECONOMY

by

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Abstract

The traditional view of oil price movements is that they represent exogenous changes in the supply of oil. In that case, oil price increases will hurt output. Recently, some have questioned whether oil price increases are actually due to higher demand for oil, in which case higher oil prices will be followed by higher output. This thesis develops a model that allows changes in the price of oil to have different effects depending on whether the price of oil and output growth are moving in the same direction (so that the increase in the price of oil was primarily due to an increase in the demand for oil) or in the opposite direction (so that the increase in the price of oil was primarily due to an oil supply shock).

The paper presents three sets of results. First, we present the model results for the 1965-2008 time period. Then we look at the 1986-2008 period separately. Finally, we construct a forecasting model for the U.S. industrial production index. The model developed does not require making identifying assumptions and can be used with the data that is available on the internet, and is well understood. Maximum likelihood estimation, which is commonly used for non-linear estimation, is used to estimate the model. We find in-sample evidence in favor of our new model for the 1986-2008 subsample. The new model is unable to provide better out-of-sample forecasts for the 1986-2008 time period.

Table of Contents

List of Figures

List of Tables

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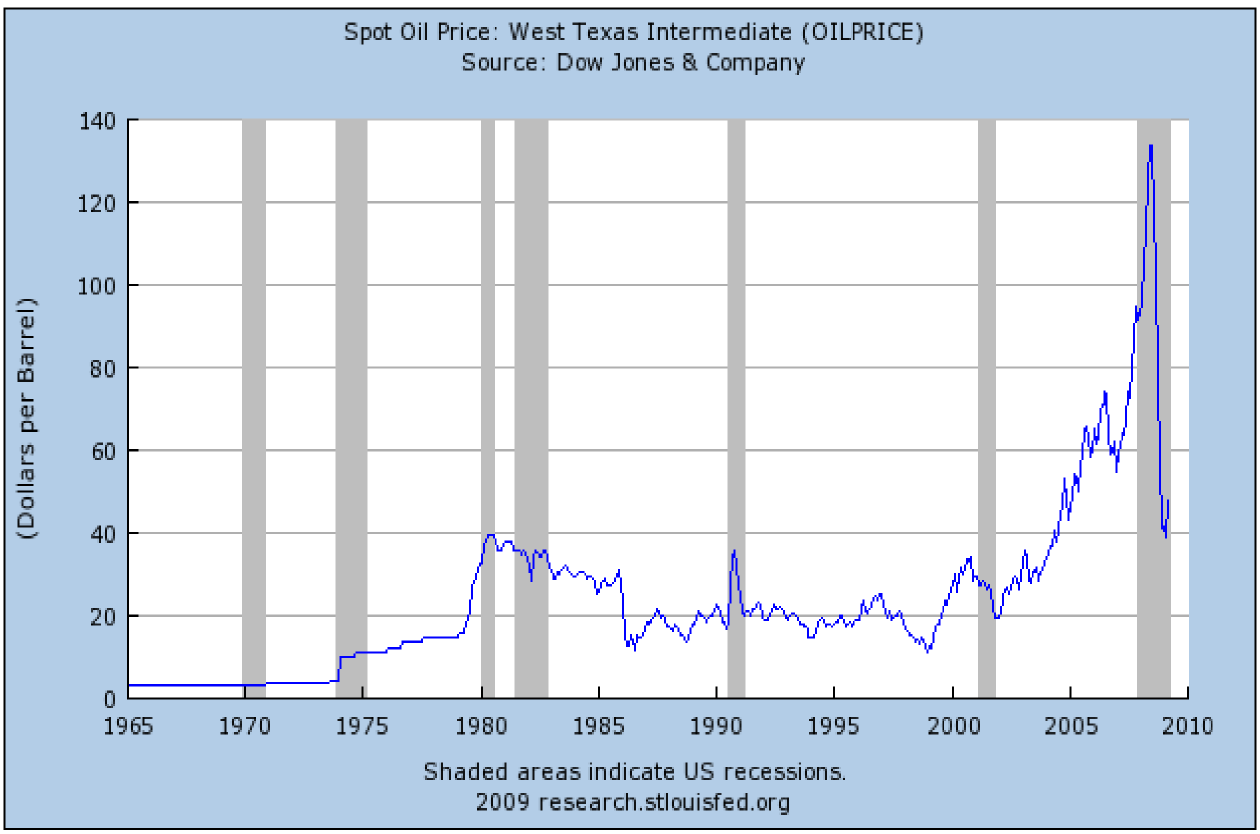
CHAPTER 1 - INTRODUCTION

Today, despite the development of different kinds of energy sources, oil remains one of the most important energy sources for the economy. According to the US Energy Information Administration, oil accounts for approximately 30% of energy consumption in Asia and Europe, 53% for the Middle East and 40% for North America. Also, approximately 30 billion barrels per year are being consumed around the world and around 24% of the whole oil consumption of the world goes to the United States.

Figure 1-1. **Crude oil prices (line) and the economic recessions in the US (shaded areas) between 1965 and 2009.**



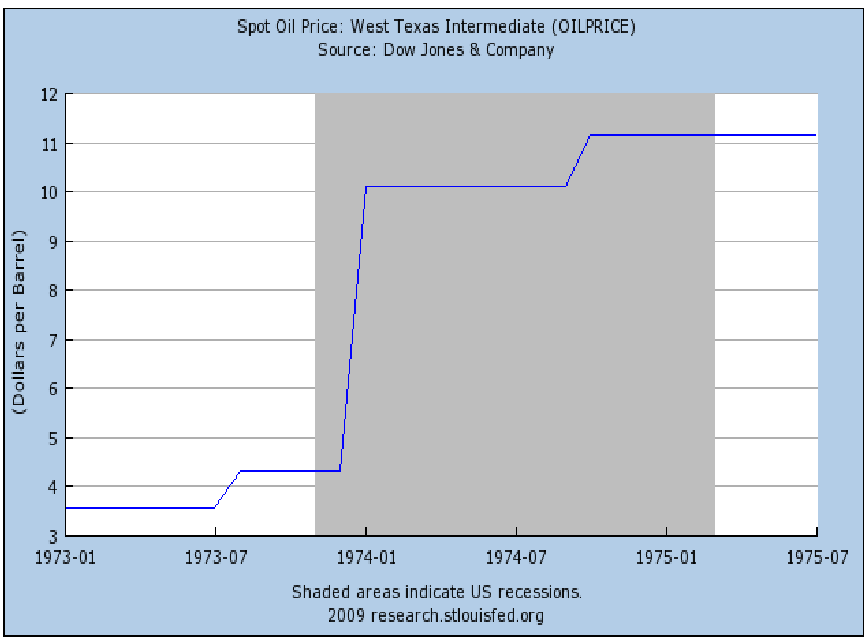
Source: FRED®

Since the 1970s oil price fluctuations have been a very important topic. Many politicians have commented about it, and many newspaper articles have been written about oil price shocks in relation to political events in the world.[1] Figure 1-1 plots oil prices and periods of economic recessions in the US and shows that often oil price spikes correspond to economic recessions. Since 1973, there have been four major oil events in the U.S. We now discuss each of these episodes in detail.

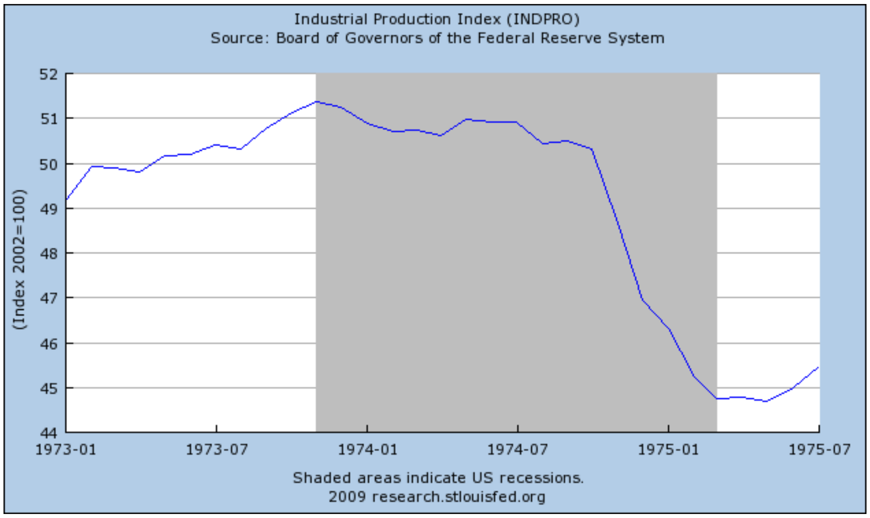
1.1. 1973 Oil Crisis.

The 1973 Oil Crisis was a result of an oil embargo imposed by Arab members of the Organization of Petroleum Exporting Countries (OPEC) against the United States. This collusion increased the price of oil four times in six months.[2] Henry Kissinger, Secretary of State of the US at that time, said that the oil embargo brought the deepest recession to the US economy since World War II (Rubenberg 1989). During this crisis OPEC countries realized that they could use oil not only as an economic but also as a political weapon and it was revealed that the U.S. was not in control of crude oil prices. Overall, the crisis was the result of supply shortages.[3]

Figure 1-2. West Texas Intermediate oil price, Industrial Production Index and Inflation in Consumer Prices after the 1973 oil crisis.



[1] Maier, Thomas. *Present oil trouble not without a past.* June 4, 2004. http://www.energybulletin.net/node/474 (accessed May 14, 2009).
[2] U.S. Department of State. *Second Arab Oil Embargo, 1973-1974.* http://www.state.gov/r/pa/ho/time/dr/96057.htm (accessed April 18, 2009).
[3] Williams, James L. *Oil Price History and Analysis.* http://wtrg.com/prices.htm (accessed April 21, 2009).



Source: FRED® and www.economagic.com

As Figure 1-2 illustrates, a big jump in oil price was followed by a plunge in industrial production.

1.2. 1979 Oil Crisis.

The 1979 Oil Crisis originated as a result of the disastrous drop in oil production in Iran during the Iranian Revolution. At one time, the production of oil was even stopped in Iran because of the view among politicians of Iran that oil was the root of all its problems (Pollack 2004). Because the U.S. economy used to get 5% of its oil from Iran, the increase in the oil price was the result of a panic in the oil market. Former President Jimmy Carter said "The single biggest factor in the increase in the inflation rate last year, was from one cause: the skyrocketing prices of OPEC oil." in his State of the Union Address in 1980.

During this oil crisis and economic recession former President Ronald Reagan deregulated the price of crude oil and refined petroleum products.[4] According to some economists, the high price of oil in this period created more opportunities for other non-OPEC and U.S. domestic producers to undertake oil field explorations. This crisis is also notable as a period in which OPEC lost market share. Additionally, deregulation of the crude oil price created efficiency in the oil market.[5]

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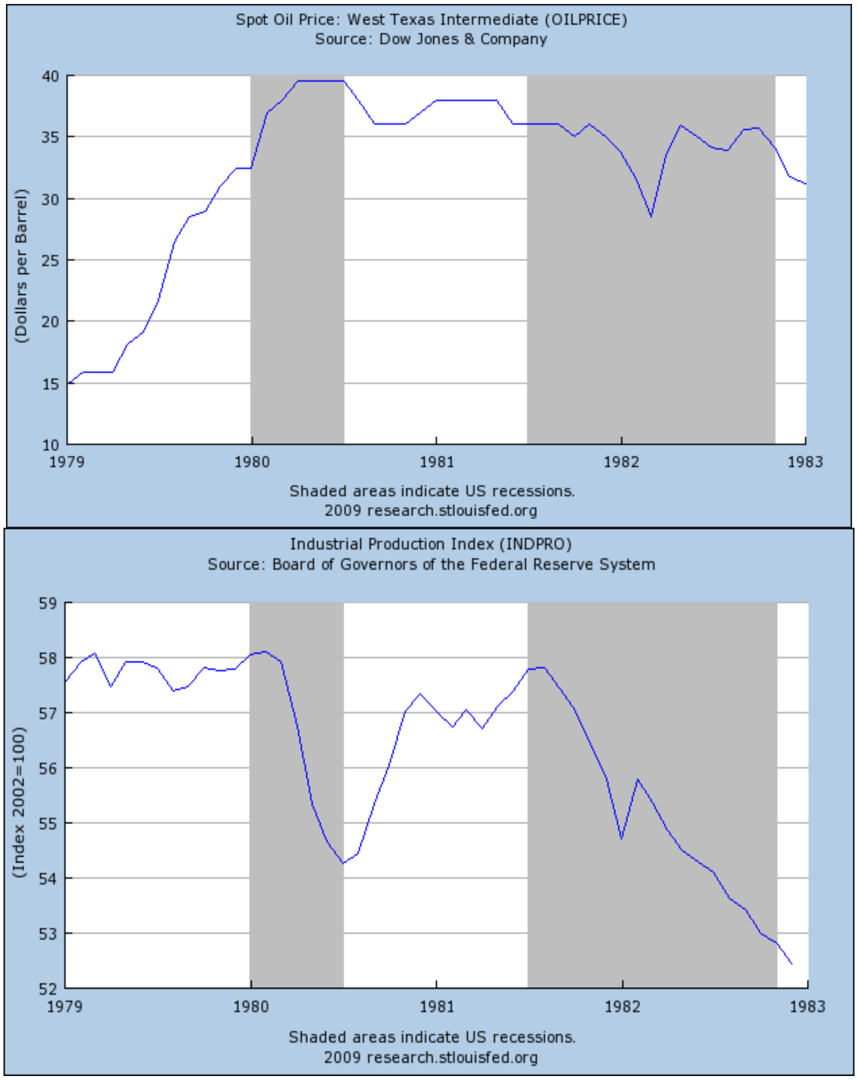
[4] "Executive Order 12287 -- Decontrol of Crude Oil and Refined Petroleum Products." January 28, 1981. http://www.reagan.utexas.edu/archives/speeches/1981/12881a.htm (accessed April 19, 2009).

[5] Williams, James L. *Market Share within OPEC.* http://wtrg.com/opecshare.html (accessed April 21, 2009).

Figure 1-3. West Texas Intermediate oil price, Industrial Production Index and Consumer Price Index after the 1979 oil crisis.



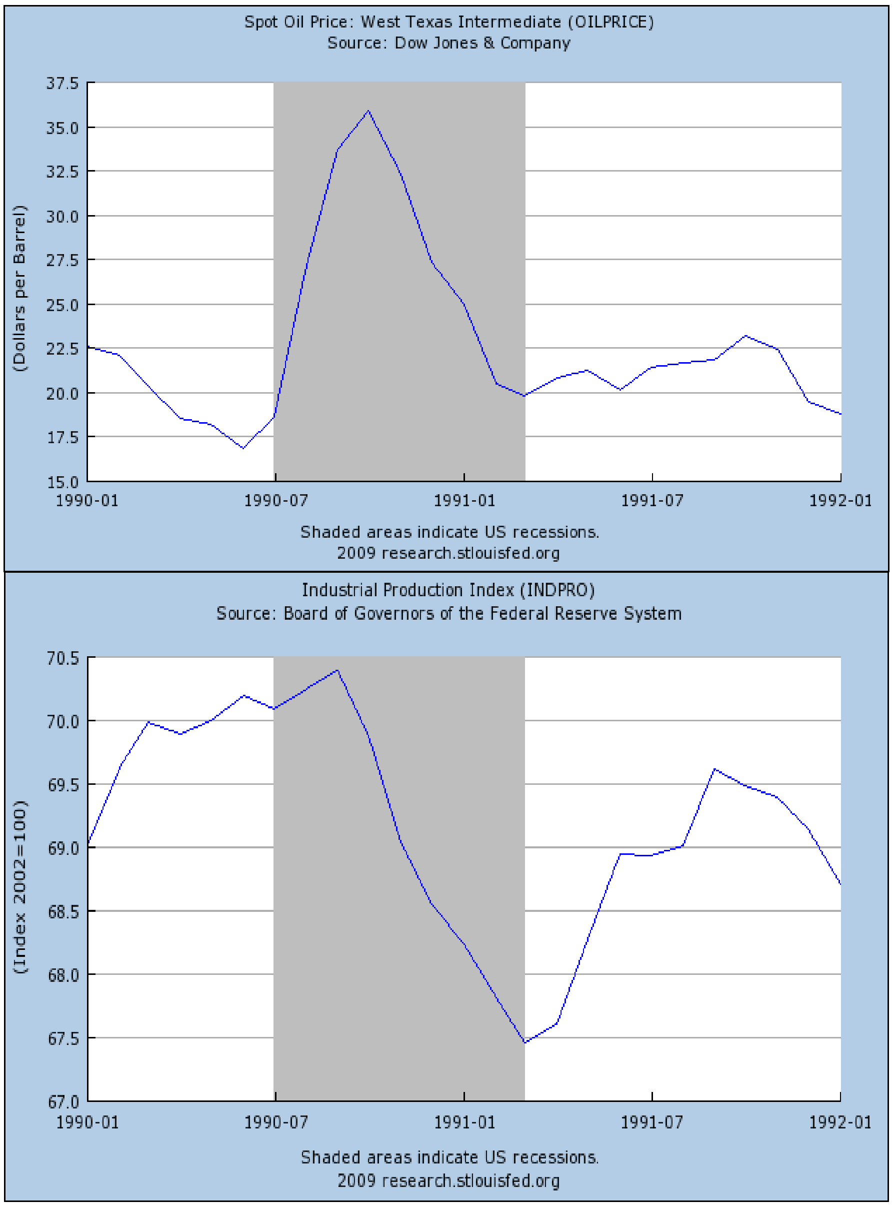
Source: FRED® and www.economagic.com

The top panel shows that oil prices stayed at a high level for a long period and industrial production decreases twice.

1.3. First Gulf War in 1990-1991.

This oil crisis was shorter than the other crises and it occurred after Iraq invaded Kuwait and the price of oil more than doubled. It occurred at the same time as the U.S. economy entered a recession at the end of 1990, which was followed by a decrease in industrial production as illustrated in Figure 1-4.[6]

Figure 1-4. West Texas Intermediate oil price, Industrial Production Index and Consumer Price Index after the 1990-91 oil crisis.



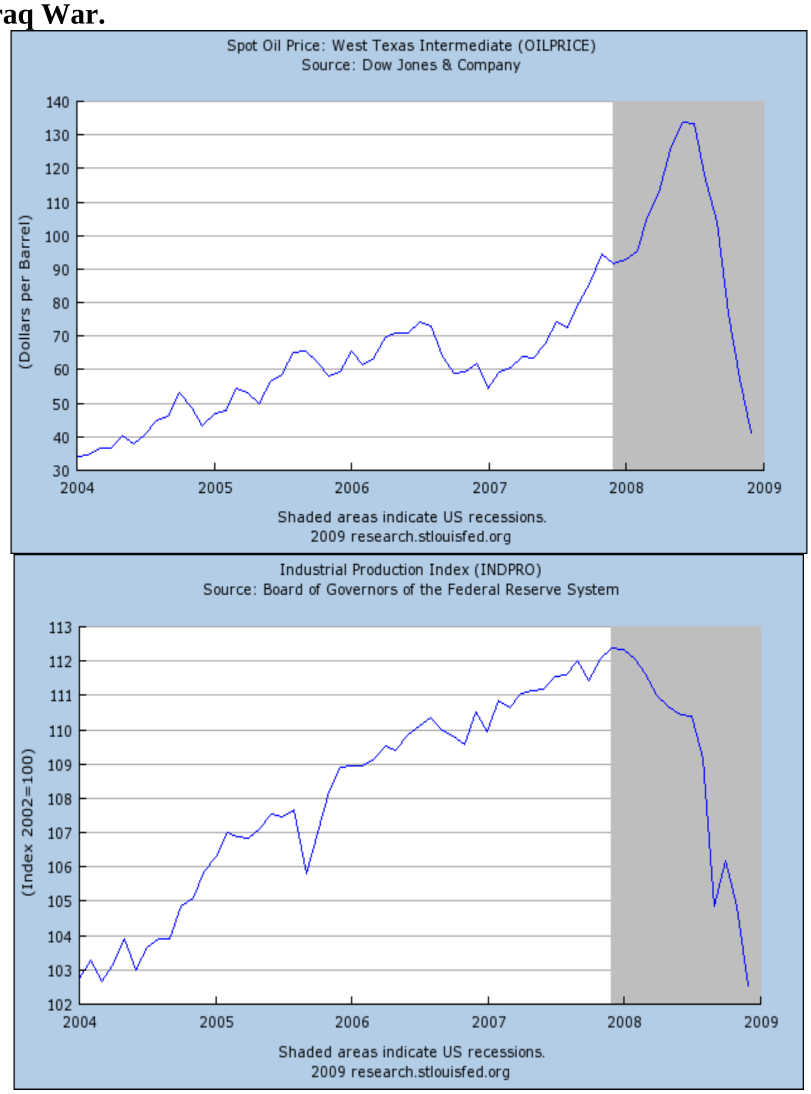
Source: FRED® and www.economagic.com

[6] Federal Reserve Bank of Dallas. "U.S. Economy in Recession." *The Southwest Economy*, 1991: 6-8.

1.4. The Second Iraq War.

Some economists argue that the Second Iraq War was the catalyst for the recent skyrocketing oil prices which reach over $150 (Bland 2008). Another argument is that high oil prices were the result of a huge increase in global demand for crude oil, which in turn is considered a result of the increase in the demand from the U.S. transportation sector and the increasing demand from developing countries such as India and China.[7] [8] This argument is largely based on the idea that economic growth is having positive effects on oil prices.

Figure 1-5. West Texas Intermediate oil price, Industrial Production Index, and Consumer Price Index after the Iraq War.



[7] U.S. Department of Transportation (US DOT). *Domestic Demand for Refined Petroleum Products by Sector.* http://www.bts.gov/publications/national_transportation_statistics/html/table_04_03.html (accessed April 22, 2009).

[8] U.S. Energy Information Administration (EIA). "International Petroleum (Oil) Consumption ." *http://www.eia.doe.gov.* http://www.eia.doe.gov/emeu/international/oilconsumption.html (accessed April 23, 2009).

Source: FRED® and www.economagic.com

Figure 1-5 illustrates that for some period the oil price was increasing despite the recession in the economy and the decrease in industrial production.

1.5. Common elements of these few episodes.

There is a large economics literature which has focused on the correlation of oil prices and the macroeconomic performance of the U.S. economy with particular emphasis directed to the oil crises and economic recessions in the United States reviewed above. Some authors who have written about this topic include Rasche and Tatom (1977, 1981), Santini (1985, 1994), Gisser and Goodwin (1986), Mork (1989), Lee, Ni and Ratti (1995), Rotemberg and Woodford (1996), Raymond and Rich (1997), Carruth, Hooker, and Oswald (1998) and Balke, Brown, and Yücel (1999). The early papers argued that oil price shocks were mostly driven by exogenous events such as the turmoil in the Middle East, which disrupted oil production (Hamilton 1983). Recently, some economists have argued that it is very important to distinguish the different types of oil price shocks to better understand the effects of such shocks (Kilian 2008). As discussed in the literature review below, Kilian argues that exogenous events, which disrupt oil production, do not have a prolonged effect and while events that mostly affect demand, have an immediate effect on the economy. He also argues that the increase in global demand for industrial commodities produces a different type of oil price shock, which in turn has long-term effects on the economy.

This thesis attempts to develop a better understanding of the effects of oil price shocks on the U.S economy. Specifically, it tries to develop a model related to Kilian's, to provide a forecasting model in the spirit of Hamilton (1983). This thesis tries to model the effect of oil price shocks in a way that captures the effect of endogeneity of oil prices.

The remainder of this thesis has the following structure. A literature review on the effects of oil price shocks will be presented in Chapter 2. Chapter 3 carries out the empirical analysis. Here the datasets that is used are discussed and analyzed. Next, an empirical analysis which estimates the effect of oil price shocks is carried out. This analysis suggests a theoretical model which is then estimated. The thesis also attempts to develop a forecasting model for U.S. industrial production based on oil price shocks. Conclusions are presented in Chapter 4.

CHAPTER 2 - A LITERATURE REVIEW

Since the 1970s, a voluminous literature has been written about the effect of oil price shocks on the economy. The aim of this chapter is to review the literature that looks into the problem of estimating the effect of oil price shocks on GDP. Much of my review will discuss papers by James D. Hamilton, which started the literature about the effect of oil price shocks, and work by Lutz Kilian, as these have been by far the most influential papers in the literature.

One of the first papers written about this topic is Hamilton (1983). He argues that there is a correlation between high oil prices and economic recessions. He presents three hypotheses in his paper for the explanation of such a correlation. The first hypothesis is that high oil prices are followed by recessions by coincidence. The second hypothesis is that other explanatory variables cause both high oil prices and economic recessions. The third hypothesis is that at least some of the economic recessions might have been caused by oil price shocks.

Hamilton tests the first hypothesis with the help of a test for statistical correlation. The second hypothesis is investigated using two methodologies. In the first, he argues that regulation by the Texas Railroad Commission (TRC) and other state regulatory agencies filters out the endogenous influences in the oil market and thus focuses on only exogenous events, such as the Iranian Revolution or Iraq War cause high oil prices. These events, he claims, occurred prior to oil shocks in the US. In the second methodology, he conducts parallel Granger-causality tests to check whether (i) some other macro variables cause oil price shocks and, (ii) whether oil price shocks cause recessions. He finds that other macro variables are statistically insignificant in predicting the oil price increases, and the oil prices Granger cause recessions.

As macroeconomic variables he takes Sims' (1980b) six-variable system, which includes real GNP and unemployment, the implicit price deflator for nonfarm business income, hourly compensation per worker, import prices and M1, which represents the financial sector. He conducts bivariate Granger-causality tests between oil price changes and detrended values of the six variables for the data until 1973. He finds that all variables except changes in import prices are not very good predictors of high oil prices. He also argues that even though changes in import prices are a statistically significant predictor of high oil prices, it doesn't explain the correlation of high oil prices and declines in output. Also, he finds that oil prices enter as a statistically significant predictor of changes in all macro variables. He shows that the six variables are collectively not statistically significant in predicting future high oil prices.

The main equation of his paper is:

$$y_t = a_0 + a_1 y_{t-1} + \ldots\ldots a_4 y_{t-4} + b_1 o_{t-1} + \ldots\ldots + b_4 o_{t-4} + u_t,$$

where y is real *GNP* and o is oil prices in the U.S. He estimates this equation for four sample periods using quarterly data. First, he estimates the equation for the period of 1949:2-1972:4 and conducts an F test of the hypothesis H_0: $b_1=b_2=b_3=b_4=0$. This statistic has an F distribution and the value from his analysis is *5.55* which exceeds the 5% critical value of 4.86 and he rejects the null hypothesis that oil prices did not Ganger-cause the real *GNP*. Next, he investigates the sub-period of 1973:1-1980:3. In this case, the the statistic has a distribution of *F(4.22)* and the computed value of *5.71* results in rejection of the null hypothesis as above. The third sub-period he investigates is 1948:2-1972:4, and the test statistics for this period has a distribution of *F(4.90)*. The value from his analysis is *1.51* and he rejects the null hypothesis. The last sub-period he analyzes is 1948:2-1980:3. Similar to the results above, the test statistic has a *F(4.121)* distribution and with the value of *5.28* from his analysis he rejects the null hypothesis that oil prices did not Granger-cause real *GNP*. He finds that the model for the period 1948:2-1972:4 fits better than the model for the period of 1949:2-1972:4, with a postsample mean squared forecast error of 1.22×10^{-1} compared to 1.46×10^{-1} from autoregressive estimation of y.

Hamilton's paper also studies the correlation of oil price changes and other output, price and financial variables and finds additional support for the above-mentioned results. He finds two series statistically significant in predicting future high oil prices: the aggregate incidence of strike activity and coal prices.

In conclusion, the main argument of Hamilton's paper is that exogenous events (such as the Iranian Revolution or Gulf War) to the United States economy caused the oil price shocks, and these shocks are statistically significant in causing changes in output in the following periods.

Some authors have challenged the results of Hamilton's paper by introducing alternative measures of oil shocks (Mork 1989, Hooker 1996). Mork (1989) finds that the positive oil price shocks have a negative effect on output, whereas negative oil price shocks do not have much effect on output growth. Hooker (1996) shows that oil price changes were not as predictive after 1986 as they were in Hamilton (1983). In response, Hamilton (1996a) introduced the concept of "net oil price increase", which means that if the oil price increases compared to the previous year's high, it will decrease output, otherwise it won't affect output at all. Lee, Ni and Ratti (1995) and Ferderer (1996) also provide their own arguments about the effect of oil price shocks on output. According to these authors, if oil prices change, whether up or down, it creates uncertainty that hurts output. Bernanke (1983) and Hamilton (1988) provide theoretical models in which oil price volatility hurts output.

In a recent paper, Kilian (2008) argues that there are two reasons why changes in oil prices cannot be taken as a result of exogenous events. These reasons are: (1) the problem of reverse causality between oil prices and macroeconomic outcomes and (2) the problem of not distinguishing supply and demand shocks in the oil market. He develops new methods to address both of these problems.

Kilian's analysis begins by modeling the global crude oil market and distinguishing supply and demand shocks. He allows for three types of shocks: (1) oil supply shocks, which occur as a result of events such as the 1973 Oil Crisis or 1990-91 crisis, (2) aggregate demand shocks, which come from the fluctuations of global demand for industrial commodities, (3) precautionary demand shocks, which come from the concerns over unexpected high demand or low supply, or over both at the same time.

In order to model aggregate demand, Kilian develops an index to measure the global real economic activity that drives global demand for industrial commodities. He uses dry cargo single voyage ocean freight rates collected by *Drewry Shipping Consultants Ltd*. to calculate this global demand index. He bases his calculation on the idea that the increase in shipping rates is driven by global economic growth and a decrease in rates is driven by global economic downturns. To eliminate the fixed effects for different routes, commodities and ship sizes the author first cumulates the average growth rate of shipping rates, deflates the index by the U.S. CPI, and then detrends it. He also addresses the issue of ships using bunker oil by allowing feedback from oil prices to shipping prices. Then he compares his index to the anecdotal evidence for global business cycles and comes to the conclusion that the index is fully consistent with those cycles.

Next, Kilian uses a Structural VAR model for $z = (dprod, rea, rpro)$ with the vector of serially and mutually uncorrelated structural innovations (ε), where *dprod* is percent change in crude oil production, *rea* is a real economic activity index developed in the paper, and *rpro* is the real price of oil. The Structural VAR he uses is as follows:

$$A_0 z_t = \alpha + \sum_{i=1}^{24} A_i z_{t-i} + \varepsilon_t,$$

He postulates that reduced form errors can be decomposed into A and structural innovations $e_t = A_0^{-1}\varepsilon_t$.

$$e_t \equiv \begin{pmatrix} e_t^{\Delta prod} \\ e_t^{rea} \\ e_t^{rpo} \end{pmatrix} = \begin{pmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} \varepsilon_t^{oil-prod-shock} \\ \varepsilon_t^{aggreagte-demand-shock} \\ \varepsilon_t^{oil-specific-demand-shock} \end{pmatrix}$$

The structural innovations vector includes shocks to crude oil production (oil supply shocks), shocks to global economic activity (aggregate demand shocks) and shocks to the real price of oil (oil-specific demand shocks). He puts restrictions on the *A* matrix in the following way: (i) crude oil production does not respond to aggregate demand shocks and oil-specific demand shocks contemporaneously, (ii) the real economic activity does not respond to oil-specific shocks contemporaneously.

Then, he plots the structural shocks of the VAR model and compares it to the timing of the oil supply, aggregate demand and oil-specific demand shocks and finds them fully consistent with the historic timing of those shocks. He finds that oil supply shocks cause a sharp decrease in oil production, which reverses back during the first year, a reduction in global economic activity and a small, temporary increase in the real price of oil. In the same way, he finds that aggregate demand shocks cause a persistent increase in global economic activity, a temporary increase in oil production and large, persistent increases in the real price of oil. Finally, he finds oil-specific demand shocks cause immediate, large and persistent positive increases in the real price of oil. Here, he notes that oil supply shocks have a small positive effect on the real price of oil which comes mainly from exogenous events and suggests that precautionary demand, i.e. oil-specific demand shocks have caused the large increases in the real price of oil after events like the Iraq War.

The cumulative effects of these shocks are analyzed next. Here again, he finds that oil supply shocks cause small changes in the real price of oil, aggregate demand shocks have prolonged effects, and oil-specific demand shocks have sharp positive and negative effects on the real price of oil. Then he compares the results with the historical episodes pointing out the periods when the real price of oil rises sharply caused by a danger of war or destruction of oil fields, for example in the Middle East, and when the price falls sharply following OPEC losing its market share, which causes the decline of oil-specific demand. He also considers many other periods of oil price falling and rising and comes to the conclusion that exogenous events, which have historically been considered to be the driving forces of high oil prices, only affect precautionary demand. Changes in precautionary demand in turn cause sharp decreases or increases in the real price of oil.

Kilian then compares the results of the model estimated using two different indices, the index based on shipping rates and an industrial production index from OECD. He argues that the index based on shipping rates measures global economic activity better. He argues alternative methods of measuring production, for example the global industrial production index from OECD, have problems such as exchange rate weighting, the effect of technological changes on the link from growing production to global demand and exclusion of emerging economies in Asia such as China and India. He argues that when using the OECD industrial production index model, most of the recent growth in the real price of oil was caused by precautionary demand, and when using the index based on shipping rates the model shows that the recent growth in the real price of oil was the result of aggregate demand shocks. He argues that the results of the two indices mostly coincide up until the recent growth in the real price of oil. He argues that the OECD production index excludes the emerging economies of China and India, and this accounts for the difference in estimations towards the end of the data as the model estimated with the OECD production index shows oil-specific demand shocks caused the recent growth of oil prices.

Kilian also analyzes the effects of oil price shocks on U.S. macroeconomic aggregates such as real GDP growth and CPI inflation. Here, he averages the monthly structural errors into quarterly errors and assumes that these quarterly errors are predetermined with respect to the above-mentioned macroeconomic aggregates, i.e. there is no feedback from real GDP growth and CPI inflation to quarterly structural errors. He argues that at the quarterly frequency the effects of structural errors and real GDP growth offset each other.

After estimating the effect of quarterly structural shocks on real GDP growth and CPI inflation with the VAR model, Kilian summarizes the results the following way: positive oil supply shocks cause output to fall temporarily and decrease the price level; positive aggregate demand shocks first raise output, then after four quarters decrease output and raise the price level; positive oil-specific demand shocks decrease the output and increase the price level. He argues that the U.S. economy does not decline immediately after such shocks.

CHAPTER 3 - EMPIRICAL ANALYSIS ON THE EFFECTS OF OIL PRICE SHOCKS

1. Dataset.

The data used in this thesis was taken from a database at the Federal Reserve Bank of St. Louis (Federal Reserve Economic Data, FRED®). We use the "OILPRICE, Spot Oil Price: West Texas Intermediate (WTI)" as the crude oil price series and the "INDPRO, Industrial Production Index" industrial production index series between January 1965 and December 2008 for the US economy. The industrial production (IP) index rather than Gross Domestic Product (GDP) series was used because the data on *IP* is available on a monthly basis.

In the literature on oil and the macroeconomy it is common to work with percentage changes of both oil prices and output (Hamilton 1983, Kilian 2008). In this study we also apply the log difference transformation of the variables to get the data in percentage change units.

It is common to pretest the variables for stationarity. Normally, if the variables are non-stationary, first differences are used[9]. We test for a unit-root following the work of Dickey and Fuller (Dickey and Fuller 1979). This procedure begins by choosing a lag length for the model. The Akaike's information criterion (AIC) was used to select the lag length and eliminate serial correlation in the residual. The regression for the Augmented Dickey-Fuller test is:

$$X_t = \alpha + \beta X_{t-1} + \gamma_1 X_{t-1} + ... + \gamma_k X_{t-k} + \varepsilon_t,$$

where X_t is the variable being tested for stationarity (see Hamilton 2009). The null hypothesis is $\beta = 1$ against the alternative hypothesis $\beta < 1$. The test cannot be carried out as a one-sided t-test because the variable is non-stationary under the null hypothesis, so the test statistic has a non-standard distribution under the null hypothesis.

[9] One of the few papers to work with oil prices in levels is Balke, Brown, and Yucel (1998)

Table 3-1. The results of Dickey-Fuller test for a unit-root.

Variables	*Value of test-statistic*	*Crit. values(5%)*	*Lag length*
log(IP)	-2.0259	-2.86	1
log(WTI)	-1.7479	-2.86	1
$\Delta log(IP)$	-10.6804	-2.86	1
$\Delta log(WTI)$	-14.8751	-2.86	1

Source: Author's estimation based on FRED®

Table 3-1 summarizes the results of the Dickey-Fuller test. The table shows that the variables *IP* and *WTI* are non-stationary in levels and stationary in differences at the 5% level. The former test statistics are greater than the critical values at the 10% significance level of -2.57. For differences, a unit root is rejected even at a 1% significance level, which has critical value of -3.43.

It is also necessary to test whether the variables *IP* and *WTI* are cointegrated. In particular, can we find α and β so that z_t given by:

$$z_t = WTI_t - \alpha - \beta IP_t,$$

is stationary. If *IP* and *WTI* are cointegrated, z_t will have to be included in the forecasting models (Enders 2004). This possibility is investigated using the Johansen test and the results are summarized in Table 3-2.

Table 3-2. Results of Johansen Test for Cointegration.

	Trace test stat.	10%	5%	1%
At most 1 CI relation	6.01	10.49	12.25	16.26
No CI relations	19.22	22.76	25.32	30.45

Source: Author's estimation based on FRED®

These results indicate that the Industrial Production (*IP*) Index and oil prices (*WTI*) are not cointegrated. In all cases, we cannot reject the null hypothesis of cointegrating rank equal to zero. Based on these results, we proceed without including error correction terms in any of the models.

2. Model.

To understand the model, it is useful to begin with Hamilton (1983), a classic reference for the relationship between output and oil shocks. As noted in the literature review section, much of the literature that followed Hamilton treats changes in the price of oil as though they are exogenous shocks in the supply of oil, such as a war in the Middle East, shipping routes being shut down, or the discovery of new oil reserves. In this case, one can use a simple linear VAR-based forecasting model:

$$\Delta GDP_t = \beta_0 + \beta_1 \Delta GDP_{t-1} + \beta_2 \Delta WTI_{t-1} + \varepsilon_t,$$

where ΔGDP_t is the percentage change in *GDP* and ΔWTI_t is the percentage change in the price of oil. It follows in a straightforward manner that if we assume ΔWTI reflects exogenous changes in the supply of oil, β_2 should be less than zero. Typically more lags are included, in which case the sum of coefficients on oil shocks should be negative.

More recently some authors, notably Kilian (2008), have challenged this assumption that changes in the oil prices are exogenous. Kilian agrees that β_2 will be negative in time periods when ΔWTI is largely due to exogenous oil supply changes. However, in his view most movements in the price of oil are not the result of exogenous supply disruptions. Much of the variation in the price of oil is due to world macroeconomic shocks. When there is a positive shock to output in the world economy, it will cause US output to rise, and because oil is a factor of production, it will cause the demand for oil to rise. In that case, β_2 will be positive.

The objective of this thesis is to apply Kilian's logic to a VAR forecasting model for output along the lines of Hamilton (1983). We want a model that allows β_2 to change depending on the reason for the change in the oil price. The claim made by Kilian (2008) and others is that when oil prices and output are moving in the same direction, the dominant shock is a shock to world *GDP*. However, when oil prices and output move in opposite directions, it is the oil shock that is dominant. One can also find many articles about the effect of economic growth on oil price shocks. One such recent story by the BBC says, "Oil prices have risen after surprisingly good US industrial output figures and warnings of cold weather heading for the US northeast."[10] Another story is, "Energy prices waver with new signs of weak economy", which says that the

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[10] BBC News. *Oil prices rise on US output data* . http://news.bbc.co.uk/2/hi/business/7732824.stm (accessed April 23, 2009)

oil prices are going down due to the weak economy.[11] The model is based on this possibility. When the growth rate of output and the change in the price of oil are moving in the same direction, then it must be news about the economy that is driving both of these changes. The model used here is structured to test this hypothesis in this thesis.

For this study, the following model is used:

$$\Delta IP_t = \beta_0 + \beta_1 \Delta IP_{t-1} + \beta_2 \Delta WTI_{t-1} + \beta_3 \delta \Delta WTI_{t-1} + \varepsilon_t \quad (1)$$

where δ is a dummy variable equal to 1 if $\varepsilon_{t-1}\Delta WTI_{t-1} > 0$ and 0 otherwise.[12] This model allows changes in the price of oil to have different effects depending on whether the change in the price of oil and *IP* growth are moving in the same direction (so that the increase in the price of oil was primarily due to an increase in the demand for oil) or in the opposite direction (so that the increase in the price of oil was primarily due to an oil supply shock).

One might ask why such a model is needed in light of the work done by Kilian (2008). There are two drawbacks to Kilian's approach if the goal is forecasting. First, his dataset is not publicly available, whereas the data used here can be downloaded from the internet. Second, his data is available only with a lag of several months while the data used here is available after a couple of weeks. Therefore, this thesis develops a model that can be used to make forecasts in a timely fashion, with publicly available data. These points were not an issue for Kilian, because his objective is not forecasting.

3. Results.

3.1. Baseline Model

Our analysis begins by estimating the baseline model, i.e. the model with one lag for each variable given in equation (1). This model is used because it is common to work with small models when the goal is to make forecasts.[13] Because the model is a highly nonlinear model, the maximum likelihood estimation method is used. This requires solving a complicated nonlinear optimization problem. For this analysis, the MLE function which is based in the "stats4" package of "R" GUI software is used to estimate the models in this thesis. Because local optima were a

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[11] Kahn, Chris. *Energy prices waver with new signs of weak economy.* April 30, 2009. http://www.star-telegram.com/461/story/1348727.html (accessed April 22, 2009).

[12] We are developing a forecasting model rather than a structural model, so we will not give the coefficients a structural interpretation,

[13] Large models, with many estimated parameters, often forecast poorly (Stock and Watson 2006, p.517).

problem, many different sets of starting values were used. The following values show convergence with the highest log-likelihood: $\beta_0=0.7$, $\beta_1=0.22$, $\beta_2=-0.09$, $\beta_3=0.03$, $\sigma=0.7$. The results are summarized in Table 3-3 when the Nelder-Mead method (the method, implemented by Nelder and Mead (1965), used throughout this thesis) of maximizing the log likelihood function is used.

Table 3-3. Estimation of baseline model.

Variable	1965:01-2008:12	
	Coefficient	Stand. Error
Constant	0.1457736	0.013624
ΔIP_{t-1}	0.3268957	0.014163
ΔWTI_{t-1}	0.0021005	0.003957
$\delta * \Delta WTI_{t-1}$	-0.003651	0.006731

Source: Author's estimation based on FRED®
-2 log L: 1129.385

As is clear from the table, β_2 and β_3 are both insignificant in the regression. This is consistent with the idea that the demand for oil is inelastic in the short-run, i.e. that the change in oil price does not affect industrial production immediately. Also, a serial correlation test showed that the residuals may be serially correlated.

One test of particular interest is the hypothesis $\beta_2 + \beta_3 = 0$. If oil shocks affect the economy as expected, we will see $\beta_2 < 0$ $\beta_2 + \beta_3 > 0$. To investigate this, the model is re-parameterized in the following way:

$$\Delta IP_t = \beta_0 + \beta_1 \Delta IP_{t-1} + \beta_2(1-\delta)\Delta WTI_{t-1} + \varepsilon_t,$$

The estimation results, which are obtained following a similar routine as above with starting values of $\beta_0=0.7$, $\beta_1=0.22$, $\beta_2=-0.09$, $\sigma=0.7$, are given in Table 3-4:

Table 3-4. Estimation of re-parameterized baseline model.

Variable	1965:01-2008:12	
	Coefficients	Stand. Error
Constant	0.144239144	0.027669047
ΔIP_{t-1}	0.319245765	0.041091272
$(1-\delta) * \Delta WTI_{t-1}$	-0.001297368	0.004219053

Source: Author's estimation based on FRED®
-2 log L: 1129.572

To test $\beta_2 + \beta_3 = 0$, a log-likelihood ratio test is conducted. The change in *-2 log L* when imposing the null hypothesis follows the Chi-square distribution with one degree of freedom and in our case this difference is equal to 0.0936. We fail to reject the null hypothesis at a 95 percent confidence level as the critical value for the Chi-square distribution with one degree of freedom is 3.84. This result is consistent with the idea that the change in oil price is not significant in the short run.

For comparison purposes, a version of the model developed by Hamilton (1983) is estimated. The starting values are the same and the results are given in Table 3-5:

Table 3-5. Estimation of VAR Model.

Variable	1965:01-2008:12	
	Coefficient	Stand. Error
Constant	0.143986128	0.032175836
ΔIP_{t-1}	0.316842028	0.041586254
ΔWTI_{t-1}	0.001218882	0.003433682

Source: Author's estimation based on FRED®
-2 log L: 1129.550

The difference in *-2 log L* between the values for the baseline model and VAR model is 0.165. As it follows the Chi-square distribution, the null hypothesis cannot be rejected with the critical value of 3.84 for Ch-square distribution at a 95 percent confidence level. The coefficient on oil price change is not significant as the t-value for the coefficient is *0.355*. The coefficients on ΔIP_{t-1} and ΔWTI_{t-1} are not much different from those in Table 3. For the full sample, the new model provides no advantages. That Hamilton's model does not find a significant coefficient on ΔWTI_{t-1} is not surprising in light of Hooker (1996), which showed a break-down of the relationship between oil price changes and output changes in 1986.

3.2. Estimation of the model by subsample.

3.2.1. The 1965-1985 Time Period.

Hooker (1996) suggested that there is a breakdown of these relationships, so that none of the proposed models have forecast power for macroeconomic variables after 1986. We test for a structural break in the coefficients of our model in 1986. To investigate this we estimate the following equation:

$$\Delta IP_t = \beta_0 + \beta_1 \Delta IP_{t-1} + \beta_2 \Delta WTI_{t-1} + \beta_3 \delta \Delta WTI_{t-1}$$
$$+ \beta_4 d_{t-1} \Delta IPt_{-1} + \beta_5\ d_{t-1} \Delta WTI_{t-1} + \beta_6\ d_{t-1} \delta \Delta WTI_{t-1} + \varepsilon_t$$

where d_t is a dummy variable, which is equal to 1 after January 1986 until December 2008, and 0 between January 1965 and December 1985. We estimate the equation with the starting values of $\beta_0=0.3,\ \beta_1=0.3,\ \beta_2=-0.03,\ \beta_3=0.03,\ \beta_4=0.003,\ \beta_5=0.003,\ \beta_6=0.003,\ \sigma=0.7.$ The results are given in Table 3-6.

Table 3-6. Estimation of the model for structural break in 1986.

Variable	1965:01-2008:12	
	Coefficient	Stand. Error
Constant	0.169918216	0.031749772
ΔIP_{t-1}	0.420316035	0.049727406
ΔWTI_{t-1}	-0.002245684	0.004688027
$\delta * \Delta WTI_{t-1}$	0.000880248	0.013951071
$d_{t-1} \Delta IP_{t-1}$	-0.441992196	0.088096080
$d_{t-1} \Delta WTI_{t-1}$	0.005596975	0.005076806
$d_{t-1} \delta * \Delta WTI_{t-1}$	0.018266497	0.014963900

Source: Author's estimation based on FRED®
-2 log L: 1106.697

The change in *-2 log L* is 22.69 and it follows Chi-square distribution. As the critical value for the Chi-square distribution with three degrees of freedom is 7.82 at a 95 percent confidence level, the null hypothesis is rejected.

We now estimate the baseline model following the same routine as above for the subsample of the data running from January 1965 until December 1985 with the starting values of $\beta_0=0.7,\ \beta_1=0.22,\ \beta_2=-0.09,\ \beta_3=0.03,\ \sigma=0.7.$ The results of the estimation are summarized in Table 3-7:

Table 3-7. Estimation of baseline model for the period 1965:01-1985:12.

Variable	1965:01-1985:12	
	Coefficient	Stand. Error
Constant	0.141776709	0.051230080
ΔIP_{t-1}	0.444710431	0.058391940
ΔWTI_{t-1}	-0.003617235	0.005487783
$\delta * \Delta WTI_{t-1}$	-0.013433637	0.025892693

Source: Author's estimation based on FRED®
-2 log L: 585.2201

One can see that in this period changes in oil prices are not informative about the future changes in industrial production. The coefficients on oil price changes are not significant and both are negative. A serial correlation test found no evidence of serial correlation in the residuals.

Next the model was estimated under the restriction that $\beta_2 + \beta_3 = 0$. The starting values for this estimation of the re-parameterized model are the same as above. The results for this estimation are given in Table 3-8:

Table 3-8. Estimation of re-parameterized baseline model.

Variable	1965:01-1985:12	
	Coefficients	Stand. Error
Constant	0.142326944	0.051274846
ΔIP_{t-1}	0.435780504	0.056942287
$(1-\delta) * \Delta WTI_{t-1}$	0.003713153	0.005491485

Source: Author's estimation based on FRED®
-2 log L: 585.6786

The log-likelihood ratio test for $\beta_2 + \beta_3 = 0$ indicates that the null hypothesis cannot be rejected with the change in *-2 log L* = 0.4585 and the critical value for $\chi^2(1)$ is 3.84.

Finally, a version of Hamilton's VAR is estimated. The results of this estimation are given in Table 3-9:

Table 3-9. Estimation of VAR Model.

Variable	1965:01-1985:12	
	Coefficient	Stand. Error
Constant	0.143007632	0.051203047
ΔIP_{t-1}	0.437183951	0.056596434
ΔWTI_{t-1}	-0.004287346	0.005336032

Source: Author's estimation based on FRED®
-2 log L: 585.4892

We conduct a log-likelihood ratio test between the baseline model and VAR model for this time period. As the difference in *-2 log L* is 0.2691 and the critical value for Chi-square distribution with one degree of freedom is 3.84, the null hypothesis cannot be rejected. As before the coefficient on oil price change is insignificant and negative. Results show that the results are largely unchanged for this subsample of the data.[14]

3.2.2. The 1986 – 2008 Time Period.

To further explore the possibility of a breakdown of the relationship after 1986, the subsample from January 1986 until December 2008 was explored. The baseline model using starting values of $\beta_0=0.7$, $\beta_1=0.22$, $\beta_2=-0.09$, $\beta_3=0.03$, $\sigma=0.7$, produced results summarized in Table 3-10:

Table 3-10. Estimation of baseline model for the period 1986:01-2008:12.

Variable	1986:01-2008:12	
	Coefficient	Stand. Error
Constant	0.16055710	0.013717396
ΔIP_{t-1}	0.03791124	0.059318308
ΔWTI_{t-1}	0.01069689	0.001754491
$\delta * \Delta WTI_{t-1}$	0.01631405	0.001719053

Source: Author's estimation based on FRED®
-2 log L: 513.6382

This regression shows several changes versus the full sample estimation. As the table illustrates, lagged *IP* growth is not a significant predictor of the *IP* change. Also, the coefficient on oil prices is positive and enters the equation as a significant predictor. The coefficient β_3 is also

[14] A model using *GDP* growth data is discussed in the Appendix.

positive and significant. A serial correlation test found that the residuals may be serially correlated.

To test $\beta_2 + \beta_3 = 0$ for this subsample the starting values are $\beta_0=0.1$, $\beta_1=0.1$, $\beta_2=-0.009$, $\sigma=0.7$ are used. The results are given in Table 3-11:

Table 3-11. Estimation of re-parameterized baseline model for 1986:01-2008:12.

Variables	1986:01-2008:12	
	Coefficients	Stand. Error
Constant	0.116859939	0.002195676
ΔIP_{t-1}	0.192322535	0.056374841
$(1-\delta)*\Delta WTI_{t-1}$	-0.009611688	0.001861993

Source: Author's estimation based on FRED®
-2 log L: 520.8234

The log-likelihood ratio test for $\beta_2 + \beta_3 = 0$ is significant (the difference in -2 log L is 7.1852, with critical value equal to 3.84).

In the same manner as above, we now estimate a VAR model as in Hamilton (1983):

Table 3-12. Estimation of VAR Model.

Variable	1986:01-2008:12	
	Coefficient	Stand. Error
Constant	0.13917980	0.038170190
ΔIP_{t-1}	0.13398971	0.060015672
ΔWTI_{t-1}	0.01165356	0.004205866

Source: Author's estimation based on FRED®
-2 log L: 516.6148

We conduct the log-likelihood ratio test between the baseline model and VAR model for this period. The difference in *-2 log L* is 2.97 which follows Chi-square distribution. The critical value for the Chi-square distribution with one degree of freedom is 3.84 which results in failing to reject the null hypothesis.

As in the previous results, this time period produces differences versus the overall sample and the early subsample. Here the coefficient on oil price change is significant as its t-value is *2.775*.

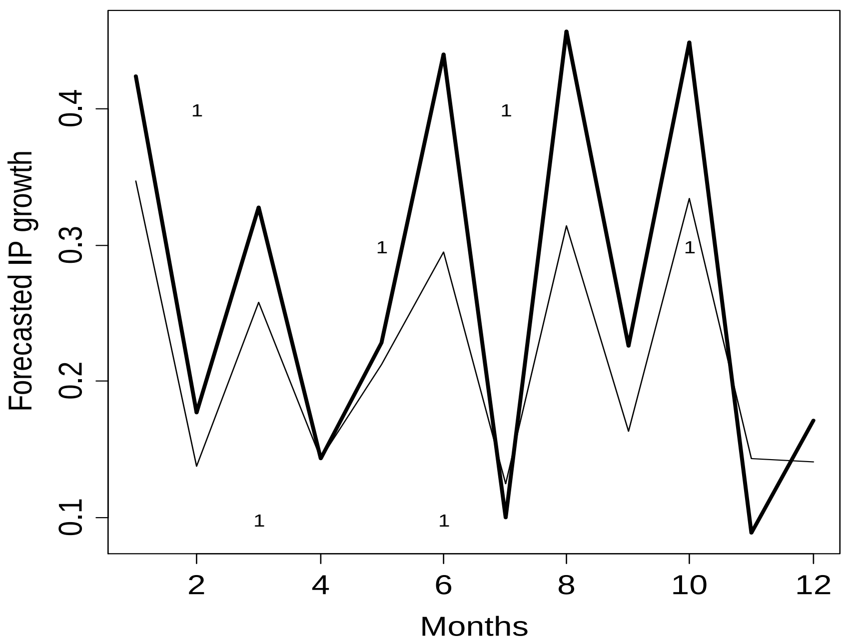
The results of the estimation for the 1986:01-2008:12 time period suggest two things:

(i) There is a positive correlation between oil price movements and industrial production after 1986, meaning endogeneity of oil prices is important, and

(ii) The model is able to pick up some time periods in which the endogeneity is most important.

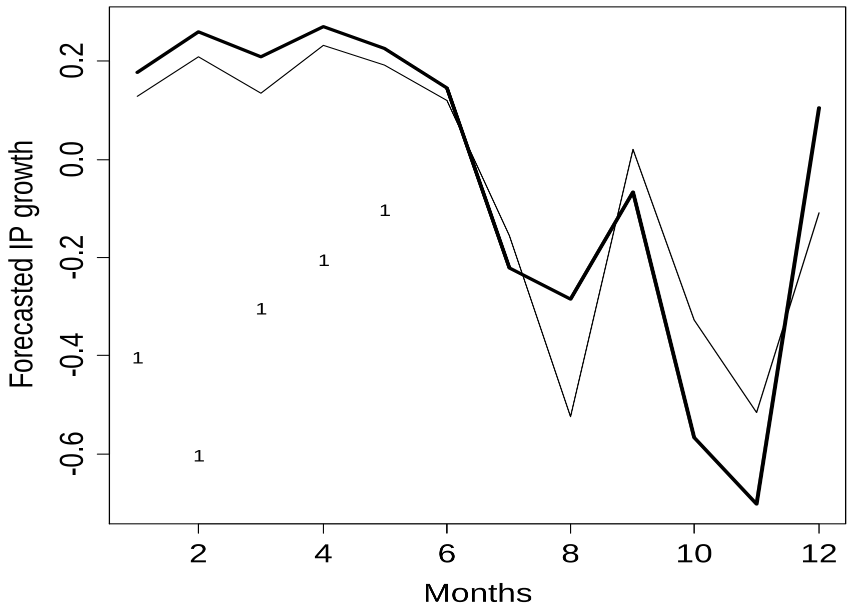
Because this is a forecasting model, so that the parameter values cannot be given a structural interpretation, we need some other metric to judge the economic significance of the results. Therefore, plots of the forecasts for 2007 and 2008 based on the results of the proposed model and Hamilton's VAR model are given in Figure 3-1 and 3-2.

Figure 3-1. Forecast for 2007. (points: Observed data; bold line: Proposed model; thin line: Hamilton's VAR model)



Source: Author's estimation based on FRED®

Figure 3-2. Forecast for 2008. (points: Observed data; bold line: Proposed model; thin line: Hamilton's VAR model)



Source: Author's estimation based on FRED®

Figures 3-1 and 3-2 show the difference in forecasts when using Hamilton's model and when using the model of this thesis. The observed data is also plotted as a comparison. We see some large difference in the forecasts for 2007 and 2008. The vertical axis of Figures 3.1-3.2 represents the growth rate of *IP*, and the horizontal axis represents months. The growth rate forecasts in June, August, and October of 2007 were much higher with my model, while the forecast for November 2008 was much lower.

3.3. Adding Lags.

Next we estimate our model with six lags for the percentage change of the industrial production index and oil price. It is common to add more lags to these models[15]. The estimation equation is:

[15] There is almost certainly a problem with serial correlation in the residuals in the model with one lag. That will have two effects. First, the reported standard errors are not correct. Second, there are some relevant predictors omitted from the model.

$$\Delta IP_t = \beta_0 + \sum_{i=1}^{6} \beta_i \Delta IP_{t-i} + \sum_{i=1}^{6} \beta_{i+6} WTI_{t-i} + \sum_{i=1}^{6} \beta_{i+12} \delta_i WTI_{t-i} + \varepsilon_t$$

The starting values are $\beta_0=0.1$, $\beta_1=0.22$, $\beta_2=0.15$, $\beta_3=0.07$, $\beta_4=0.09$, $\beta_5=0.09$, $\beta_6=0.05$, $\beta_7=0.0001$, $\beta_8=-0.0001$, $\beta_9=-0.0003$, $\beta_{10}=-0.0003$, $\beta_{11}=-0.0004$, $\beta_{12}=-0.0004$, $\beta_{13}=0.0003$, $\beta_{14}=0.0002$, $\beta_{15}=0.0002$, $\beta_{16}=0.0001$, $\beta_{17}=0.0001$, $\beta_{18}=0.0001$, $\sigma=0.7$ and the results of the estimation are given in Table 3-13:

Table 3-13. Estimation of six-lag model for 1965:01-2008:12.

Variable	1965:01-2008:12	
	Coefficient	Stand. Error
Constant	0.1033991049	0.001100774
ΔIP_{t-1}	0.2130705395	0.0346815064
ΔIP_{t-2}	0.1442721429	0.0058893758
ΔIP_{t-3}	0.1051037433	0.0353701885
ΔIP_{t-4}	0.0626947247	0.0533121348
ΔIP_{t-5}	-0.0416394327	0.0104816541
ΔIP_{t-6}	0.0352863290	0.0217622646
ΔWTI_{t-1}	-0.0002909953	0.0025837632
ΔWTI_{t-2}	-0.0009984913	0.0042252763
ΔWTI_{t-3}	-0.0062887808	0.0017554130
ΔWTI_{t-4}	-0.0002603792	0.0004881645
ΔWTI_{t-5}	-0.0038754531	0.0028463217
ΔWTI_{t-6}	-0.0025668357	0.0022767038
$\delta_1 * \Delta WTI_{t-1}$	0.0064345387	0.0026502113
$\delta_2 * \Delta WTI_{t-2}$	-0.0059871136	0.0039867912
$\delta_3 * \Delta WTI_{t-3}$	0.0065688524	0.0010375509
$\delta_4 * \Delta WTI_{t-4}$	0.0002427909	0.0004799109
$\delta_5 * \Delta WTI_{t-5}$	0.0025445078	0.0066802929
$\delta_6 * \Delta WTI_{t-6}$	-0.0002404982	0.0022956648

Source: Author's estimation based on FRED®
-2 log L: 1089.548

Almost all the coefficients on oil price change lags are insignificant. A serial correlation test found no evidence of serial correlation in the residuals. Next a test of $\beta_7 + \beta_{13} = 0$, $\beta_8 + \beta_{14} = 0$, $\beta_9 + \beta_{15} = 0$, $\beta_{10} + \beta_{16} = 0$, $\beta_{11} + \beta_{17} = 0$, $\beta_{12} + \beta_{18} = 0$ is produced. This is investigated re-parameterizing the model as follows:

$$\Delta IP_t = \beta_0 + \sum_{i=1}^{6} \beta_i \Delta IP_{t-i} + \sum_{i=1}^{6} \beta_{i+6} (1-\delta_i) WTI_{t-i} + \varepsilon_t,$$

The results of estimating the re-parameterized model with the starting values $\beta_0=0.12$, $\beta_1=0.22$, $\beta_2=0.14$, $\beta_3=0.14$, $\beta_4=0.08$, $\beta_5=0.0001$, $\beta_6=0.05$, $\beta_7=-0.0001$, $\beta_8=-0.0001$, $\beta_9=-0.0003$, $\beta_{10}=-0.0003$, $\beta_{11}=-0.002$, $\beta_{12}=-0.002$, $\sigma=0.7$ are given in Table 3-14:

Table 3-14. Estimation of re-parameterized six-lag model for 1965:01-2008:12.

Variable	1965:01-2008:12	
	Coefficient	Stand. Error
Constant	0.1082354	0.030492
ΔIP_{t-1}	0.2168819	0.039362
ΔIP_{t-2}	0.138954	0.040402
ΔIP_{t-3}	0.1394373	0.041553
ΔIP_{t-4}	0.08922057	0.043083
ΔIP_{t-5}	-0.1006098	0.042819
ΔIP_{t-6}	0.5532237	0.041533
$(1-\delta_1)*\Delta WTI_{t-1}$	0.0003201	0.003817
$(1-\delta_2)*\Delta WTI_{t-2}$	-0.0021305	0.007067
$(1-\delta_3)*\Delta WTI_{t-3}$	-0.0047474	0.007298
$(1-\delta_4)*\Delta WTI_{t-4}$	0.001604	0.006927
$(1-\delta_5)*\Delta WTI_{t-5}$	-0.0069528	0.006712
$(1-\delta_6)*\Delta WTI_{t-6}$	-0.0013979	0.006864

Source: Author’s estimation based on FRED®
-2 log L: 1091.801

Because the change in -2 log L is 2.253 the log-likelihood ratio test for $\beta_7 + \beta_{13} = 0$, $\beta_8 + \beta_{14} = 0$, $\beta_9 + \beta_{15} = 0$, $\beta_{10} + \beta_{16} = 0$, $\beta_{11} + \beta_{17} = 0$, $\beta_{12} + \beta_{18} = 0$ does not reject the null hypothesis with a critical value of 12.79 for $\chi^2(6)$. Again, it is consistent with the result above, i.e. insignificant coefficients for oil price changes.

For comparison a VAR model is estimated. The results of the estimation are summarized in Table 3-15:

Table 3-15. Estimation of six-lag VAR model for 1965:01-2008:12.

Variable	1965:01-2008:12	
	Coefficient	Stand. Error
Constant	0.1069392422	0.034187155
ΔIP_{t-1}	0.2233339278	0.043669133
ΔIP_{t-2}	0.1319758587	0.043921140
ΔIP_{t-3}	0.1572281738	0.044624364
ΔIP_{t-4}	0.0699134504	0.046252960

ΔIP_{t-5}	-0.0747155658	0.045950918
ΔIP_{t-6}	0.0258468801	0.044806333
ΔWTI_{t-1}	-0.0001355775	0.003365362
ΔWTI_{t-2}	-0.0020848466	0.003421113
ΔWTI_{t-3}	-0.0043910464	0.003436871
ΔWTI_{t-4}	0.0008868665	0.003445347
ΔWTI_{t-5}	-0.0036881680	0.003453307
ΔWTI_{t-6}	-0.0020639460	0.003428793

Source: Author's estimation based on FRED®
-2 log L: 1089.817

One can see negative coefficients on oil price changes, but they are all insignificant, which is similar to early results. The difference in *-2 log L* for the unrestricted model and VAR model is 0.269, the critical value for Chi-square distribution with six degrees of freedom is 12.59 at a 95 percent confidence level and the null hypothesis cannot be rejected.

3.4. Estimation of the model with more lags by subsample.

3.4.1. The 1965 – 1985 Time Period for the model with more lags.

We now explore the larger lag length model over the same two subintervals. For the period of 1965:01-1985:12 a six-lag model is estimated using starting values of $\beta_0=0.1$, $\beta_1=0.22$, $\beta_2=0.15$, $\beta_3=0.11$, $\beta_4=0.07$, $\beta_5=0.06$, $\beta_6=0.05$, $\beta_7=0.0001$, $\beta_8=-0.0001$, $\beta_9=-0.0003$, $\beta_{10}=-0.0003$, $\beta_{11}=-0.0004$, $\beta_{12}=-0.0004$, $\beta_{13}=0.0003$, $\beta_{14}=0.0002$, $\beta_{15}=0.0002$, $\beta_{16}=0.0001$, $\beta_{17}=0.0001$, $\beta_{18}=0.0001$, $\sigma=0.7$. The results are given in Table 3-16:

Table 3-16. Estimation of six-lag model for 1965:01-1985:12.

Variable	1965:01-1985:12	
	Coefficient	Stand. Error
Constant	0.1224854823	0.052825
ΔIP_{t-1}	0.3373071037	0.060820
ΔIP_{t-2}	0.1225066619	0.064028
ΔIP_{t-3}	0.0991389669	0.064597
ΔIP_{t-4}	0.0883211161	0.064200
ΔIP_{t-5}	-0.1194246180	0.064167
ΔIP_{t-6}	0.0197645247	0.060477
ΔWTI_{t-1}	-0.0038994430	0.018512
ΔWTI_{t-2}	-0.0008926408	0.020460

ΔWTI_{t-3}	-0.0010885073	0.005107
ΔWTI_{t-4}	0.0012095745	0.016613
ΔWTI_{t-5}	-0.0026110241	0.005101
ΔWTI_{t-6}	-0.0017099974	0.005083
$\delta_1 * \Delta WTI_{t-1}$	-0.0196017394	0.019735
$\delta_2 * \Delta WTI_{t-2}$	-0.0406093136	0.021122
$\delta_3 * \Delta WTI_{t-3}$	0.0056414623	0.018157
$\delta_4 * \Delta WTI_{t-4}$	-0.0055873375	0.017388
$\delta_5 * \Delta WTI_{t-5}$	0.0037551606	0.018546
$\delta_6 * \Delta WTI_{t-6}$	0.0150579561	0.022209

Source: Author's estimation based on FRED®
-2 log L: 566.0505

A serial correlation test found no evidence of serial correlation in the residuals. Next, the re-parameterized model is estimated with the starting values as above for the corresponding coefficients. These results are summarized in Table 3-17.

Table 3-17. Estimation of re-parameterized six-lag model for 1965:01-1985:12.

Variable	19865:01-2008:12	
	Coefficient	Stand. Error
Constant	0.1191356887	0.058145835
ΔIP_{t-1}	0.3736604828	0.063369943
ΔIP_{t-2}	0.0787262780	0.064163834
ΔIP_{t-3}	0.1143969428	0.048219751
ΔIP_{t-4}	0.0847059208	0.063291644
ΔIP_{t-5}	-0.1537311778	0.067154307
ΔIP_{t-6}	0.0451309603	0.062129066
$(1-\delta_1) * \Delta WTI_{t-1}$	-0.0042137348	0.005447806
$(1-\delta_2) * \Delta WTI_{t-2}$	-0.0003869267	0.005394698
$(1-\delta_3) * \Delta WTI_{t-3}$	-0.0016252999	0.005376315
$(1-\delta_4) * \Delta WTI_{t-4}$	0.0026761864	0.005101299
$(1-\delta_5) * \Delta WTI_{t-5}$	-0.0043818485	0.005190657
$(1-\delta_6) * \Delta WTI_{t-6}$	0.0002356526	0.005384323

Source: Author's estimation based on FRED®
-2 log L: 570.6402

The log-likelihood ratio-test for $\beta_7 + \beta_{13} = 0$, $\beta_8 + \beta_{14} = 0$, $\beta_9 + \beta_{15} = 0$, $\beta_{10} + \beta_{16} = 0$, $\beta_{11} + \beta_{17} = 0$, $\beta_{12} + \beta_{18} = 0$ indicates that the null hypothesis cannot be rejected as the change in *-2 log L* is *4.5897* and the critical value is 12.6 for $\chi^2(6)$.

Finally a VAR model for this period is estimated using the same starting values as above. The results of this regression are summarized in Table 3-18.

Table 3-18. Estimation of six-lag VAR model for 1965:01-1985:12.

Variable	1965:01-1985:12	
	Coefficient	Stand. Error
Constant	0.1200566	0.054673717
ΔIP_{t-1}	0.3736911	0.063250052
ΔIP_{t-2}	0.0774900	0.064742608
ΔIP_{t-3}	0.1147598	0.063250421
ΔIP_{t-4}	0.0850828	0.063301283
ΔIP_{t-5}	-0.1496465	0.063289286
ΔIP_{t-6}	0.04268538	0.060702367
ΔWTI_{t-1}	-0.00478286	0.005277733
ΔWTI_{t-2}	-0.00157300	0.005225423
ΔWTI_{t-3}	-0.00023542	0.005226971
ΔWTI_{t-4}	0.00151368	0.005221474
ΔWTI_{t-5}	-0.00358460	0.005197560
ΔWTI_{t-6}	0.00004845	0.005253051

Source: Author's estimation based on FRED®
-2 log L: 570.7616

These results show that the coefficients on oil prices are insignificant and mostly negative, which is similar to the results of the proposed model. We conduct the log likelihood ratio test as we have done above. The difference in *-2 log L* for the unrestricted model and VAR model is 4.71, the critical value for Chi-square distribution with six degrees of freedom at a 95 percent confidence interval is 12.59 which results in failing to reject the null hypothesis.

3.4.2. The 1986 – 2008 Time Period for the model with more lags.

Following the idea above, a six-lag model for the data starting January 1986 is estimated with the same starting values as used in the above estimation for the period of 1965:01-2008:12. The results are given in Table 3-19.

Table 3-19. Estimation of six-lag model for 1986:01-2008:12.

Variable	1986:01-2008:12	
	Coefficient	Stand. Error
Constant	0.090966984	0.0019218337
ΔIP_{t-1}	0.207886449	0.0046127934
ΔIP_{t-2}	0.151878132	0.0470061
ΔIP_{t-3}	0.111975913	0.0480525
ΔIP_{t-4}	0.070092604	0.0031100159
ΔIP_{t-5}	0.061881575	0.0008355041
ΔIP_{t-6}	0.048616566	0.0021127776
ΔWTI_{t-1}	0.006590565	0.0018719968
ΔWTI_{t-2}	-0.005843246	0.0011467036
ΔWTI_{t-3}	-0.012953600	0.0012828147
ΔWTI_{t-4}	0.002939927	0.0016722697
ΔWTI_{t-5}	-0.005950301	0.0002130640
ΔWTI_{t-6}	-0.007312358	0.0013245293
$\delta_1 * \Delta WTI_{t-1}$	-0.003950577	0.0024570773
$\delta_2 * \Delta WTI_{t-2}$	0.006724587	0.0014740413
$\delta_3 * \Delta WTI_{t-3}$	0.015052815	0.0019603179
$\delta_4 * \Delta WTI_{t-4}$	0.001369849	0.0094665
$\delta_5 * \Delta WTI_{t-5}$	0.015748060	0.0024381541
$\delta_6 * \Delta WTI_{t-6}$	0.007104880	0.0012893787

Source: Author's estimation based on FRED®
-2 log L: 493.4085

A serial correlation test found no evidence of serial correlation in the residuals.

A re-parameterized model for the period starting from January 1986 with the same starting values as in the previous models is also estimated. These results are given in Table 3-20.

Table 3-20. Estimation of re-parameterized six-lag model for 1986:01-2008:12.

Variable	19865:01-2008:12	
	Coefficient	Stand. Error
Constant	0.0591139648	0.039492088
ΔIP_{t-1}	-0.0160099435	0.059252415
ΔIP_{t-2}	0.1669894316	0.061308650
ΔIP_{t-3}	0.1862958677	0.060504004
ΔIP_{t-4}	0.1356336951	0.063854653

ΔIP_{t-5}	0.1683444128	0.065747521
ΔIP_{t-6}	0.0772350675	0.054410
$(1-\delta_1)^* \Delta WTI_{t-1}$	0.0005903655	0.004985
$(1-\delta_2)^* \Delta WTI_{t-2}$	-0.0030014309	0.002688007
$(1-\delta_3)^* \Delta WTI_{t-3}$	-0.0142945360	0.002975336
$(1-\delta_4)^* \Delta WTI_{t-4}$	-0.0095372446	0.005709665
$(1-\delta_5)^* \Delta WTI_{t-5}$	-0.0032441385	0.002914384
$(1-\delta_6)^* \Delta WTI_{t-6}$	-0.0131238927	0.002413302

Source: Author's estimation based on FRED®
-2 log L: 466.6608

The log-likelihood ratio test for $\beta_7 + \beta_{13} = 0$, $\beta_8 + \beta_{14} = 0$, $\beta_9 + \beta_{15} = 0$, $\beta_{10} + \beta_{16} = 0$, $\beta_{11} + \beta_{17} = 0$, $\beta_{12} + \beta_{18} = 0$ does reject the null hypothesis (difference in *-2 log L* is 26.7477) as the critical value for the Chi-square distribution with six degrees of freedom is 12.6. In both estimations for the baseline model and the model with added lags the coefficients on oil prices are significant. This is consistent with the idea that the deregulation of crude oil during the economic recession that started after the 1979 energy crisis ended the dominance of OPEC in the oil market[16]. The sum of coefficients on the ΔWTI terms is -2.255, so that oil shocks not representing oil demand shocks have a negative effect on *IP* growth. The sum of coefficients on the $\delta^*\Delta WTI$ terms is 4.202. Oil shocks that correspond to increases in the demand for oil are associated with faster *IP* growth.

Once again testing for structural break in 1986, we sum the the values for *-2 log L* for the two subsamples and compare it with the value of *-2 log L* from the full sample. The value of *-2 log L* for the full sample is 1089.548, for the period of 1965:01-1985:12 is 566.0505 and for 1986:01-2008:12 is 493.4085. The sum of *-2 log L* for two subsamples is 1059.459. The difference in *-2 log L* between the full sample and the sum of the subsamples is *30.089*. The null hypothesis is rejected as the critical value for Chi-square distribution is *28.97* at 95 percent confidence level, so we do find a structural break.

For comparison, a VAR model from Hamilton (1983) is estimated. The results are summarized in Table 3-21.

[16] http://www.wtrg.com/opecshare.html

Table 3-21. Estimation of six-lag VAR model for 1986:01-2008:12.

Variable	1986:01-2008:12	
	Coefficient	Stand. Error
Constant	0.0238317649	0.039444558
ΔIP_{t-1}	-0.0134380407	0.060038732
ΔIP_{t-2}	0.1558019279	0.061259113
ΔIP_{t-3}	0.2395313564	0.062311831
ΔIP_{t-4}	0.1821057646	0.062723033
ΔIP_{t-5}	0.1528340844	0.065980664
ΔIP_{t-6}	0.0678180539	0.068992693
ΔWTI_{t-1}	0.0075247939	0.004083446
ΔWTI_{t-2}	-0.0003759956	0.004293662
ΔWTI_{t-3}	-0.0067452323	0.004342942
ΔWTI_{t-4}	-0.0022175855	0.004380736
ΔWTI_{t-5}	-0.0037211813	0.004401158
ΔWTI_{t-6}	-0.0036466621	0.004259467

Source: Author's estimation based on FRED®
-2 log L: 466.7973

We do another log-likelihood ratio test. The change in *-2 log L* for the unrestricted model and VAR model is 26.61. At 95 percent confidence interval the critical value for Chi square distribution with six degrees of freedom is 12.59 and we reject the null hypothesis. Most of the coefficients on lags of ΔWTI are negative indicating an overall negative effect, but in our new model, the coefficients on the $\delta\Delta WTI$ are positive. This provides very strong support for the proposed model.

Again, for comparison purposes I plot the forecasts for 2007 and 2008 based on the results of the proposed model and Hamilton's VAR model based on the estimations of six-lag models.

Figure 3-3. Forecast for 2007. (points: Observed data; bold line: Proposed model; thin line: Hamilton's VAR model)

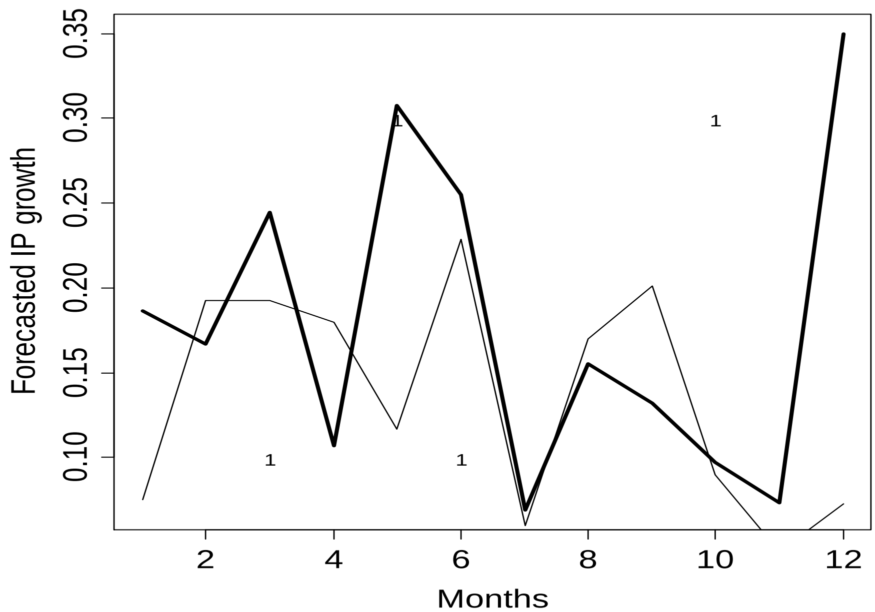
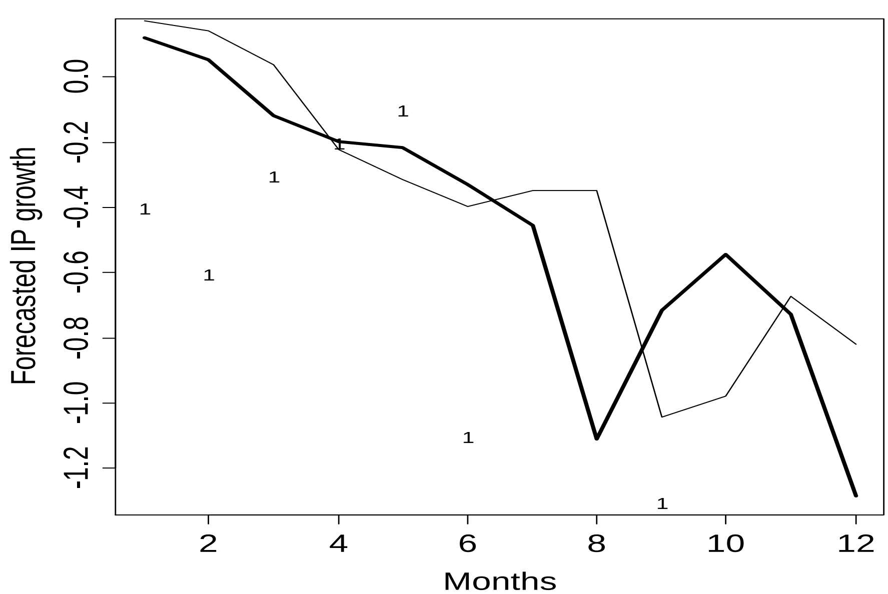


Figure 3-4. Forecast for 2008. (points: Observed data; bold line: Proposed model; thin line: Hamilton's VAR model)



Source: Author's estimation based on FRED®

Figures 3.3-3.4 show the difference in forecasts when using Hamilton's VAR model and when using the model proposed in this thesis with six lags. For comparison, the observed data also plotted. On the vertical axis there is the growth rate of *IP*, and on the horizontal axis - months. The forecasts for the growth rate of *IP* in May and December of 2007, October 2008 were much higher with my model, while the forecast for August and December of 2008 was much lower.

3.5. Out-of-Sample Forecasts.

Next, we look at out-of-sample forecasts for the period of 1986:01-2008:12 based on the model we have developed. A rolling regression algorithm is followed where a sequence of one-step-ahead forecast is generated. The algorithm works as follows. First, we estimate the following model by ordinary least squares for the period of 1965:01-1985:12:

$$\Delta IP_t = \beta_0 + \beta_1 \Delta IP_{t-1} + \beta_2 \Delta WTI_{t-1} + \varepsilon_t,$$

After getting the residuals from this estimation, we use it to define δ as a dummy variable equal to 1 if $\varepsilon_{t-1}\Delta WTI_{t-1} > 0$ and 0 otherwise. Next the model developed in this paper is estimated:

$$\Delta IP_t = \beta_0 + \beta_1 \Delta IP_{t-1} + \beta_2 \Delta WTI_{t-1} + \beta_3 \delta \Delta WTI_{t-1} + \varepsilon_t ,$$

and a one-step-ahead forecast for 1986:01 is obtained. This process is repeated with an additional observation to obtain the forecast for 1986:02. The process is repeated until there are 276 one-step-ahead forecasts through 2008:12. A forecast summary is provided in Table 3-22.

Table 3-22. Forecast Summary Statistics (1986:01-2008:12).

Model	Mean-square error	Mean-absolute error
AR Model	0.3898748	0.4411839
Hamilton’s VAR Model	0.3927839	0.4410397
Model of this paper	0.5341558	0.5236597

Source: Author’s estimation based on FRED®

Next, one-step-ahead forecasts for the period of 1997:01-2008:12 are obtained following a similar routine as above, but using only data after January 1986. The one-step-ahead forecast summary statistics are presented in Table 3-23.

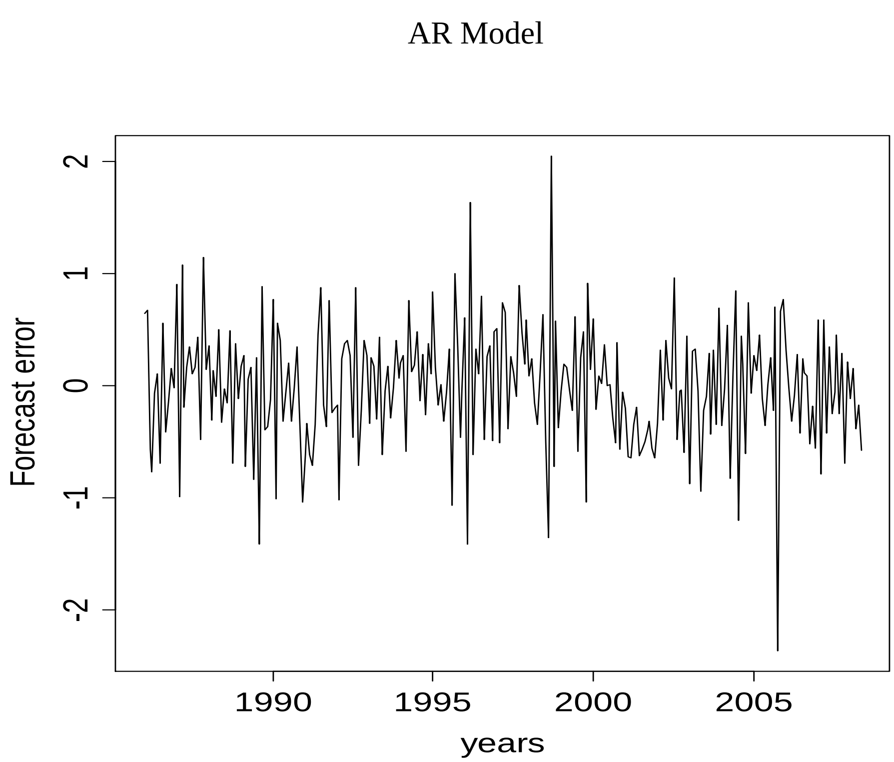
Table 3-23. Forecast Summary Statistics (1997:01-2008:12).

Model	Mean-square error	Mean-absolute error
AR Model	0.4185067	0.4555182
Hamilton's VAR Model	0.4097793	0.4535093
Model of this paper	0.5899985	0.5527983

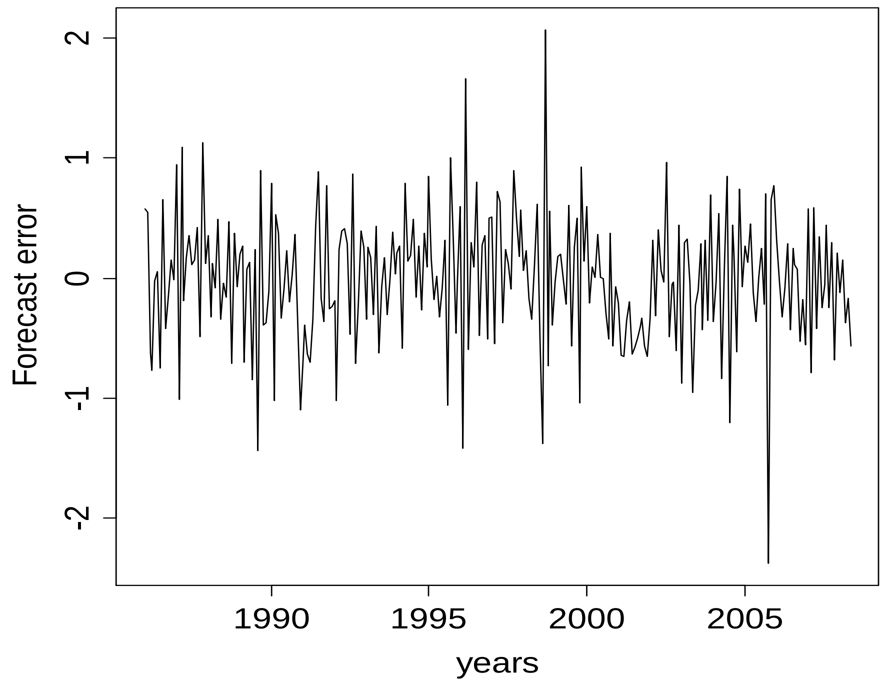
Source: Author's estimation based on FRED®

As the table illustrates, the model developed in this thesis does not do a better job than the autoregressive model or the VAR model. The reason for this is that apparently adding additional terms will add noise to the estimation, so that the model does not forecast well. I have plotted the forecast errors to make sure these results are not driven by outliers. We do not see any big outliers.

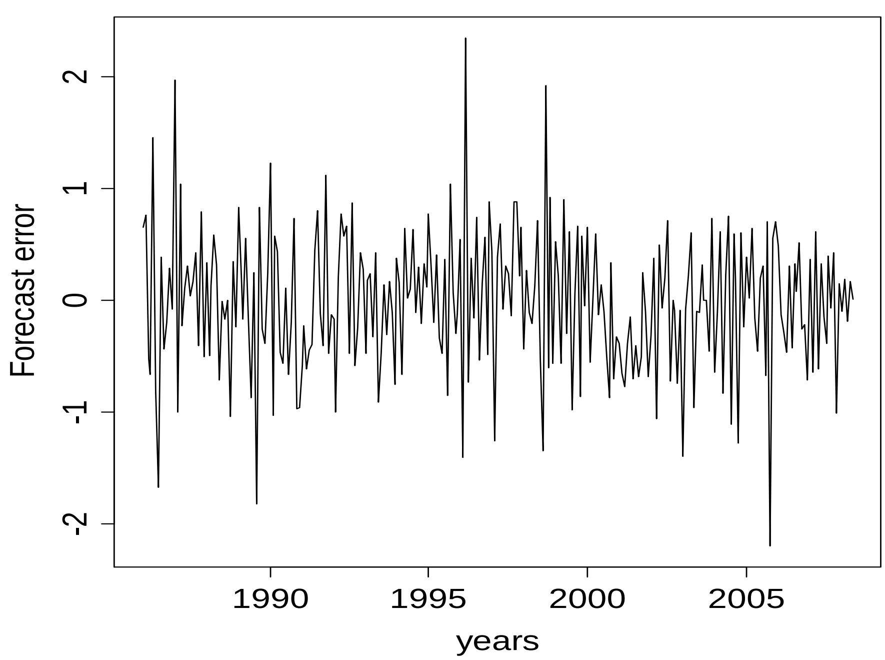
Figure 3-5. The forecast errors through time for AR, VAR and my model.



VAR Model



Proposed model.



Source: Author’s estimation based on FRED®

CHAPTER 4 - CONCLUSIONS

Based on the analysis described here, the following conclusions are made. Oil price changes are not strong predictors of future Industrial Production or GDP changes for the full sample period of 1965:01-2008:12. Nor do they enter the estimation significantly for the sample period of 1965:01-1985:12. However, there is strong support for the model developed in this thesis from the estimations for the sample period of 1986:01-2008:12.

In this later period it was shown that there is a positive correlation between oil price changes and industrial production changes. This supports the idea that oil price movements are endogenous. Second, the model developed in this thesis picks up some important periods when endogeneity of oil prices is most important.

Additionally, the estimations of the VAR model developed by Hamilton with the monthly data on *IP* and *WTI* give mostly negative coefficients for the oil price changes. But the estimations of the model in this thesis gives positive coefficients when our model defines the oil shock as primarily a shock to the demand for oil.

Out-of sample forecasts for the 1986:01-2008:12 and 1997:01-2008:12 time periods are not better than Autoregressive (AR) or Vector Autoregressive (VAR) models, most plausibly a result of the difficulty of estimating the parameters of a non-linear model accurately.

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Appendix A - Estimations using GDP

To compare the results we get estimating with *IP* I estimate the baseline model using *GDP* series from FRED®. The data on *GDP* is quarterly based. I transform the data for *WTI* into quarterly average. The starting values are: $\beta_0=0.7$, $\beta_1=0.22$, $\beta_2=-0.09$, $\beta_3=0.03$, $\sigma=0.7$.

Table A-1. Estimation of baseline model with GDP.

Variable	1965:01-2008:12	
	Coefficient	Stand. Error
Constant	1.076891901	0.15135473
ΔGDP_{t-1}	0.383042864	0.07450191
ΔWTI_{t-1}	0.001121007	0.01515925
$\delta * \Delta WTI_{t-1}$	0.006017940	0.01858075

Source: Author's estimation based on FRED®
-2 log L: 454.4227

I re-parameterized the model as above and the starting values are the same.

Table A-2. Estimation of re-parameterized baseline model with GDP.

Variable	1965:01-2008:12	
	Coefficients	Stand. Error
Constant	1.062476406	0.15006631
ΔGDP_{t-1}	0.390731889	0.07373145
$(1-\delta) * \Delta WTI_{t-1}$	-0.001324307	0.01512814

Source: Author's estimation based on FRED®
-2 log L: 454.5472

The test for $\beta_2 + \beta_3 = 0$ shows that the null hypothesis cannot be rejected, as the change in *-2 log L* is 0.1245 and the critical value for $\chi^2(1)$ is 3.84. This result is similar to the results of the estimation with *IP*.

The starting values are the same as above in the following estimation:

Table A-3. Estimation of baseline model with GDP for the period 1965:01-1985:12.

Variable	1965:01-1985:12	
	Coefficient	Stand. Error
Constant	1.843620079	0.27745026
ΔGDP_{t-1}	0.180643507	0.11332876
ΔWTI_{t-1}	0.008373675	0.02261202
$\delta^* \Delta WTI_{t-1}$	-0.042442795	0.05713635

Source: Author's estimation based on FRED®
-2 log L: 242.4513

One can see that in this estimation also oil price changes are not strong predictor of future *GDP* for this period.

Table A-4. Estimation of re-parameterized baseline model with GDP.

Variable	1965:01-1985:12	
	Coefficients	Stand. Error
Constant	1.885405744	0.27164148
ΔGDP_{t-1}	0.158035098	0.10865134
$(1-\delta)^* \Delta WTI_{t-1}$	-0.006956248	0.02250629

Source: Author's estimation based on FRED®
-2 log L: 242.9096

As the difference in *-2 log L* is equal to 0.4583 and the critical value for Chi-square distribution with one degree freedom is 3.84, the null hypothesis of $\beta_2 + \beta_3 = 0$ cannot be rejected.

The starting values are $\beta_0=1.1, \beta_1=0.3, \beta_2=0.05, \beta_3=0.05, \sigma=0.7$:

Table A-5. Estimation of baseline model with GDP for the period 1986:01-2008:12.

Variable	1986:01-2008:12	
	Coefficient	Stand. Error
Constant	0.950115714	0.175381310
ΔGDP_{t-1}	0.274031917	0.123294534
ΔWTI_{t-1}	-0.006790596	0.007727742
$\delta^* \Delta WTI_{t-1}$	0.006448612	0.008906200

Source: Author's estimation based on FRED®
-2 log L: 144.9896

Contrary to the results above, the coefficients on oil price terms are insignificant. I estimate the re-parameterized model in the same manner as above with the starting values: $\beta_0=0.3, \beta_1=0.22, \beta_2=-0.009, \sigma=0.7$:

Table A-6. Estimation of re-parameterized baseline model with GDP.

Variable	1986:01-2008:12	
	Coefficients	Stand. Error
Constant	0.8534714798	0.17991408
ΔGDP_{t-1}	0.3389496113	0.12639329
$(1-\delta)*\Delta WTI_{t-1}$	0.0001160034	0.01265562

Source: Author's estimation based on FRED®
-2 log L: 144.8575

The log-likelihood ratio test shows the null hypothesis of $\beta_2 + \beta_3 = 0$ cannot be rejected (The difference in -2 log L is 0.1321, critical value is 3.84). It is contrary to the results for our first model estimated for the period starting from 1986. Apparently, estimating the model with quarterly GDP data makes the estimation results very imprecise.

The starting values for this estimation are: $\beta_0=0.1$, $\beta_1=0.22$, $\beta_2=0.15$, $\beta_3=0.11$, $\beta_4=0.07$, $\beta_5=0.0001$, $\beta_6=-0.0001$, $\beta_7=-0.0003$, $\beta_8=-0.0003$, $\beta_9=0.0003$, $\beta_{10}=0.0002$, $\beta_{11}=0.0002$, $\beta_{12}=0.0001$, $\sigma=0.7$.

Table A-7. Estimation of four-lag model with GDP for 1965:01-2008:12.

Variable	1965:01-2008:12	
	Coefficient	Stand. Error
Constant	0.7045544395	0.20323180
ΔIP_{t-1}	0.2689371340	0.07665350
ΔIP_{t-2}	0.1685630706	0.07911671
ΔIP_{t-3}	0.0108893224	0.07896392
ΔIP_{t-4}	0.1670373926	0.07680083
ΔWTI_{t-1}	-0.0275667971	0.02504435
ΔWTI_{t-2}	0.0023047281	0.02690335
ΔWTI_{t-3}	-0.0367687185	0.02709374
ΔWTI_{t-4}	-0.0063043921	0.02982904
$\delta_1*\Delta WTI_{t-1}$	0.0270055814	0.02564732
$\delta_2*\Delta WTI_{t-2}$	-0.0047769305	0.02745186
$\delta_3*\Delta WTI_{t-3}$	0.0378309540	0.02766629
$\delta_4*\Delta WTI_{t-4}$	0.0002422517	0.03034268

Source: Author's estimation based on FRED®
-2 log L: 432.1916

We do not see much difference in this table from previous results, almost all the coefficients are insignificant. Next, following the same idea as above, the re-parameterized model is estimated with the starting values of β_0=0.5, β_1=0.4, β_2=0.3, β_3=0.2, β_4=0.07, β_5=-0.01, β_6=-0.01, β_7=-0.03, β_8=-0.003, σ =0.7.

Table A-8. Estimation of re-parameterized four-lag model with GDP.

Variable	1965:01-2008:12	
	Coefficient	Stand. Error
Constant	0.686632899	0.20093643
ΔIP_{t-1}	0.268092148	0.07685841
ΔIP_{t-2}	0.170919163	0.07922046
ΔIP_{t-3}	0.014332510	0.07905300
ΔIP_{t-4}	0.167411555	0.07681255
$(1-\delta_1)^* \Delta WTI_{t-1}$	-0.027569069	0.02510987
$(1-\delta_2)^* \Delta WTI_{t-2}$	0.003197445	0.02696598
$(1-\delta_3)^* \Delta WTI_{t-3}$	-0.036115918	0.02716073
$(1-\delta_4)^* \Delta WTI_{t-4}$	-0.005544991	0.02988888

Source: Author's estimation based on FRED®
-2 log L: 433.3571

Again, I test the null hypothesis of $\beta_5 + \beta_9 = 0$, $\beta_6 + \beta_{10} = 0$, $\beta_7 + \beta_{11} = 0$, $\beta_8 + \beta_{12} = 0$. The null hypothesis cannot be rejected as the change in *2 log L* is 1.1655 and the critical value for Chi-square distribution with four degrees of freedom is 9.49. I find that the results of this table are also consistent with the insignificant coefficients on oil price changes obtained for this period from the estimations of other models.

The starting values: β_0=0.1, β_1=0.22, β_2=0.15, β_3=0.11, β_4=0.07, β_5=-0.0001, β_6=-0.0001, β_7=-0.0003, β_8=-0.0003, β_9=0.0003, β_{10}=0.0002, β_{11}=0.0002, β_{12}=0.0001, σ =0.7.

Table A-9. Estimation of four-lag model with GDP for 1965:01-1985:12.

Variable	1965:01-1985:12	
	Coefficient	Stand. Error
Constant	0.79155877	0.0748783826
ΔIP_{t-1}	0.27987586	0.0748659199
ΔIP_{t-2}	0.01748425	0.0003321794
ΔIP_{t-3}	0.06812956	0.0005655150
ΔIP_{t-4}	0.19531281	0.0004583347
ΔWTI_{t-1}	0.01600967	0.2649813562
ΔWTI_{t-2}	0.71768942	0.2251993196
ΔWTI_{t-3}	-0.42242888	0.2503371992
ΔWTI_{t-4}	0.73405126	0.2027547889

$\delta_1 * \Delta WTI_{t-1}$	0.07593452	0.2805390846
$\delta_2 * \Delta WTI_{t-2}$	0.64708715	0.2511101494
$\delta_3 * \Delta WTI_{t-3}$	0.56898904	0.2820054098
$\delta_4 * \Delta WTI_{t-4}$	-0.60170864	0.2387158665

Source: Author's estimation based on FRED®
-2 log L: 222.7391

The starting values for the re-parameterized model estimation are: $\beta_0=0.5$, $\beta_1=0.4$, $\beta_2=0.3$, $\beta_3=0.2$, $\beta_4=0.07$, $\beta_5=-0.01$, $\beta_6=-0.01$, $\beta_7=-0.03$, $\beta_8=-0.003$, $\sigma=0.7$.

Table A-10. Estimation of re-parameterized four-lag model with GDP.

Variable	1965:01-1985:12	
	Coefficient	Stand. Error
Constant	1.59774454	0.43665176
ΔIP_{t-1}	0.14101815	0.10729578
ΔIP_{t-2}	0.04419158	0.10754794
ΔIP_{t-3}	-0.01596512	0.10470179
ΔIP_{t-4}	0.08692415	0.10818377
$(1-\delta_1) * \Delta WTI_{t-1}$	0.03395966	0.12110867
$(1-\delta_2) * \Delta WTI_{t-2}$	0.27143499	0.11655012
$(1-\delta_3) * \Delta WTI_{t-3}$	0.04950155	0.11966423
$(1-\delta_4) * \Delta WTI_{t-4}$	0.19593095	0.11955697

Source: Author's estimation based on FRED®
-2 log L: 232.9296

I conduct the log-likelihood ratio test of $\beta_5 + \beta_9 = 0$, $\beta_6 + \beta_{10} = 0$, $\beta_7 + \beta_{11} = 0$, $\beta_8 + \beta_{12} = 0$. As the change in *-2 log L* is 10.19 and the critical value of the Chi-square distribution for 4 degrees freedom is 9.49. The null hypothesis is rejected.

With the starting values of $\beta_0=0.4$, $\beta_1=0.27$, $\beta_2=0.17$, $\beta_3=0.3$, $\beta_4=0.07$, $\beta_5=0.005$, $\beta_6=-0.005$, $\beta_7=-0.003$, $\beta_8=-0.002$, $\beta_9=0.001$, $\beta_{10}=0.001$, $\beta_{11}=0.0003$, $\beta_{12}=0.001$, $\sigma=0.7$ I estimate the model adding four lags of each variable using *GDP*.

Table A-11. Estimation of four-lag model with GDP for 1986:01-2008:12.

Variable	1986:01-2008:12	
	Coefficient	Stand. Error
Constant	0.3578665133	0.011889524
ΔIP_{t-1}	0.2197492729	0.142789100
ΔIP_{t-2}	0.1228655769	0.133490737
ΔIP_{t-3}	0.2368562463	0.134669473
ΔIP_{t-4}	0.0272757287	0.001225798

ΔWTI_{t-1}	-0.0043143627	0.00349946
ΔWTI_{t-2}	-0.0138352016	0.003430289
ΔWTI_{t-3}	-0.0059355372	0.001214377
ΔWTI_{t-4}	0.0034761803	0.003251173
$\delta_1*\Delta WTI_{t-1}$	0.0200695667	0.005378276
$\delta_2*\Delta WTI_{t-2}$	0.0256951058	0.004848334
$\delta_3*\Delta WTI_{t-3}$	-0.0009181989	0.009986062
$\delta_4*\Delta WTI_{t-4}$	0.0233309296	0.007881204

Source: Author's estimation based on FRED®
-2 log L: 145.9177

I estimate the re-parameterized model for this time period. The starting values are as follows: $\beta_0=0.4$, $\beta_1=0.27$, $\beta_2=0.17$, $\beta_3=0.3$, $\beta_4=0.07$, $\beta_5=0.005$, $\beta_6=-0.005$, $\beta_7=-0.003$, $\beta_8=-0.002$, $\sigma=0.7$.

Table A-12. Estimation of re-parameterized four-lag model with GDP for 1986:01-2008:12.

Variable	1986:01-2008:12	
	Coefficient	Stand. Error
Constant	0.392446549	0.0020509707
ΔIP_{t-1}	0.314253721	0.0020471331
ΔIP_{t-2}	0.149236954	0.0020452611
ΔIP_{t-3}	-0.041257989	0.0020557064
ΔIP_{t-4}	0.225960625	0.0023503788
$(1-\delta_1)*\Delta WTI_{t-1}$	0.001528599	0.0034811928
$(1-\delta_2)*\Delta WTI_{t-2}$	-0.013632397	0.0006659228
$(1-\delta_3)*\Delta WTI_{t-3}$	-0.005376011	0.0108297293
$(1-\delta_4)*\Delta WTI_{t-4}$	0.006418259	0.0118653674

Source: Author's estimation based on FRED®
-2 log L: 131.1363

In the same manner as above, the test of $\beta_5 + \beta_9 = 0$, $\beta_6 + \beta_{10} = 0$, $\beta_7 + \beta_{11} = 0$, $\beta_8 + \beta_{12} = 0$ is conducted. *-2 log L* changes by 14.7814 and the critical value for $\chi^2(4)$ is 9.49. Therefore, the null hypothesis is rejected. My new model is informative even with quarterly GDP data.