

Oil Prices and Real-Time Output Growth[†]

Working Paper

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February 5, 2010

Abstract

Research has shown that oil price shocks help forecast subsequent real Gross Domestic Product (GDP) growth. This research, however, uses revised data which contains information unavailable to the forecaster at the time of analysis and does not provide an operational model for predicting GDP growth. This paper utilizes real-time data as the dependent variable and determines if previous model specifications are supported empirically. We order real-time GDP growth first and oil prices second in a recursively identified bivariate structural vector autoregression (VAR) model. The results are supportive of the relationship of GDP and oil in the context of Granger causality with real-time data. Using different releases of GDP growth estimates and net oil price changes, we predict the economy is changing direction earlier than would be predicted by solely using initial GDP releases. Given that we can predict GDP growth better with oil prices, the previous analysis of the relationship between the two variables is verified and creates an operational model. The model provides compelling evidence of negative GDP growth predictability in response to oil price shocks, which could shorten the “recognition lag” for successful implementation of discretionary counter-cyclical policies.

Keywords: Oil Price, Energy, Real-Time Data, GDP Forecasting

JEL Classification: E37, E66, Q43

[†] I thank David Papell for encouragement and guidance, and Chris Murray, Sebnem Kalemli-Ozcan, Bent Sorensen, Peter Hartley, and Kenneth Medlock for helpful comments and discussions. All remaining errors are my own.

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Introduction

The world financial system has recently been buffeted by a series of heart-stopping events: an oil price peak and plunge, the U.S. subprime mortgage crisis, a systematic credit crunch, a synchronous global economic downturn, a record-setting fiscal stimulus package and unconventional quantitative easing policies. The response from fiscal and monetary authorities rely heavily gross domestic product (GDP) to determine policy implementation. Unfortunately, these policy decisions are based on imperfect estimates of GDP, particularly after shocks to the economy.

Historically, abrupt oil price increases have coincided with slower economic growth. Since World War II, 10 of the past 11 recessions have been preceded by sharp increases in oil prices. Empirical studies have found that economic growth is impacted by abrupt increases in the price of oil. When oil prices peak at a level greater than the previous 3-years, we can identify this event as an “oil price shock”.¹

Economic theory suggests that the real effect of an oil price increase depends on its underlying fundamentals. If the price increase stems from a change in supply the resulting price increase depresses economic activity, as energy inputs are more expensive. Examples of oil supply shocks are the 1973-74 oil embargoes by OPEC, the Iranian Revolution in 1978, the Iran-Iraq War in 1980, and the First Persian Gulf War of 1990. Each of these events was followed by a global economic recession after the abrupt rise in oil prices stemming from a supply shock. Hamilton (2009) supports the conventional interpretation: historical oil price shocks were primarily caused by significant disruptions in crude production that were brought about by largely geopolitical events.

When oil prices rise due to a demand shock rather than a supply shock, the effects on the economy are different. If higher oil prices stem from increased demand by emerging countries, production in the U.S. is subject to both a negative effect from higher input costs and a positive effect from greater demand for U.S. goods and services by the growing emerging economies. For example, the 9.4% annual increase of global GDP over the two years of 2004 and 2005 increased the consumption of world petroleum by 5 million barrels creating a demand shock. The demand driven oil shock had a net positive effect in the U.S. because the benefits from increased demand outweighed the negative effect from increased input costs and inflation.

As long as potential disruptions exceed the amount of additional production capacity that can be brought online quickly geopolitical concerns will weigh heavily on oil markets. Actual supply disruptions directly affect world oil markets due to a loss of physical barrels available to the

¹ Hamilton(2003) pioneered this definition of an oil price shock.

market. The most significant of these recent disruptions to supply resulted from ongoing strife in the Middle East and Nigeria. High oil prices in 2006 were driven by tensions in the Middle East, home to nearly 80% of global oil resources. As a result, the fear of oil supply disruption due to geopolitical factors such as Iran's nuclear stand-off with the West and worsening secular violence in Iraq caused the price to jump to \$74.00 in July 2006. From February 2006 to November 2007, Nigeria, the world's eighth-largest oil exporter cut supplies because of militant attacks on the country's oil industry. Oil companies have detailed about 547,000 bbl/d of shut-in Nigerian production due to attacks and sabotage. In March 2008 Iraq lost more than 500,000 barrels per day of oil exports. A month later Nigeria lost more than 1.4 million barrels per day. Due to these additional supply shocks and increased uncertainty, oil prices jumped to \$147.27 a barrel on July 11, 2008, the highest nominal price ever recorded.

The current economic downturn resembles the pattern of the past to the extent that these oil price shocks in 2006-2008 coincide with a recession. The National Bureau Economic Research (NBER) dates the peak of economic activity to the fourth quarter of 2007 and the U.S. economy is now in a recession. The recession has been exacerbated by the credit weakness banks were suffering from mortgage backed securities.

Policymakers responded aggressively with twin initiatives while output and unemployment continued to decline into 2009. First, fiscal policymakers enacted the \$787 billion American Reinvestment and Recovery Act of 2009 (ARRA) stimulus package in February to quicken the pulse of the economy. Even more dramatically, monetary authorities pressed the target Federal Funds rate to effectively zero and unleashed quantitative measures, notably a \$1.25 trillion balance sheet expansion in March 2009. Currently, the effects of the ARRA fiscal stimulus and quantitative easing are taking longer than expected because the economy was in far worse shape than the policymakers inferred from imperfect estimates of GDP.

Many macroeconomic time series initial estimates are subject to data revision, especially for GDP. The estimates for quarterly GDP growth are revised multiple times as more information becomes available. For example, policymakers in January of 2009 thought the initial annualized quarterly GDP growth estimate for Q4 2008 was -3.8%. However, in March 2009, the estimate for Q4 2008 was revised downward from -3.8% to -6.3%. The stimulus has not been as effective because the policy decisions were based on higher initial estimates of GDP growth which were revised downward. Economists suggest the "recognition lag" of timely estimates could be a major impediment to the successful implementation of discretionary counter-cyclical policies. The problem of lagged information is particularly important around business cycle peaks or troughs, where there may be some evidence that economy is changing direction.

Currently, estimates for the economy are creating a debate among policymakers for the need of a second stimulus. For example, the economy has not stabilized with the U.S. unemployment rate hitting 9.5% in June 2009; the highest is nearly 26 years. The cost of the “recognition lag” for economic measures lowers the benefit from policy intervention. Therefore, policymakers would gain from more precise predictions of current and future GDP growth because their policy is reliant upon the pulse of the economy. An accurate calculation of the economy’s pulse allows for the policymakers to judge what dose of medicine is needed to bring the US economy back to health more quickly. The credibility of the policymaker is strengthened when decisions are based on better information of the economy’s health.

Improved information of a slowing economy could arise from the study of oil shocks. Since oil shocks and recessions coincide, the causal relationship can be tested to determine whether this correlation provides better estimates for policymakers. The causal nexus among oil prices and recessions is a well-documented and pervasive problem in contemporary macroeconomics. Numerous empirical studies investigate the causal relationship of oil price changes and the quantitative effects on revised estimates of GDP. Specifically, researchers use a bivariate linear regression with GDP growth as the dependent variable and the independent variable as lagged percent changes in oil. Hamilton (1983) finds the relation of quarterly symmetric oil price changes to GDP statistically significant from 1948:Q2 – 1980:Q3. The paper also establishes the link between dramatic oil price increases followed by slowing GDP growth three or four quarters later, suggesting a relationship that is not symmetric.

A linear (or symmetric) relationship between oil price changes and GDP growth would imply stimulation of growth when oil prices decline. However, when oil prices declined in the 1980’s economic growth was not stimulated. The failure of decreasing oil prices to stimulate economic growth implicitly suggests that after the 1980’s oil price increases are more important for the economy. The economy and the relationship positive oil price changes are investigated by Mork (1989) by including the collapse in the price of oil in 1986. Mork (1989) finds an asymmetric relationship of positive oil price changes and GDP growth.² The asymmetric quarterly changes are defined as the positive increase of quarterly changes of oil prices and the study verified Hamilton’s negative correlation between output growth and oil price increases. In fact, the correlation was even stronger than expected for oil price increases.

Numerous specifications of non-linear alternatives have produced different functional forms of oil price increases. The non-linear relation investigated by Hamilton(2003) utilizes a structural bivariate VAR model regressing each quarter’s growth on four lags of GDP growth and the net

² Mork(1989) confirms oil price declines have little effect on the economy.

oil price increase over three years. The functional form of the net oil price increase is the difference of the current quarter and the previous 3-year maximum of prices. The paper reports clear evidence of nonlinearity, consistent with earlier claims in the literature that oil price increases are much more important than oil price decreases. The functional form of net oil price increases over the previous three years does an adequate job of capturing the dynamic relationship between oil price shocks and revised real GDP growth.

Previous research has studied Granger causality among oil shocks and revised GDP estimates. Using the latest revised GDP estimate is the best way to evaluate the “true” relationship with oil shocks and GDP. However, revised GDP estimates are unavailable to either policymakers or market participants at the time and therefore cannot be used to evaluate the accuracy of forecasted GDP. An additional step towards forecasting reality is to construct forecasts of GDP using real-time GDP data that is available at the time of analysis. Real-time analysis provides an operational model to evaluate forecasts of GDP growth using oil shocks to determine if the “recognition lag” can be shortened for policy decisions.

This paper considers, measures and evaluates the effects of oil shocks in real-time on GDP growth forecasts for the United States. In particular, we study 3 vintages of GDP growth and two definitions of oil prices. The model is used extensively for determining the Granger causality relation between oil shocks and GDP growth from 1949 to 2009. Using the model from Hamilton (2003) model, we isolate the oil shock effect and forecast outcomes that actually affected real-time GDP growth. With the use of real-time data, we add to the previous literature by creating an operational model for forecasting GDP growth after these oil shock events.

We quantify the relationship of oil shocks and GDP growth in real-time. First, we observe real-time and revised data differences for GDP. Second, we inspect the relationship of real-time GDP and oil in the context of Granger causality. Third, we examine the out-of-sample predictive content with and without the inclusion of oil shocks. Fourth, we examine the results with real-time data of GDP and two different oil prices and evaluate our predictions compared to current economic events. Finally, we draw conclusions about the relationship of oil shocks and GDP growth for policy.

We discover that Granger causality of oil shocks and GDP is quantitatively supported by real-time data. In this regard, our findings are consistent with those of Hamilton (2003), although our approach is different by using real-time data. Regression estimates of the relation between oil shocks and real-time GDP suggest that oil shocks may substantially affect GDP growth. Specifically, different vintages of real-time GDP and oil shocks support in-sample predictive

content for Granger causality. The causal relationship between oil price shocks and GDP is verified and out-of-sample predictability of GDP is improved with real-time data vintages.

We find that different vintages of GDP data with oil shocks produce forecasts of negative GDP growth in 2008 without ever taking into account the financial crisis. Specifically, our forecasts indicate negative GDP growth of -1.4% for the second quarter of 2008. By predicting negative GDP a quarter earlier, in real-time with oil shocks, we shorten the “recognition lag” for policymakers of a slowing economy.

The largest negative impact resulting from the recent oil shock occurred in 2009. Our model indicates the most negative growth of the current recession occurred in the first quarter of 2009:Q1 at -4.3%. Our model predicts less negative GDP growth for the second quarter of 2009, suggesting the trough of the business cycle occurred in 2009:Q1. This result is congruent with information recently released by the BEA.³ For example, our model forecasts annualized quarterly growth for 2009:Q2 as -1.6%. Therefore, our model indicates the negative impact from the recent oil shock has ameliorated in the second quarter of 2009.⁴ Our prediction of GDP growth for 2009:Q3 is +2.6%, indicating the economy is recovering. This prediction, if correct, could provide information for policymakers that would assist in the debate among a second stimulus.

Although the current economic downturn is perceived as a result of the credit crisis, this recession is similar to past recessions because it is preceded by an oil supply shock. These oil shocks partially explain real-time GDP without including news of financial variables. Without including financial variables, we determine the proportion of GDP growth that our model predicts to the actual initial values. The initial GDP growth estimates average -5.9% over 2008:Q4 and 2009:Q1. For the same two quarters, our model predicts an average of -3.4% using real-time GDP data and oil shocks transformed from Crude PPI. These predictions from our model account for 57% of actual GDP estimates which is equivalent to the same percentage of crude oil imports for U.S. consumption.⁵ Without including oil shocks, the univariate model predicts average GDP growth of 2008:Q4 and 2009:Q1 is only 0.05% which gets the size and decimal point wrong.

³ The BEA released at 8:30 A.M. Friday, July 31st, 2009 that 2009:Q1 had been revised downward to -6.4% resulting in 2009:Q1 GDP growth more negative than 2008:Q4 estimates of -5.4%.

⁴ The BEA released at 8:30 A.M. Friday, July 31st, 2009 that the Advance estimate for was less negative at -1.0% for 2009:Q2 when compared to the previous quarter of -6.4% for 2009:Q1

⁵ The United States consumed 19.5 million barrels per day of petroleum products during 2008, making us the world’s largest petroleum consumer. Altogether, net imports of crude oil and petroleum products (imports minus exports) accounts for 57% of our total petroleum consumption in 2008.

See http://tonto.eia.doe.gov/energyexplained/index.cfm?page=oil_imports

Regardless of the myriad of economic and financial indicators, our simple bivariate model with real-time GDP and oil improves predictions of the economy's direction. Since our predictions show signs of recovery in 2009:Q3, the recent monetary and fiscal policy decisions appear to be effective as a panacea for our economic difficulties. Future decisions based on GDP forecasts that incorporate oil prices could shorten the "recognition lag" for successful implementation of discretionary counter-cyclical policies.

1. The Model

Our model for the relationship between y_t and o_t approximates the potential effects of percentage oil prices changes on real GDP growth. We regress each quarter's GDP growth (y_t) on a constant, four lags of GDP growth and four lags of the percent change in the nominal price of crude petroleum (o_{t-i}):

$$y_t = \alpha_0 + \sum_{i=1}^n \delta_i y_{t-i} + \sum_{i=1}^n \beta_i o_{t-i} + \varepsilon_t \quad (1.1.1)$$

Where y is the quarterly percent change in real GDP, o is the quarterly percent change in the oil price series, n is the number of lagged quarterly percent change variables, and ε is the indecently and identically distributed disturbance term. The disturbance or error term, defined as ε_t , is a random (stochastic) variable.

The econometric model in (1.1.1) hypothesizes that the dependent variable y_t (output) is linearly related to the explanatory variables of lagged y_t and lagged o_t but that the relationship between the two is not exact. The random error term is assumed to be normally distributed in order to conduct tests on the significance of the parameters. These assumptions of the classical regression model allow for Ordinary Least Squares method for estimation of the relationship among the two variables. The specification of lag length for our model is reliant upon the lag-length chosen by Hamilton (2003).

The two variables Hamilton (2003) considers are revised real GDP growth and oil price changes with four lags. We include oil prices and real-time real GDP growth in our model since our main objective is to create an operational model. Our model incorporates real-time GDP data in order to estimate our benchmark AR(4) model:

$$y_t^{real-time} = \alpha_0 + \delta_1 y_{t-1}^{real-time} + \delta_2 y_{t-2}^{real-time} + \delta_3 y_{t-3}^{real-time} + \delta_4 y_{t-4}^{real-time} + \varepsilon_t \quad (1.1.2)$$

Where $y_t^{real-time}$ denotes the real-time estimate of GDP growth and ε is the independent and identically distributed disturbance term. We use the benchmark model to compare the significance of the real-time estimates for the above univariate model to a bivariate model that includes oil prices.

The bivariate model is relevant for efforts to establish the conditional expectation of GDP growth on lagged GDP growth and lagged oil prices changes. When we include oil prices as an explanatory variable in our model, we can estimate the equation:

$$y_t^{real-time} = \alpha_0 + \delta_1 y_{t-1}^{real-time} + \delta_2 y_{t-2}^{real-time} + \delta_3 y_{t-3}^{real-time} + \delta_4 y_{t-4}^{real-time} + \beta_1 o_{t-1} + \beta_2 o_{t-2} + \beta_3 o_{t-3} + \beta_4 o_{t-4} + \varepsilon_t \quad (1.1.3)$$

Let o_t denote the percentage change of oil price transformations. The quarterly percentage change of GDP growth available to the forecaster at the time of analysis is denoted by $y_t^{real-time}$ and ε is the independent and identically distributed error term. We include four lags of each variable congruent with Hamilton (2003). Specifically, Hamilton (2003) found the coefficient on o_{t-4} to be negative and statistically significant at the 1% level. Since our model uses different GDP growth data, the signs and sizes of the variables may change over his sample period and an extended sample period when comparing the restricted and unrestricted models.

A comparison of the restricted and unrestricted linear regression models allow us to analyze the differences of real-time GDP estimates and oil shocks. The following two models are estimated:

$$\text{Model(1)} \quad y_t^{real-time} = \alpha_0 + \sum_{i=1}^4 \delta_i y_{t-i}^{real-time} + \varepsilon_t \quad (1.1.4)$$

$$\text{Model(2)} \quad y_t^{real-time} = \alpha_0 + \sum_{i=1}^4 \delta_i y_{t-i}^{real-time} + \sum_{i=1}^4 \beta_i o_{t-i} + \varepsilon_t \quad (1.1.5)$$

The variable $y_t^{real-time}$ represents the quarterly percentage change in real-time GDP growth and o_t represents the percentage change of oil prices. Let o_t denote the amount by which oil prices in quarter t exceed their value over a defined number of quarters. The first model represents a special case of the second model.

To assert a causal relationship between oil prices and GDP, we must find that Model(2) does a better job explaining y_t relative to Model(1). Our objective is to estimate the unknown parameters of each model to study the validity of the proposition in which oil shocks Granger cause real GDP growth. The estimation of the parameters allow us to determine if previous movements in oil prices help explain movements in GDP even in the presence of the lagged value of GDP.

The value of the additional explanatory content of o_t can be assessed by computing the *adjusted-R²* of the unrestricted regression and comparing it to that a univariate autoregression with four lagged dependent variables in (1.1.4). The comparison of the *adjusted-R²* from each

model will reveal whether GDP is explained better with the additional oil price change in real-time analysis. This analysis using real-time GDP data creates an operational model from Hamilton(2003) . The model provides a framework to evaluate the relationship of oil prices and GDP using various types of oil prices and real-time data.

2. Real-Time Data and Oil Shocks

GDP is one of the most comprehensive and closely watched economic statistics measuring aggregate output. Real Gross Domestic Product (GDP) is a macroeconomic measure of economic activity adjusted for price changes and inflation. To determine the health of the economy, economists and policymakers turn to National Income and Product Accounts (NIPA) produced by the Bureau of Economic Analysis (BEA). The NIPAs are a set of economic accounts that provide information on the value and compositions of GDP produced in the U.S. during a given period. It is the GDP data, and the forecaster's perceptions of the data, that determined how to set policy structured in the wake of oil shocks. The surprises, additions, and revisions of the data determined how they were interpreted and were conditioned on the release of GDP estimates from the BEA.

The BEA prepares three current quarterly vintages of GDP estimates in the following order: Advance, Preliminary, and Final. Specifically, the Advance estimate is released about a month after the previous quarter in January, April, July, and October. The Preliminary estimates for the quarter are released about two months after the quarter. The Final estimates are given three months after the quarter in March, June and December. The term "Final" is misleading due to the multiple revisions which will occur in the future. The BEA annually revises the preceding 3 years of GDP quarterly estimates during the month of July. After about 5 years, these annual revisions are superseded by comprehensive benchmark revisions that incorporate changes in definitions and classifications as well as methodological changes. The latest available revised estimates incorporate all the revisions made to the initial estimates of GDP.

The initial monthly estimates of quarterly GDP are not accurate estimates, and must be revised as new information is revealed through time. Data on about 25 percent of GDP, especially in the service sector, are not available for these monthly estimates. So these sectors of the economy are based on past trends and whatever data are available. For example, estimates for consumer spending on medical care, education, and welfare services are extrapolated using employment, hours, and earnings data for these services sectors from the Bureau of Labor Statistics. These extrapolations are revised as more complete data become available. The successive revisions can be significant, but the initial estimates provide a snapshot of the appearance of the economy's health.

2.1. Real-Time Data

The real-time datasets of GDP have been compiled for the United States by Croushore and Stark (2001) at the Federal Reserve Bank of Philadelphia Federal Reserve.⁶ The real-time datasets have a triangular format with the estimated quarterly dates on the vertical axis and the horizontal date contain the vintage date. The term vintage denotes the date for which we have data as they appeared in time. Because GDP data is not contemporaneously available, vintage dated are paired with the last available observations from the previous quarter. The revised data is constructed from the latest available 2009:Q1 vintage, or the last column, of the real-time dataset. The dataset provides the latest revised and the initial values of each vintage along the diagonal of the matrix which provides different approaches for modeling real-time GDP with lagged variables.

Three specifications of lagged real-time GDP data are considered in our model. The first specification referred to as “Diagonal” assumes that each of the diagonal initial releases is used as the dependent lagged variable to forecast the diagonal initial release of the next period. The second specification includes a vector of additional variables, includes the latest vintage sample data of the dependent variable which is pseudo-revised and is referred to as “Vintage” data to predict the next period initial release. We can use the Diagonal and Vintage specifications for Advance and Final estimates. The third specification uses the same dependent lagged variables which are in the last column of the matrix referred to as the latest “Revised” estimates.

For estimation of growth, we use quarterly non-seasonally adjusted real GDP estimates in levels. We calculate the percent changes from quarter to quarter levels for each estimate and vintage. Specifically, we use the Advance and Final estimates for the Diagonal and Vintage specifications. The Preliminary estimates are not included in the data set from the Philadelphia Federal Reserve because they are very similar to Final estimates. Therefore, we use Advance, Final, and latest Revised estimates for GDP. For Revised estimates, the lagged dependent variable does not change so a specification of Diagonal or Vintage is not needed. We use the following specifications of real-time estimates: (1) Advance Diagonal Estimates, (2) Advance Vintage Estimates, (3) Final Diagonal Estimates, (4) Final Vintage Estimates, and (5) Latest Revised Estimates. These five specifications of real-time GDP data provide the framework for our baseline model.

The GDP estimates are in real-time taken from a Survey of Current Business published by the BEA on a quarterly basis. For the latest estimate of GDP from the BEA, the real-time dataset

⁶ <http://www.philadelphiafed.org/research-and-data/real-time-center/real-time-data/data-files/>

from the Philadelphia Federal Reserve is not updated immediately so we must incorporate this new information. For example, the BEA just released the 2009:Q2 estimates on July 31st, 2009. However, the real-time dataset has yet to be updated. To resolve this issue, we simply take the annualized estimate from the BEA and divide by 4 to attain the quarterly GDP growth rate.

2.2. Oil Prices

According to the Department of Energy, there are 161 different types of crude oil and several different prices at which crude oil trades on the international market. We choose two types of oil prices defined by the nominal crude oil producer price index (seasonally unadjusted) or the nominal West Texas Intermediate Spot price of crude oil. The end-of-quarter monthly average values for oil prices are used, congruent with previous literature. The two series for crude oil represent different calculations of oil prices to compare which oil price is a better predictor of GDP growth.

The Crude Petroleum Producer Price Index (PPI) of the Bureau of Labor Statistics (BLS) measures the average change over time in the price of crude petroleum received by domestic producers of goods and services. The PPI of crude oil represents the perspective from the sellers in contrast to the Consumer Price Index (CPI) which measures the prices change from the purchaser's perspective. Prices are submitted by mail to the BLS from survey respondents and are effective on the Tuesday of the week containing the 13th of the month.

West Texas Intermediate crude oil (WTI) is a standard marker for crude oil on international markets. WTI is crude oil of a specific gravity and sulfur content delivered at Cushing, Oklahoma. The combination of characteristics, combined with its location, make it ideal crude oil to be refined in the United States, the largest gasoline consuming country in the world. It is used as a benchmark in oil pricing in North America and is the underlying commodity for New York Mercantile Exchange's (NYMEX) oil futures contracts.

The NYMEX light, sweet crude oil futures (CL) contract is the world's most liquid crude contract in the world. The CL contract is also the world's largest volume contract with physical delivery at expiration. The trading unit is 1,000 U.S. barrels (42,000 gallons) and the price quotation is in U.S. dollars and cents per barrel. The price of the "front-month" oil futures contract trading on the NYMEX covers the price of West Texas Intermediate grade oil, delivered at a specific date within the next month at a transfer hub in Cushing, Oklahoma. Because most speculators and traders do not take delivery of such barrels of oil, they often get out of the positions near the end of the fiscal quarter. We take the average spot price over the last month of the quarter to provide more accurate settlements of WTI Crude. The knowledge of the settlement price for WTI determined daily and is not subject to revision.

2.3. Oil Price Shocks

Finally, we have to address the choice of using a simple oil price measure or the net percentage increase above previous peak oil price measure, as advocated by Mork et al. (1994) and Hamilton(1996,2003). In order to account for the asymmetric effects of oil prices, we use positive changes for the definition of an oil shock. The net increase is defined as the positive change of the oil price:

$$o_t^+ = \begin{cases} o_t & \text{if } o_t > 0 \\ 0 & \text{otherwise} \end{cases} \quad (2.2.1)$$

Hamilton analyzed the above measure and found that Granger causality does not hold by the definition of positive quarterly changes. However, he did find the net increase over three years support the causal relationship.

Indeed, as has been argued in section 1, an adequate measure of the magnitude of a given oil price shock would be the net percentage increase in the price of oil above the maximum price reached in the previous 12 quarters. More precisely, net oil price increases (NOP3) are defined as the difference between the current price of oil and the previous 3 year maximum if positive, or zero otherwise.

$$o_t^{NOP3} = \begin{cases} o_t^{NOP3} & \text{if } \{o_t - \max(o_{t-1}, o_{t-2}, \dots, o_{t-12})\} > 0 \\ 0 & \text{if } \{o_t - \max(o_{t-1}, o_{t-2}, \dots, o_{t-12})\} \leq 0 \end{cases} \quad (2.2.2)$$

Each of the net oil prices increases over the previous 3-year maximum are calculated for crude PPI and WTI spot prices.⁷ We use these calculations as additional explanatory variables in our Model (2) for deriving the magnitude of an oil price shock.

The non-linear transformation has been proposed in the literature for restoring the relationship between oil price increases and GDP growth. Specifically, the transformation avoids the forecasting of a non-existent GDP increases when oil prices decrease. Although this transformation of oil price changes is non-linear, the oil shock variable is linear in the parameters of the model. Therefore, the relationship of GDP growth and oil shocks can be described as a linear regression model.

3. Results

We use quarterly observations on real-time aggregate output and two different types of oil prices spanning from 1949:Q2 to 2009:Q1. The series for real output is the quarterly growth rate

⁷ Hamilton uses the first difference of the logarithm of the level of oil prices. We use percentage change of oil prices since the average oil shock is 8.64% for Crude PPI and 14.42% for WTI Spot.

of real-time estimates of real GDP.⁸ The oil price series is the percentage growth rate transformation of the nominal crude oil price defined by two types of prices. The first series we use is the nominal Crude Oil Domestic Producer Price Index (Crude PPI), seasonally unadjusted.⁹ The second series we use is the nominal West Texas Intermediate (WTI) Spot Price.¹⁰ The sample period for estimation runs from t=1949:Q2 to 2009:Q1, for a total of T=240 usable observations.

3.1. The Data Descriptive Statistics

The real-time GDP growth estimates are first examined by looking at the graphs of both series for the Advance estimate and the Final estimate. Figure 1 compares U.S. real-time gross domestic product with those available from the revised latest available data in 2009:Q2. The upper panel graphs Advance initial estimates, while the bottom panel presents Final initial estimates. Three observations are apparent from Figure 2 which compares real-time data vintages. First, the differences between the latest Revised estimates are more pronounced for Advance estimates compared to Final estimates. Second, the recession of 1974-1975 appeared less severe with revised data than with real-time data. Finally, the discrepancies between real-time estimates and revised estimates of GDP are larger prior to the 1980's compared to more recent estimates. These observations suggest the results of the different vintages of GDP data as inputs could affect model specifications.

Table 1 provides summary statistics, which illustrate these points in a more formal way. The average Advance estimate of GDP growth is 0.72, which is less than the Final estimate average of 0.75. The latest Revised estimates on average are higher than the Advance and Final estimates with a mean of 0.81. The differences in means suggest upward revisions of initial estimates, however, these differences in means could be a result of specific major revisions of the initial estimates.

In order to determine if these mean differences from initial estimates are from specific episodes of large revisions, we present Table 2. In Table 2 we can see the estimates for first quarter 1974 were -1.5% and -1.8% for Advance and Final estimates but for the same period the

⁸ Data for U.S. quarterly GDP growth is from the Philadelphia Federal Reserve web page <http://www.philadelphiafed.org/research-and-data/real-time-center/>. Revised data are in 2005 dollars.

⁹ The monthly WPI0561 series is converted to quarterly by using end-of-quarter monthly averages. (Base=100 in 1982). The data is from the Bureau of Labor Statistics <http://data.bls.gov/>

¹⁰ Data is converted to quarterly by using the monthly average of the last month of the quarter. Data is from the St. Louis Fed website: <http://research.stlouisfed.org/fred2/series/OILPRICE/downloaddata?cid=98>. The source is the Dow Jones Company which releases the spot price in the Wall Street Journal.

Revised estimate of -0.9% is half as negative as the initial estimate. The largest revision of initial estimates from 1949:Q2 to 2009:Q1 occurred in 1978:Q2. Specifically, the Revised estimate for 1978:Q2 is 3.9% which is half the initial Advance estimate of 1.8%. With revisions greater for earlier initial estimates, we expect to find differences in the estimated coefficients.

Using the transformation of the data from equation (2.2.2), we can calculate the different values for each oil price series. Figure 3 depicts the oil shocks, which are shown to occur prior to 10 of the 11 recessions as defined by the NBER. Because these shocks, as seen in Figure 3, are much larger than 5%, the log approximation does not accurately represent the percent change. Therefore, we use the percent change from the maximum value over the previous year to the current value for our value of the oil shock. We calculate the oil shock for both Crude PPI and WTI spot prices using the price from the average price of the last month of the quarter. Since Crude PPI represents the cost to firms and WTI represents the market settlement price for crude, we can determine which type of oil price is a better predictor of GDP growth.

3.2. OLS Estimation Results

An interesting question is whether real-time data add support for the relationship between GDP and oil prices. First, we want to examine the in-sample period defined by Hamilton (2003) to determine the parameter estimates from 1949:Q2 to 2001:Q3 with 210 usable observations for both models. Secondly, we want to extend the in-sample period to 2009:Q1 with 240 usable observations to see if current conditions support the relationship. Finally, we want to compare in-sample difference of the magnitudes and signs of the parameters estimated with different estimates of real-time GDP.

The OLS estimates from the different sample periods for each model are obtained using real-time GDP data and oil price shocks. Our baseline univariate specification from Equation (1.1.4) includes an auto-regressive equation with four lagged real-time estimates of GDP growth. We use different data for the lagged real-time GDP variable in equation (1.1.4). For example, we referred to our different methods for the lagged real-time variable selection as Diagonal and Vintage, which we can use for both Advance and Final estimates. The analysis of the univariate provides a benchmark for the model and allows us to clearly evaluate whether oil shocks help explain GDP better or whether the real-time estimates improve the fit of the model. This allows for a concise comparison since Model (1) from equation (1.1.4) is nested in the equation (1.1.5) of our unrestricted model. The estimates for both models allow us to compare the coefficients for Hamilton(2003) sample period and for an extended sample period. The comparison of *adjusted-R²* for the regressions from Model 1 and Model 2 illustrates whether the addition of the oil shock variable helps to explain GDP.

3.2.1. OLS Estimation Results from 1949:Q2 to 2001:Q3

The first purpose was to determine if the relationship among the real-time GDP estimates and oil shock variables supported previous results using revised GDP. Hamilton used revised GDP data as the dependent variable and the Producer Price Index for domestic crude net oil price increases.¹¹ Specifically, Hamilton (2003) finds that the coefficient on o_{t-4} is significant at the 1% level for the sample from 1949:II to 2001:III. In addition, Hamilton (2003) shows that including lagged oil price shocks improves the fit when compared to the univariate regression. We use real-time GDP data to evaluate whether these results are still valid.

Table 3 presents the OLS estimates of the AR(4) using the sample period from 1949:Q2 to 2001:Q3 with 210 usable observations. It shows that a univariate regression of quarterly percent changes of GDP requires four lags of the dependent variable. Column 1 includes the GDP revised estimates available to Hamilton in 2001:Q3 with the fourth lag of GDP significant at the 5% level. Column 2 includes the latest revised GDP estimates, which have changed since Hamilton's analysis in 2003, and suggest the fourth lag in the regression is statistically insignificant. Columns 3-6 use real-time estimates as the dependent variable and have the fourth lag of GDP statistically significant at the 10% level or higher. The estimates in Table 3 are therefore consistent with the necessary inclusion of four lagged dependent variables.

Table 4 presents the OLS estimates of the effect of oil shocks on GDP from 1949:Q2 to 2001:Q3. It shows that using real-time data increases the predicted effect of oil shocks on GDP. The first column replicates Hamilton (2003) results with the revised estimates available at the time of his paper and Crude PPI for the oil shock transformation. Column 1 indicates the coefficient on o_{t-4} has the most negative value of -0.042 and a significance level of 1%. Column 2 replaces Hamilton's revised GDP with the latest GDP revisions and the oil shock effect is supported with the coefficient on o_{t-4} significant at the 1% level.

Columns 3 through 6 replace the revised estimates with real-time estimates of GDP. Interestingly, the coefficient on o_{t-4} is less significant for real-estimates but the coefficient on o_{t-3} is significant for real-time GDP data at the 1% level. For example, the coefficient on o_{t-4} is -0.027 and is statistically significant at the 5% level when using initial Final estimates as the dependent variable and Crude PPI oil shocks. In general, the coefficients on the variables

¹¹ Hamilton(2003) used revised estimates of Real GDP chain-weighted in 1996 dollars (SAAR).

$y_{t-4}^{real-time}$ and o_{t-4} are significant at the 10% level. The estimates in Table 4 are therefore consistent with the lag selection of four for each variable.

The second to last row in Table 4 represents the *adjusted-R²* for the regression. The latest available Revised estimate in column 2 has an *adjusted-R²* of 0.197 which differs slightly from Hamilton's result in Column 1 of 0.195. The use of real-time estimates with Final GDP data has an *adjusted-R²* of .285. Using real-time data, rather than revised, produces large differences in the estimates suggesting oil shocks explain real-time GDP over the sample period 1949:Q2 to 2001:Q3.

3.2.2. OLS Estimation Results from 1949:Q2 to 2009:Q1

Regarding the second purpose, we review estimates of an extended sample from 1949:Q2 to 2009:Q1 with 240 observations. We compare statistics among the restricted AR(4) and the augmented AR(4) including oil shocks transformed from either Crude PPI or WTI Spot Prices. Reviewing the restricted and unrestricted models coefficients and *adjusted-R²* allows us to determine if GDP is explained better with oil shocks with an extended sample. Our baseline specification includes a univariate equation with four lagged real-time estimates of GDP growth known as our AR(4) using different vintages of real-time data. The baseline includes analysis for both Diagonal and Vintage data, as well as latest Revised GDP growth estimates available in 2009:Q2.

Table 5 presents the OLS estimates of an AR(4) from 1949:Q2 to 2009:Q1 and shows that the real-time estimates improve the *adjusted-R²* for each benchmark specification. The real-time Diagonal Advance estimates and Diagonal Final estimates *adjusted-R²* have the greatest values of 0.220 and 0.203 respectively. Vintage data, in column (3) and (5), does not explain the dependent variable as well when compared to Diagonal estimates implying that Vintage real-time data performs worse than Diagonal data in terms of fit. The first lag of GDP remains significant at the 1% level for all estimates; however, the fourth lag is significant at the 10% level for advance and final vintage estimates. The fourth lag of the Diagonal Final estimate has the highest significance of 4%. We can use these benchmark estimations for comparisons with our unrestricted model that contains the oil shock variable.

Table 6 presents the OLS estimates of the effect of Crude PPI oil shocks on GDP from 1949:Q2 to 2009:Q1. It shows that including the measure of oil shocks dramatically increases the predicted effect of GDP growth. The *adjusted-R²* is higher for the Diagonal specification when compared to Vintage specification. For example, the *adjusted-R²* is .326 using Advance Diagonal GDP estimates which are higher than the Advance Vintage *adjusted-R²* .322. The lowest

adjusted-R² for the real-time estimates is Final Vintage of .310. The coefficient on o_{t-4} is significant at the 10% level and the coefficient on o_{t-3} is significant at the 1% level for Advance and Final Estimates as the dependent variable. The comparison of real-time estimates clearly supports the presumption that oil shocks Granger cause GDP growth.

Table 7 presents the OLS estimates of the effect of oil shocks from WTI Spot prices on GDP from 1949:Q2 to 2009:Q1. It shows that including the measure of oil shocks from WTI spot prices does not increase the predicted effect of GDP growth when compared to Crude PPI. The *adjusted-R²* is higher for the Vintage specification when compared to Diagonal specification. For example, the *adjusted-R²* is .287 using Advance Diagonal GDP estimates are lower than the Advance Vintage *adjusted-R²* .292. The lowest *adjusted-R²* for the real-time estimates is Final Vintage of .283. The coefficient on o_{t-3} is significant at the 1% level when using Crude PPI. The comparison of real-time estimates clearly supports the presumption that oil shocks granger cause GDP and a bigger proportion of the variance is explained using real-time data and Crude PPI oil shocks.

4. Granger Causality

The usual OLS model only identifies the relationship between variables but does not help determine the direction of the relationship. If changes in oil prices precede changes in output growth, then we can rule out changes in GDP growth causing oil price changes. Using this logic we can estimate the regression with and without oil prices as an explanatory variable. Suppose we want to test a hypothesis that oil shocks do not help forecast GDP growth. The null hypothesis stating that o_t is not Granger causing y_t corresponds to all coefficients on the oil prices equal to zero. If we fail to reject the null then the unrestricted Model 2 of (1.1.5) reduces to the restricted Model 1 of (1.1.4). All usual OLS t-tests and F- tests on the OLS estimates are valid for drawing conclusions about the relationship.

We calculate the p-value for the F-Test of the null hypothesis stating that the population coefficients of the oil variables are all zero. If coefficients on o_t are all zero then we conclude oil shocks do not Ganger-cause real GDP growth. The F-test statistic for the null hypothesis that the coefficients on the oil shock variable, β_i , are equal to zero over the entire sample model are shown in each table for the unrestricted model.

4.1. Evidence of Granger Causality

Hamilton calculates the p-value of the F-Test of the null hypothesis that the oil price coefficients, β , were all zero in a regression of GDP growth on a constant, four of its own lags, and four lags of the oil price measure. The test statistic is shown in the last row for Column (1) of

Table 4. The null hypothesis is rejected at the 1% level for the sample period from 1949:Q2 to 2001:Q3. The 3-year net oil price increase of the Crude PPI measure exhibits statistical significance. For example, with the Crude PPI NOP3 the relation to revised GDP is significant. The hypothesis that the Crude PPI NOP3 measure has no effect on revised GDP is rejected.

The last row of Table 4 contains the F-Statistic which is also known as the Granger-Causality Test Statistic. The F-Statistic is higher for real-time estimates with 7.095 and 7.071 for Advance and Final respectively, compared to the latest revised F-statistic of 5.978. The F-Statistics are all significant at the 1% level suggesting that the oil price shock variables Granger causes initial estimates of GDP growth. The null hypothesis that all lagged oil coefficients are zero is rejected with both revised and real-time estimates of GDP. In general, the F-Statistics are all significant at the 1% level suggesting that the oil price shock variable from Crude PPI Granger causes GDP growth over the sample period 1949:Q2 to 2001:Q3.

The results from the extended time period in the last row of Table 6 support the relationship between oil shocks and GDP growth for 1949:Q2 to 2009:Q1 when compared to the sample from 1949:Q2 to 2001:Q3. The null hypothesis that all lagged oil coefficients are zero is rejected for all vintages at the 1% level. Also, this suggests that the fit of GDP and oil shocks is improving with our extended sample. More importantly, the Final estimates as the dependent variable and Crude PPI Oil shocks as the explanatory variable now has the highest F-statistic of 8.10 which is significant at the 1% level. This suggests that Granger causality is the strongest with the Final release of GDP growth and Crude PPI oil shocks. Table 7 presents OLS estimates using WTI spot prices for the oil shock transformation. The results are congruent with Crude PPI and further support the Granger causality analysis.

4.2. Evidence of Granger Causality Over Time

When using real-time GDP data rather than Revised, we can determine if Granger causality exists at different in-sample start dates. The graphs in Figure 4 and Figure 5 plot the *p-value* of a function of the sample starting data t_1 to 2007:4, therefore the lower the *p-value*, the more evidence of Granger Causality. First, we estimate a fixed-coefficient regression by OLS over $t=t_1, 2009:1$, using every possible starting point t_1 between 1949:2 and 2007:4. Then for each t_1 we calculate the *p-value* of the F-test of the null hypothesis that the oil price coefficients were all zero. The figure provides evidence of Granger causality when using the specification of the net oil price increase over the previous 3-year maximum when using real-time data. Extending the

Hamilton(2003) sample and comparing the real-time GDP estimates with oil shocks, we can determine if Granger Causality holds at different starting points.¹²

Figure 4 presents the results of an oil price transformation from Crude PPI oil shocks. The symmetric change is the positive and negative quarterly percent change of prices in Panel 1. The Mork specification in Panel 2 consists of the oil price change from equation (2.2.1). In Panel 3, the oil shock variable is the 1-year net increase measure. Panel 4 uses the 3-year net oil price increase from equation (2.2.2). The symmetric, Mork and 1-year net increase transformations for the explanatory oil variable do not Granger cause GDP growth after 1970 congruent with Hamilton's findings. Granger causality holds among all real-time GDP estimates for the 3-year net oil price increase. Figure 5 uses WTI Spot prices for the oil shocks variable which are similar to the findings using Crude PPI. However, when using WTI Spot prices for the oil shock transformation, we see the net oil price increase over three years does not Granger cause GDP in 1980. This suggests that the relationship of Crude PPI and GDP growth is preferred.

The results of in-sample Granger causality tests for predictive content and stability of the coefficients suggest three conclusions. First, when using real-time GDP estimates for the sample period defined by Hamilton (2003) from 1949:Q2-2001:Q3, the use real-time data improves the F-statistic, indicating these relations have substantial in-sample predictive content. Secondly, there is increasing evidence of predictive content when we extend the sample period to 2009:Q1. Finally, we find the evidence of Granger causality for real-time GDP data using the 3-year net oil increase measure transformed from Crude PPI. The Crude PPI oil shock measure is preferred over the measure transformed from WTI Spot prices.

5. Testing Out-of-Sample Predictability

There are several competing forecasting models; however we restrict our attention to out-of sample criteria for bivariate linear regressions. For forecasting, it is better to use out-of-sample criteria to compare models. A model may provide a good fit to the dependent variable in the sample used to estimate the parameter, but this does imply good forecasting performance. An out-of-sample comparison involves using the first part of the sample to estimate parameters of the model and saves the latter part of the sample to gauge forecasting capabilities. This mimics what we would have to do in practice if we did not yet know the future values of the variables.

Let $z_t = (1, y_{t-1}, y_{t-2}, y_{t-3}, y_{t-4})'$ denote the vector of explanatory variables and $x_t = (o_{t-1}^{nop3}, o_{t-2}^{nop3}, o_{t-3}^{nop3}, o_{t-4}^{nop3})'$ a candidate vector of lagged nonlinear oil price transformations.

¹² I am grateful to James D. Hamilton for making the computer code publicly available at <http://weber.ucsd.edu/~jhamilto/>.

We can represent the restricted model, denoted as Model 1, and the unrestricted model, denoted as Model 2, with the following equations:

$$\begin{aligned} \text{Model 1} & : y_t = z_t' \delta + \varepsilon_t, \\ \text{Model 2} & : y_t = z_t' \delta + x_t' \beta + \varepsilon_t, \end{aligned} \tag{5.1.1}$$

For the above equations (5.1.1), our first model, denoted as Model 1, is a univariate autoregression with four lags of the dependent variable from equation (1.1.4). The second model, denoted as Model (2), is an unrestricted linear model from equation (1.1.5) with four lags of the dependent variable and four lags of the oil shock variable. We compute summary statistics for appropriate critical values when the first model is nested in the second model.

The null hypothesis is that baseline forecasts without oil shocks have the same predictive power as forecasts with oil shocks. Thus, under the null the MSPE will be equal:

$$\begin{aligned} H_0 & : \sigma_1^2 - \sigma_2^2 = 0 \\ H_1 & : \sigma_1^2 - \sigma_2^2 > 0 \end{aligned} \tag{5.1.2}$$

The null hypothesis of equal population MSPEs can be tested against the alternative hypothesis that the unrestricted linear model has a smaller MSPE.

The test statistic is constructed for recursive regressions, adding an observation to the end of the sample period, fitting the model, making an out-of-sample forecast, and comparing it to the actual realization of the data. To evaluate forecasts, the last P observations of the sample are used for comparison. The first R observations are used to construct an estimation of the regression for the prediction of one-step ahead. We estimate the regression from R observations to predict each P observation, such that $R+P = T+1$. Using the sample, we compare the predictive ability of two parametric regression models one-step ahead. This structure allows for the applications discussed below.

Given the pair of restricted and unrestricted models, two sequences of one-step-ahead forecasts are constructed using a recursive theme. Let $\hat{\beta}_t$ and $\hat{\delta}_t$ denote the vector of regression parameters whose estimates are used to make predictions. These parameters are updated as the observations are added at each time period for the new forecast origin, $R+1$. The size of the sample used for estimation grows as one makes predictions of successive observations. Specifically, at time $t=R, \dots, T$ the parameter estimation of $\hat{\beta}_t$ and $\hat{\delta}_t$ depend explicitly on all past information from $s=1, \dots, t$. Using parameter estimates, we can create forecasts one-step ahead to determine forecast errors and losses constructed for each model utilizing a recursive scheme.

The one-step ahead prediction for Model (1) is $z_{t+1}'\hat{\delta}_t$ and $z_{t+1}'\hat{\delta}_t + x_{t+1}'\hat{\beta}_t$ for the alternative Model (2). The sample forecast errors $\hat{e}_{1,t+1}$ and $\hat{e}_{2,t+2}$ are $\hat{e}_{1,t+1} = y_{t+1} - z_{t+1}'\hat{\delta}_t$ and $\hat{e}_{2,t+1} = y_{t+1} - z_{t+1}'\hat{\delta}_t - x_{t+1}'\hat{\beta}_t$. If we square the sample errors and divide by the number of predictions, we can obtain the mean square prediction error of each model for performance comparison. The Mean Square Prediction Error (MSPE) for each model is shown by:

$$\begin{aligned}\hat{\sigma}_1^2 &= P^{-1} \sum_{t=T-P+1}^T \left(y_{t+1} - z_{t+1}'\hat{\delta}_t \right)^2 \\ \hat{\sigma}_2^2 &= P^{-1} \sum_{t=T-P+1}^T \left(y_{t+1} - z_{t+1}'\hat{\delta}_t - x_{t+1}'\hat{\beta}_t \right)^2\end{aligned}\tag{5.1.3}$$

We are interested in testing the null hypothesis that output growth is equally linearly predictable with the nested and non-nested model.

The square root of the MSPE provides a unit free analysis of the comparison of the two models. We use the Root Mean Squared Prediction Error (RMSPE) to compare each model's out-of-sample predictability. The RMSPE is essentially the sample standard deviation of the forecast error (without any degrees of freedom adjustment). The ratio of RMSPE is shown by:

$$\text{Ratio of RMSPE} = \frac{\sqrt{\hat{\sigma}_2^2}}{\sqrt{\hat{\sigma}_1^2}}\tag{5.1.4}$$

The ratio of RMSPE is equal to one when Model (1) and Model (2) have the same out-of-sample predictability. We prefer the method with the smallest out-of-sample RMSPE. Therefore, ratios less than one show that the unrestricted model outperforms the univariate restricted model.

The accuracy of the forecast is important to policymakers. A standard test of forecast accuracy is the one proposed by Diebold and Mariano(1995). However, the statistic from Diebold and Mariano (1995) is undersized when used to compare predictive ability of two nested models. The Clark and McCracken (2001) test is a modification of Diebold and Mariano (1995) and West (1996) (DMW), which is valid when mean square prediction errors are compared for nested models. These considerations are important in the context of GDP growth forecasting because Model(1) is always nested in Model(2). We use critical values from McCracken (2007) to compute the significance of MSPE-F and MSPE-t statistics for nested models. The out-of-sample statistics are based on forecasts computed for each model, horizon and real-time GDP series.

5.1. Out-of-Sample Predictability Results

We framed the investigation in the form of a pure question about forecasting, to determine if types of oil shocks are the correct functional form for describing the conditional expectation of

GDP growth conditional on lagged GDP growth and lagged oil price changes. The answer to this forecasting question is reliant on the use of real-time data which could be given causal interpretation given we are persuaded oil price shocks improve predictions of GDP. When compared to the restricted model, we determine if predictability increases with the addition of oil shocks as an explanatory variable.

The out-of-sample 1-quarter-ahead forecast comparisons are evaluated using the Clark and McCracken(2001) test statistics with diagonal and vintage real-time estimates and two types of oil shocks. The RMSPE ratio is the unrestricted RMSPE from Model (2) relative to the restricted RMSPE from Model (1). As such, if the unrestricted Model has a lower RMSE than the restricted, the ratio will be less than 1. We use McCracken (2007) to determine if the differences of predictions among the models are significant.

First, we want to determine which combinations have lower RMSPE ratios by comparing Advance or Final estimates with Diagonal and Vintage specifications. We evaluate RMSPE ratios for forecasting one-step ahead for the last 10% of the sample. Secondly, we want to determine if real-time estimates have lower ratios with shorter in-sample periods and an increased out-of sample period of 15%. Finally, we want to determine if different types of prices transformed into oil shocks improve the ability to forecast current revised estimates which contain better information.

The results for 1-quarter-ahead out-of-sample forecast evaluation of the last 10% of the sample are presented in Table 8. First, the comparison of the out-of-sample predictability for 2003:Q4 to 2009:Q1 is determined with the in-sample period from 1949:Q2 to 2003:Q3. Rows 1 and 2 show that advance estimates do not perform significantly better than the restricted model for the out-of-sample period from 2003:Q4 to 2009:Q1 using the Crude PPI oil shock as an explanatory variable. The Final estimates have lower RMSPE ratios than Advance estimates. However, the AR(4) RMSPE of 0.667 and 0.669 for Final Diagonal and Final Vintage are higher than those of Advance RMSPE of 0.564 and 0.569. The significance of RMSPE is higher for Final Estimates compared to Advance estimates because Advance estimates are more predictable.

The RMSPE ratios are larger for the model that uses Crude PPI for the oil shock transformation when compared to the WTI Spot prices. The last two columns of Table 8 show Crude PPI oil shocks do not forecast GDP as well as WTI Spot prices. Specifically, Final Diagonal ratios for Crude PPI and WTI are 0.952 and 0.885 respectively. The RMSPE ratios of Final Diagonal are lower than Advance Diagonal which is 0.885 for PPI and 0.972 for WTI. Given that estimates have lower RMSPE ratios for the last 10% of the sample, we can extend the evaluation to a larger percentage at the end of the sample.

Table 9 shows the results for the RMSPE ratio of the unrestricted Model 1 relative to the restricted model for evaluation of the last 15% of the sample. First, the comparison of the out-of-sample predictability for 2001:Q4 to 2009:Q1 is determined with the in-sample period from 1949:Q2 to 2001:Q3. The Final Vintage RMSPE ratios of 0.926 are the lowest for initial estimates and statistically significant at the 5% level. Although the out-of-sample RMSE for the diagonal PPI estimate is only significant at the 5% level while the other ratios are significant at the 1% level for WTI Spot oil shocks.

6. Predicted GDP Growth

In order to evaluate the predictions of growth we can examine the one-step-ahead predictions of the restricted and unrestricted model using oil shocks transformed from Crude PPI and WTI Spot prices. First, we graph these predictions for both models to determine if the oil shocks indicate negative GDP growth during previously defined recessions. We quantify these predictions by calculating the contribution of the oil shock by taking the difference of GDP growth with and without the oil shock. After determining if the defined oil shock of the two types of oil prices accounts for most of the deviation of the trend, then we can examine the current predictions for GDP and analyze these predictions for policy.

We graph the predictions for GDP growth to determine how our different models performed over time. We show these out-of-sample forecasts for one-step ahead using Advance and Final Diagonal estimates as our baseline AR(4) and the unrestricted model with each type of oil shock. From the solid line in panel 1 of Figure 6 and Figure 7, we observe that the AR(4) restricted model predicts negative GDP growth only in deep recessions. The predictions of each AR(4) are shown by the solid line in the first panel and this line only dips below zero after a deep recession.

The unrestricted Model 2 predictions provide a comparison to the benchmark AR(4) model. The evaluation of oil shocks transformed by Crude PPI and WTI Spot prices as the additional explanatory variables are in Panels 2 and 3 respectively. For example, the forecasts for GDP using Crude PPI oil shock transformations with real-time vintage GDP are found in Panel 2 of Figure 6 and Figure 7. This transformation from Crude PPI predicted negative GDP growth during each recession. Specifically, in 1981 the predicted GDP growth using Crude PPI oil shocks is negative. However, Panel 3 in Figure 6 and Figure 7 does not show predicted negative GDP growth when using WTI Spot Prices for the oil shock transformation. These results suggest that the type of oil price transformed is important for predicting GDP. The comparison of predictions with the two oil prices suggests Crude PPI oil prices perform better than WTI Spot oil prices, and thus Crude PPI should be used for predicting GDP growth.

Interestingly, GDP growth predictions are slightly negative for the last two quarters of 2005 when using Crude PPI oil shocks. For example, the solid line in the second panel of Figure 6 or Figure 7 suggests near zero and slightly negative predictions of GDP growth in 2005 when using Crude PPI. The lack of negative effects from the rise in oil prices in 2005 suggests that the oil price shock was demand driven, rather than supply driven. The actual positive growth as opposed to the predicted negative growth over the calendar year of 2005 suggests the oil shock was from increased demand rather than an exogenous supply shocks.

The recent predictions for GDP growth using the unrestricted model are more negative for oil shocks transformed from Crude PPI compared to those transformed from WTI Spot Prices. These results suggest that WTI Spot Price oil shocks do not predict GDP growth as well as Crude PPI. The predictions for GDP estimates with WTI Spot oil shocks are shown as a solid line in the third panel of Figure 6 and Figure 7. Specifically, the third panel in Figure 6 and 7 suggest WTI Spot oil shocks did not predict negative GDP growth in the 1982 recession nor the 2001 recession. The current prediction using WTI Spot oil shocks predicted negative GDP growth in 2008:Q4, which is later than the initial estimates of negative growth in 2008:Q3. These results suggest oil shocks defined by WTI Spot prices are outperformed by Crude PPI oil shocks.

6.1. Magnitude of the Coefficients

We quantify the contributions of each oil shock variable to real-time GDP estimates for each year following the oil shock episode. We examine one-step-ahead predictions to get a sense of the magnitudes implied by the coefficients in Tables 6 and 7 for the relation from 1949:Q2 to 2009:Q1. We calculate for each quarter following the episode of oil shocks the difference of predictions between the restricted and the unrestricted model.

Specifically, we calculate the difference between the 1-quarter ahead forecast implied by Model (2), and what that 1-quarter ahead forecast would have been if the oil price measure had instead been equal to zero resulting in the AR(4) from our restricted Model (1). We took the difference as a measure of the contribution of the oil shock to that quarter's real GDP growth. If the forecasts for each quarter are less negative for the AR(4) when compared to the unrestricted model, then the GDP growth would have been positive without the occurrence of the oil shock. These quarterly differences of the two predictions are annualized then averaged over the specified year.

Table 10 represents the average of quarterly growth for the defined period following the oil shocks mentioned previously. Using initial estimates, we took the 1-step-ahead forecasts for the restricted and unrestricted model. The average of the differences over the defined period is presented for each real-time vintage and oil price. Interestingly, in 1981:Q2-82:Q2, the WTI oil

shock does not suggest that growth would have been positive. Using the WTI Spot oil shock suggests -0.84% growth for Final Diagonal estimates and -0.90% growth for Advance Diagonal estimates. This time period coincide with our findings that WTI Spot oil shocks do not Granger cause GDP when our sample period start date is in 1982. However, the Crude PPI oil shock does suggest positive growth without the oil shock with 1.93% and 1.65% over the same period.

From the results in Table 10, it appears that WTI Spot prices do not capture the deviation from the trend when compared to Crude PPI oil shocks. However, Crude PPI oil shock specification would attribute some of the deviation from trend in each of the five recessions to the shock alone. The positive GDP growth for each year after the shock had it not occurred provides evidence that the oil shock arising from Crude PPI consistently contributes to negative GDP growth.

6.2. Forecasts of GDP Growth

Table 11 shows the comparison of recent actual estimates of GDP and out-of-sample forecasts with the restricted AR(4) in equation (1.1.4) and the unrestricted model from equation (1.1.5). The forecasts from Advance and Final estimates using our model are in the corresponding row of the initial estimate. For example, the first row in Column (1) in Table 11 shows the initial Advance estimate for 2008:Q2 GDP growth of 1.9% which was released one month after the quarter on July 31st, 2008. The forecasts from the restricted AR(4) model are in Colum(5). For example, Column 5 shows the restricted AR(4) model forecasts as 1.6% growth (Advance release) and 1.7% (Final release) for 2008:Q2. The restricted model does not forecast negative GDP growth until 2009:Q1.

The unrestricted model forecasts are in Column (6) and in Column (7) for oil shocks transformed from Crude PPI and WTI Spot prices, respectively. The forecast for 2008:Q2 growth is negative using Crude PPI oil shocks as an explanatory variable. Specifically, the annualized quarterly predictions for 2008:Q2 are -1.4% for Advance and -1.4% for Final Releases. However, the WTI Spot oil shocks do not predict negative GDP growth until the fourth quarter of 2008. These predictions using WTI Spot oil shocks further support the belief that this type of oil price does not predict GDP growth as well as the oil shocks transformed from Crude PPI.

Figure 8 shows our model using Crude PPI oil shocks predicts negative GDP growth for the past five quarters. The simple bivariate model suggests that negative growth would have occurred without taking into account the financial crisis. We predict the most negative impact arising from the oil shock of 2007-2008 occurs in the 2009:Q1 with a Final forecast of annualized quarterly percent change of -4.3%. However, the predictions for 2009:Q2 are less negative with -1.5% and -1.6% for Advance and Final suggesting the largest negative impact from the oil shock is over.

When we incorporate the latest release of GDP for 2009:Q1 we are able to predict growth for 2009:Q2. When updating our series with the latest Advance release estimates of -1.0% for 2009:Q2, we predict positive GDP growth of 2.6% for 2009:Q3, suggesting the economy is moving toward potential output. The prediction for 2009:Q3 is much higher than some forecasts because our model does not take into account financial conditions such as the current credit crisis. However, future research should incorporate other financial variables, such as the yield curve, to improve predictions over our bivariate model.

7. Conclusion

The analysis of the paper used the context of Granger causality to quantify the effects of oil shocks on GDP growth in real-time. The addition of real-time GDP data as the dependent variable makes the model operational for forecasting. Using a simple bivariate model, we address the question of how the current recession differs from previous recessions. Without taking into account the financial crisis, we identify the recent business cycle trough using only GDP and oil shocks in our model.

Our empirical analysis leads to four main conclusions in concern with the relation of GDP and oil shocks. First, the model's explanatory power is dramatically improved by utilizing real-time data as the explained variable. Second, in-sample tests reveal oil shocks Granger cause real-time GDP growth. Third, the operational model in real-time improves predictive accuracy for GDP. Fourth, predictions of current GDP growth are similar to recently revised estimates from the BEA. Specifically, the bivariate model with Crude PPI shocks predicts the trough of the current recession in 2009:Q1 with less negative growth for 2009:Q2.

Although a plethora of factors are related to GDP growth, Crude PPI oil shocks predict negative growth following each oil shock episode. We suggest the specification of oil shocks transformed from Crude PPI when developing a model to predict Real GDP growth. The Crude PPI oil shocks with real-time GDP data inform us of the directional change of the underlying economy. This is done without taking into account the financial crisis but accounts for roughly half of the downturn. We conclude that directional changes of the economy are indicated by our model in the wake of a shock in real-time.

Real-time data is especially important around business cycle troughs, where there may be some evidence that the economy is changing direction. Our model predicts the most negative impact from the 2007-2008 oil shock occurred during the first quarter of 2009. Moreover, our operational model predicted 57% of 2008 GDP growth which is the same percentage of net petroleum imports for the U.S during the same year. Our results show less negative GDP growth for the second quarter of 2009, suggesting the worst impact from the oil supply shock is over.

This result, if correct, would indicate that the economy is moving toward potential output, with positive GDP growth for 2009:Q3. Our results suggest the negative impact from the recent oil shock has dissipated and the economy is recovering. The next oil shock will slow the pulse of the economy; however knowing the importance of these occurrences could help with prescient policy decisions.

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Table 1

Descriptive Statistics

| | <i>Obs</i> | <i>Mean</i> | <i>SD</i> | <i>Min</i> | <i>Max</i> |
|--|------------|-------------|-----------|------------|------------|
| <i>Real-Time GDP Estimates</i> | | | | | |
| Latest Available Revised Estimates | 240 | 0.81 | 0.98 | -2.76 | 4.02 |
| Initial Final Estimates | 240 | 0.75 | 0.99 | -3.03 | 4.92 |
| Initial Advance Estimates | 240 | 0.72 | 0.96 | -2.74 | 4.92 |
| <i>Oil Prices and Oil Shocks</i> | | | | | |
| Crude Producer Price Index | 240 | 49.8 | 51.48 | 8 | 367.5 |
| WTI Spot Price | 240 | 17.35 | 19.49 | 1.62 | 133.93 |
| Crude Producer Price Index Oil Shocks | 240 | 2.13 | 6.23 | 0.00 | 51.67 |
| West Texas Intermediate Spot Price Oil Shock | 240 | 2.55 | 10.77 | 19.53 | 134.57 |

Notes: Real-time vintages are from the Philadelphia Reserve's Real-Time data set. Real-Time GDP Estimates are quarterly percent changes. Latest available revised Real GDP estimates are in 2005 dollars. The domestic Crude Producer Price Index (Crude PPI) is from the Bureau of Labor Statistics. The West Texas Intermediate Spot (WTI SPOT) price is from the Wall Street Journal. Oil shocks are the net percentage increase in the price of oil above the maximum price reached in the previous 12 quarter. The total number of shocks from Crude PPI is 59 with an average of 8.64%. The total number of shocks from WTI Spot prices is 44 with an average of 15.42%.

Table 2A**Descriptive Differences of Initial and Revised GDP Growth Estimates**

| Period | Advance(Q) | Final(Q) | Revised(Q) | Advance(Y) | Final(Y) | Revised(Y) |
|---------|------------|----------|--------------|------------|----------|--------------|
| 1970:Q2 | 0.1% | 0.2% | 0.2% | 0.3% | 0.6% | 0.8% |
| 1974:Q1 | -1.5% | -1.8% | -0.9% | -6.0% | -7.2% | -3.5% |
| 1974:Q2 | -0.3% | -0.4% | 0.3% | -1.2% | -1.6% | 1.2% |
| 1974:Q4 | -2.4% | -2.3% | -0.4% | -9.1% | -9.0% | -1.6% |
| 1975:Q1 | -2.7% | -3.0% | -1.2% | -10.8% | -11.9% | -4.8% |
| 1978:Q2 | 1.8% | 2.1% | 3.9% | 7.40% | 8.7% | 16.7% |
| 1980:Q2 | -2.3% | -2.5% | -2.0% | -9.4% | -10.0% | -8.1% |
| 1981:Q3 | -0.1% | 0.4% | 1.2% | -0.6% | 1.4% | 4.8% |

Real-time vintages are from the Philadelphia Reserve's Real-Time data set. Percentage changes are calculated from unrounded data and annualized. "Real" Revised estimates are in chained (2005) dollars available in 2009:Q2.

Table 2B**Descriptive Differences of Crude PPI and WTI Spot Oil Shocks**

| Period | Crude PPI Price | Crude PPI NOP3 | WTI Spot Price | WTI SPOT NOP3 |
|---------|-----------------|----------------|----------------|---------------|
| 1969:Q1 | 14.3 | 3.6% | 3.25 | 5.9% |
| 1970:Q4 | 15.4 | 6.2% | 3.56 | 6.3% |
| 1973:Q3 | 18.2 | 6.4% | 4.31 | 21.1% |
| 1974:Q1 | 27.5 | 38% | 10.1 | 138% |
| 1979:Q3 | 57.6 | 18.5% | 28.5 | 49.2% |
| 1981:Q1 | 114.99 | 33% | 38 | 0% |
| 1990:Q3 | 91 | 51.6% | 33.7 | 59.7% |
| 2000:Q1 | 86.9 | 22.4% | 29.89 | 14.6% |
| 2005:Q1 | 145 | 22.6% | 54.31 | 18.2% |
| 2008:Q2 | 367.5 | 23% | 133.9 | 26.9% |

The Crude PPI is from the BLS. The WTI Spot price is from the Wall Street Journal. The oil price is an average over the last month of the quarter. The NOP3 variable is defined as an oil shock which is positive if the quarterly price is greater than the previous three year maximum and zero otherwise.

Table 3**OLS estimates of GDP Growth (y_t) Using Lagged GDP**

| | <i>Sample Period from 1949:Q2 to 2001:Q3</i> | | | | | |
|--------------------|--|----------------------|----------------------|----------------------|----------------------|----------------------|
| | Hamilton GDP | Latest Revised | Advance Diagonal | Advance Vintage | Final Diagonal | Final Vintage |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Constant | 0.668 *** (0.112) | 0.654 *** (0.110) | 0.503 *** (0.092) | 0.506 *** (0.092) | 0.537 *** (0.097) | 0.539 *** (0.097) |
| GDP{1} | 0.298 *** (0.068) | 0.291 *** (0.069) | 0.430 *** (0.069) | 0.437 *** (0.068) | 0.398 *** (0.069) | 0.406 *** (0.069) |
| GDP{2} | 0.130 (0.072) | 0.138 * (0.072) | 0.092 (0.075) | 0.068 (0.071) | 0.105 (0.074) | 0.094 (0.073) |
| GDP{3} | -0.058 (0.072) | -0.070 (0.072) | -0.074 (0.075) | -0.047 (0.070) | -0.050 (0.074) | -0.057 (0.073) |
| GDP{4} | -0.116 ** (0.069) | -0.111 (0.069) | -0.116 * (0.069) | -0.125 * (0.065) | -0.141 ** (0.068) | -0.130 ** (0.068) |
| Adj-R ² | 0.121 | 0.120 | 0.219 | 0.217 | 0.200 | 0.197 |

Notes: Standard errors are in parentheses. Real-time vintages are from the Philadelphia Reserve's Real Time data set. The regression is evaluated from 1949:Q2 to 2001:Q3 to resemble the Hamilton(2003) sample period. The GDP variable is the quarterly percentage change of each vintage. There are 210 usable observations and 205 degrees of freedom. For the reported p-values, ***, **, * denote the significance at the 1, 5, and 10 percent levels, respectively.

Table 4**OLS Estimates of GDP Growth (y_t) Using Lagged GDP and Crude PPI (oil_t)**

| | <i>Sample Period from 1949:Q2 to 2001:Q3</i> | | | | | |
|--------------------|--|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| | Hamilton | Latest | Advance | Advance | Final | Final |
| | GDP | Revised | Diagonal | Vintage | Diagonal | Vintage |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Constant | 0.982 *** (0.126) | 0.961 *** (0.123) | 0.798 *** (0.104) | 0.796 *** (0.104) | 0.844 *** (0.109) | 0.845 *** (0.109) |
| GDP{1} | 0.214 *** (0.069) | 0.211 *** (0.068) | 0.326 *** (0.068) | 0.332 *** (0.068) | 0.297 *** (0.068) | 0.304 *** (0.068) |
| GDP{2} | 0.1 (0.070) | 0.105 (0.069) | 0.068 (0.071) | 0.054 (0.067) | 0.078 (0.070) | 0.071 (0.069) |
| GDP{3} | 0.079 (0.069) | -0.089 (0.069) | -0.08 (0.071) | -0.057 (0.066) | -0.06 (0.070) | -0.07 (0.069) |
| GDP{4} | -0.149 ** (0.067) | -0.15 ** (0.066) | -0.157 ** (0.065) | -0.162 ** (0.062) | -0.18 *** (0.065) | -0.168 ** (0.065) |
| NOP3{1} | -0.024 * (0.014) | -0.022 * (0.011) | -0.018 * (0.010) | -0.018 * (0.011) | -0.017 (0.011) | -0.017 (0.011) |
| NOP3{2} | -0.021 (0.014) | -0.021 * (0.011) | -0.022 ** (0.011) | -0.022 ** (0.011) | -0.02 * (0.011) | -0.02 * (0.011) |
| NOP3{3} | -0.018 (0.014) | -0.014 (0.012) | -0.034 *** (0.011) | -0.034 *** (0.011) | -0.035 *** (0.011) | -0.034 *** (0.011) |
| NOP3{4} | -0.042 *** (0.014) | -0.035 *** (0.012) | -0.021 * (0.011) | -0.021 * (0.011) | -0.027 ** (0.011) | -0.027 ** (0.011) |
| Adj-R ² | 0.195 | 0.197 | 0.302 | 0.301 | 0.285 | 0.282 |
| F(4,201)= | 5.858 *** | 5.977 *** | 7.095 *** | 7.095 *** | 7.071 *** | 7.054 *** |

Notes: Standard errors are in parentheses. Real-time vintages are from the Philadelphia Reserve's Real-Time data set. The Crude PPI is from the BLS. The regression is evaluated from 1949:Q2 to 2001:Q3 to resemble the Hamilton (2003) sample period. The GDP variable is the quarterly percentage change for each vintage. The NOP3 variable is defined as an oil shock which is positive if the price is greater than the previous three year maximum and zero otherwise. There are 210 usable observations and 201 degrees of freedom. For the reported p-values, ***, **, * denote the significance at the 1, 5, and 10 percent levels, respectively.

Table 5**OLS Estimates of GDP Growth (y_t) Using Lagged GDP (AR(4))**

| | <i>Sample Period from 1949:Q2 to 2009:Q1</i> | | | | |
|--------------------|--|-------------------------|------------------------|-----------------------|----------------------|
| | Latest Revised (1) | Advance Diagonal (2) | Advance Vintage (3) | Final Diagonal (4) | Final Vintage (5) |
| Constant | 0.578 *** (0.099) | 0.470 *** (0.084) | 0.472 *** (0.085) | 0.503 *** (0.089) | 0.504 *** (0.089) |
| GDP{1} | 0.318 *** (0.065) | 0.437 *** (0.065) | 0.447 *** (0.064) | 0.413 *** (0.064) | 0.421 *** (0.064) |
| GDP{2} | 0.128 * (0.068) | 0.095 (0.070) | 0.063 (0.067) | 0.097 (0.070) | 0.084 (0.069) |
| GDP{3} | -0.064 (0.068) | -0.075 (0.070) | -0.046 (0.066) | -0.046 (0.070) | -0.055 (0.069) |
| GDP{4} | -0.090 (0.065) | -0.106 (0.065) | -0.111 * (0.062) | -0.130 ** (0.065) | -0.116 * (0.065) |
| Adj-R ² | 0.128 | 0.220 | 0.217 | 0.203 | 0.200 |

Notes: Standard errors are in parentheses. Real-time vintages are from the Philadelphia Reserve's Real-Time data set. The regressions are evaluated from 1949:Q2 to 2009:Q1 to extend the sample period. The GDP variable is the quarterly percentage change for each vintage. There are 240 usable observations and 235 degrees of freedom. For the reported p-values, ***, **, * denote the significance at the 1, 5, and 10 percent levels, respectively.

Table 6**OLS Estimates of GDP Growth (y_t) Using Lagged GDP and Crude PPI (oil)**

| | <i>Sample Period from 1949:Q2 to 2009:Q1</i> | | | | |
|--------------------|--|-------------------------|------------------------|-----------------------|-----------------------|
| | Latest Revised (1) | Advance Diagonal (2) | Advance Vintage (3) | Final Diagonal (4) | Final Vintage (5) |
| Constant | 0.888 *** (0.111) | 0.749 *** (0.095) | 0.746 *** (0.095) | 0.796 *** (0.100) | 0.797 *** (0.100) |
| GDP{1} | 0.234 *** (0.064) | 0.340 *** (0.064) | 0.348 *** (0.064) | 0.316 *** (0.064) | 0.323 *** (0.064) |
| GDP{2} | 0.096 (0.066) | 0.072 (0.067) | 0.049 (0.063) | 0.073 (0.066) | 0.063 (0.066) |
| GDP{3} | -0.086 (0.066) | -0.082 (0.067) | -0.056 (0.063) | -0.054 (0.066) | -0.067 (0.066) |
| GDP{4} | -0.119 * (0.063) | -0.136 ** (0.062) | -0.136 ** (0.059) | -0.157 ** (0.062) | -0.142 ** (0.062) |
| NOP3{1} | -0.018 * (0.010) | -0.013 (0.009) | -0.013 (0.009) | -0.011 (0.009) | -0.012 (0.009) |
| NOP3{2} | -0.016 (0.010) | -0.015 * (0.009) | -0.015 * (0.009) | -0.015 (0.009) | -0.015 (0.010) |
| NOP3{3} | -0.018 * (0.010) | -0.033 *** (0.009) | -0.033 *** (0.009) | -0.034 *** (0.010) | -0.034 *** (0.010) |
| NOP3{4} | -0.031 *** (0.010) | -0.018 * (0.010) | -0.017 * (0.010) | -0.022 ** (0.010) | -0.022 ** (0.010) |
| Adj-R ² | 0.236 | 0.326 | 0.322 | 0.313 | 0.310 |
| F(4,231)= | 7.035 *** | 7.917 *** | 7.865 *** | 8.109 *** | 8.100 *** |

Notes: Standard errors are in parentheses. Real-time vintages are from the Philadelphia Reserve's Real Time data set. The Crude PPI is from the BLS. The regression is evaluated from 1949:Q2 to 2009:Q1. The GDP variable is the quarterly percentage change for each vintage. The NOP3 variable is defined as an oil shock which is positive if the price is greater than the previous three year maximum and zero otherwise. There are 240 usable observations and 231 degrees of freedom. For the reported p-values, ***, **, * denote the significance at the 1, 5, and 10 percent levels, respectively.

Table 7**OLS Estimates of GDP Growth (y_t) Using Lagged GDP and WTI SPOT (oil)**

| | <i>Sample Period from 1949:Q2 to 2009:Q1</i> | | | | |
|--------------------|--|-------------------------|------------------------|-----------------------|-----------------------|
| | Latest Revised (1) | Advance Diagonal (2) | Advance Vintage (3) | Final Diagonal (4) | Final Vintage (5) |
| Constant | 0.793 *** (0.109) | 0.704 *** (0.092) | 0.709 *** (0.093) | 0.755 *** (0.097) | 0.759 *** (0.097) |
| GDP{1} | 0.260 *** (0.065) | 0.346 *** (0.064) | 0.354 *** (0.064) | 0.320 *** (0.064) | 0.328 *** (0.064) |
| GDP{2} | 0.087 (0.067) | 0.072 (0.067) | 0.046 (0.064) | 0.076 (0.067) | 0.064 (0.066) |
| GDP{3} | -0.073 (0.067) | -0.099 (0.067) | -0.075 (0.063) | -0.076 (0.067) | -0.087 (0.066) |
| GDP{4} | -0.113 * (0.064) | -0.128 ** (0.062) | -0.132 ** (0.059) | -0.153 ** (0.062) | -0.139 ** (0.062) |
| NOP3{1} | -0.006 (0.006) | -0.004 (0.005) | -0.004 (0.005) | -0.004 (0.005) | -0.004 (0.005) |
| NOP3{2} | -0.014 ** (0.006) | -0.008 (0.005) | -0.008 * (0.005) | -0.006 (0.005) | -0.007 (0.005) |
| NOP3{3} | -0.009 (0.006) | -0.020 *** (0.005) | -0.020 *** (0.005) | -0.022 *** (0.005) | -0.022 *** (0.005) |
| NOP3{4} | -0.014 ** (0.006) | -0.015 *** (0.005) | -0.015 *** (0.005) | -0.017 *** (0.006) | -0.017 *** (0.006) |
| Adj-R ² | 0.167 | 0.287 | 0.292 | 0.275 | 0.283 |
| F(4,231)= | 4.617 *** | 7.294 *** | 7.335 *** | 7.763 *** | 7.825 *** |

Notes: Standard errors are in parentheses. Real-time vintages are from the Philadelphia Reserve's Real-Time data set. The WTI Spot Price is from WSJ. The regression is evaluated from 1949:Q2 to 2009:Q1. The GDP variable is the quarterly percentage change for each vintage. The NOP3 variable is defined as an oil shock which is positive if the price is greater than the previous three year maximum and zero otherwise. There are 240 usable observations and 231 degrees of freedom. For the reported p-values, ***, **, * denote the significance at the 1, 5, and 10 percent levels, respectively.

Table 8**Evaluating Forecasts by the Ratio of RMSE With Oil Shocks Relative to the AR4**

| $\pi = 10\%$ | Out-of-Sample | AR(4) RMSE | PPI | WTI |
|------------------|----------------------|-------------------|------------|------------|
| Advance Diagonal | 2003:Q4 - 09:Q1 | 0.564 | 0.972 * | 0.855 *** |
| Advance Vintage | 2003:Q4 - 09:Q1 | 0.569 | 0.982 | 0.865 *** |
| Final Diagonal | 2003:Q4 - 09:Q1 | 0.667 | 0.952 ** | 0.885 *** |
| Final Vintage | 2003:Q4 - 09:Q1 | 0.669 | 0.951 ** | 0.885 *** |
| Revised | 2003:Q4 - 09:Q1 | 0.752 | 0.904 *** | 0.904 *** |

Notes: Data are presented as RMSE. The AR(4) models are regressions from Table 5 and create the baseline forecasts. The base AR(4) forecast model is augmented with either oil shocks calculated from the WTI Spot price or the Crude PPI. The augmented models are regressions from Table 6 and Table 7. The base and alternative models are estimated for the period 1949:Q2-2003:Q3 and one-step-ahead pseudo-forecasts are estimated for 2003:Q4-2009:Q1. The ratio of the augmented model to the AR(4) is represented in columns 5 and 6. According to McCracken (2007), ***, **, * denote the significance at the 1, 5, and 10 percent levels, respectively.

Table 9**Evaluating Forecasts by the Ratio of RMSE With Oil Shocks Relative to the AR4**

| $\pi = 15\%$ | Out-of-Sample | AR(4) RMSE | PPI | WTI |
|------------------|----------------------|-------------------|------------|------------|
| Advance Diagonal | 2001:Q4 - 09:Q1 | 0.586 | 0.992 | 0.910 *** |
| Advance Vintage | 2001:Q4 - 09:Q1 | 0.597 | 0.998 | 0.918 *** |
| Final Diagonal | 2001:Q4 - 09:Q1 | 0.658 | 0.967 ** | 0.920 *** |
| Final Vintage | 2001:Q4 - 09:Q1 | 0.663 | 0.926 ** | 0.920 *** |
| Revised | 2001:Q4 - 09:Q1 | 0.706 | 0.954 *** | 0.946 *** |

Notes: Data are presented as RMSE. The AR(4) models are regressions from Table 5 and create the base forecasts. The base AR(4) forecast model is augmented with either oil shocks calculated from the WTI Spot price or the Crude PPI. The augmented models are regressions from Table 6 and Table 7. The base and alternative models are estimated for the period 1949:Q2-2001:Q3 then one-step-ahead pseudo-forecasts are estimated for 2001:Q4-2009:Q1. The ratio of the augmented model to the AR(4) is represented in columns 5 and 6. According to McCracken (2007), ***, **, * denote the significance at the 1, 5, and 10 percent levels, respectively.

Table 10**Average Annual Real GDP Growth Rates Under Alternative Scenarios**

| PERIOD | Actual Revised Estimate | Actual Final Estimate | Actual Advance Estimate | Final Estimates Without Oil Shock (PPI) | | Final Estimates Without Oil Shock (WTI) | | Advance Estimates Without Oil Shock (PPI) | | Advance Estimates Without Oil Shock (WTI) | |
|---------------|-------------------------|-----------------------|-------------------------|---|----------------|---|----------------|---|----------------|---|----------------|
| | | | | <i>Diagonal</i> | <i>Vintage</i> | <i>Diagonal</i> | <i>Vintage</i> | <i>Diagonal</i> | <i>Vintage</i> | <i>Diagonal</i> | <i>Vintage</i> |
| 1974:Q1-75:Q1 | -2.47% | -6.40% | -6.06% | 2.63% | 2.64% | 3.93% | 3.98% | 2.46% | 2.53% | 3.69% | 3.74% |
| 1979:Q2-80:Q2 | -0.41% | -1.21% | -1.56% | 1.60% | 1.59% | 2.09% | 2.13% | 1.53% | 1.63% | 1.98% | 2.08% |
| 1981:Q2-82:Q2 | -1.46% | -1.57% | -2.03% | 1.93% | 1.94% | -0.84% | -0.85% | 1.65% | 1.80% | -0.90% | -0.08% |
| 1990:Q3-91:Q3 | -0.08% | -0.33% | -0.09% | 2.03% | 2.02% | 1.57% | 1.58% | 1.92% | 1.93% | 1.49% | 1.48% |
| 2007:Q4-08:Q4 | -0.67% | -0.51% | -0.20% | 2.63% | 2.64% | 1.34% | 1.37% | 2.58% | 2.66% | 1.30% | 1.36% |

Notes: The suggested contribution of abrupt oil price increases is defined as the difference of the average annual growth rates. The comparison of Crude PPI and WTI Spot contributions illustrates the advantage of the specification of a Net Oil Price Increase over 3 years (NOP3). The above Crude PPI oil shock specification would suggest almost all the deviation from the trend in each of the recessions to the oil shock. This further supports the notation that had these oil shocks not occurred, GDP would have grown rather than fallen in at least some of these episodes.

Table 11**Comparison of Recent Actual and Predicted GDP Growth**

| Release | Estimate | Quarter | AR(4) | | | | +PPI | +WTI | |
|-----------|----------------------|---------|------------|-------------|-------------|-------------|-------------|-------------|-------------|
| | | | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| 31-Jul-08 | Advance Estimate | 2008:Q2 | 1.9 | | | | 1.6 | -1.4 | 0.5 |
| 28-Aug-08 | Preliminary Estimate | 2008:Q2 | 3.3 | | | | | | |
| 26-Sep-08 | Final Estimate | 2008:Q2 | 2.8 | | | | 1.7 | -1.4 | 0.5 |
| 30-Oct-08 | Advance Estimate | 2008:Q3 | | -0.3 | | | 2.3 | -2.3 | 0.1 |
| 25-Nov-08 | Preliminary Estimate | 2008:Q3 | | -0.5 | | | | | |
| 23-Dec-08 | Final Estimate | 2008:Q3 | | -0.5 | | | 2.6 | -2.3 | 0.2 |
| 30-Jan-09 | Advance Estimate | 2008:Q4 | | | -3.8 | | 1.8 | -2.3 | -0.1 |
| 27-Feb-09 | Preliminary Estimate | 2008:Q4 | | | -6.2 | | | | |
| 26-Mar-09 | Final Estimate | 2008:Q4 | | | -6.3 | | 2.0 | -2.5 | -0.1 |
| 25-Apr-09 | Advance Estimate | 2009:Q1 | | | | -6.1 | -0.1 | -3.2 | -1.9 |
| 27-May-09 | Preliminary Estimate | 2009:Q1 | | | | -5.7 | | | |
| 26-Jun-09 | Final Estimate | 2009:Q1 | | | | -5.5 | -1.0 | -4.3 | -2.9 |
| 31-Jul-09 | Advance Estimate | 2009:Q2 | | | | | -1.5 | -1.5 | -1.6 |
| 27-Aug-09 | Preliminary Estimate | 2009:Q2 | | | | | | | |
| 26-Sep-09 | Final Estimate | 2009:Q2 | | | | | -1.4 | -1.6 | -1.5 |

Notes: Quarterly estimates are annualized for comparison of well known published releases from the BEA. The direct forecasts for vintage real-time estimates are shown for comparison to the actual release. Using the baseline specification of the univariate model, estimates are shown under AR(4). The forecasts for GDP using Crude PPI oil shocks as an explanatory variable are shown under the column labeled "+PPI". The Crude PPI variable predicts negative growth in 2008:Q2, congruent with expectations of future downward revision. ***On July 31st, 2009 the estimate for 2009:Q1 was revised downward from -5.5% to -6.4%. Our estimates show the most negative impact from the oil shock occurring in 2009:Q1 which is congruent with revised estimates for that quarter.

Figure 1

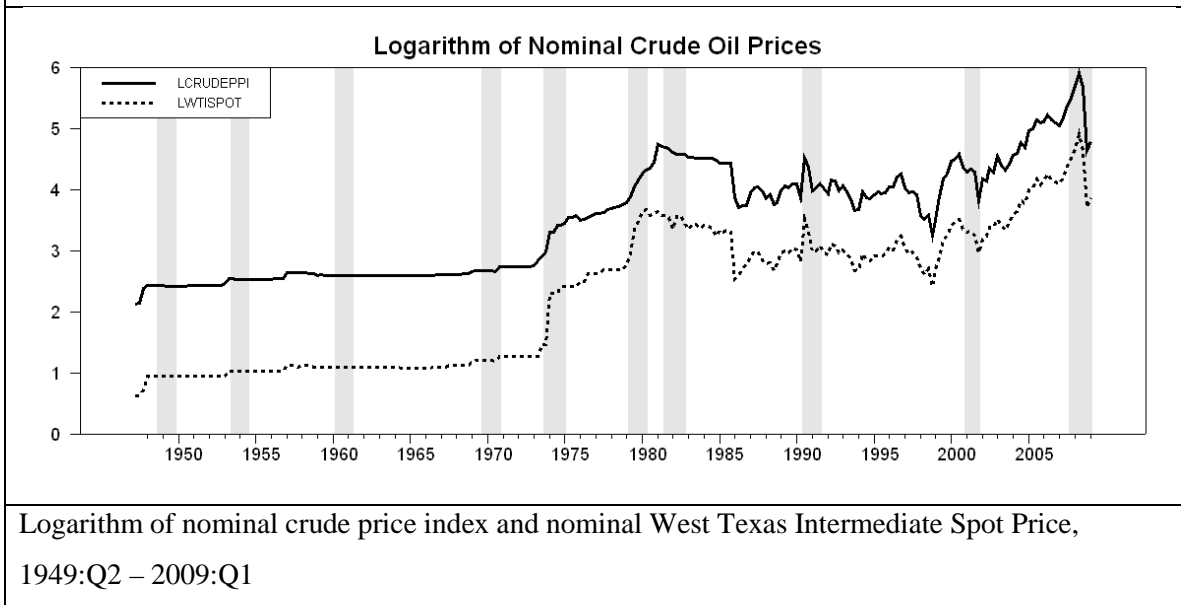
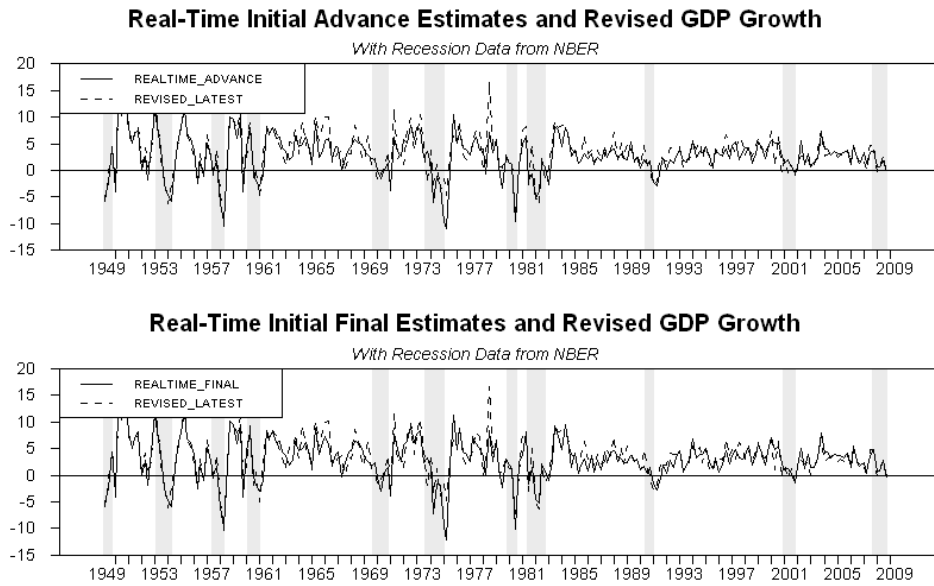
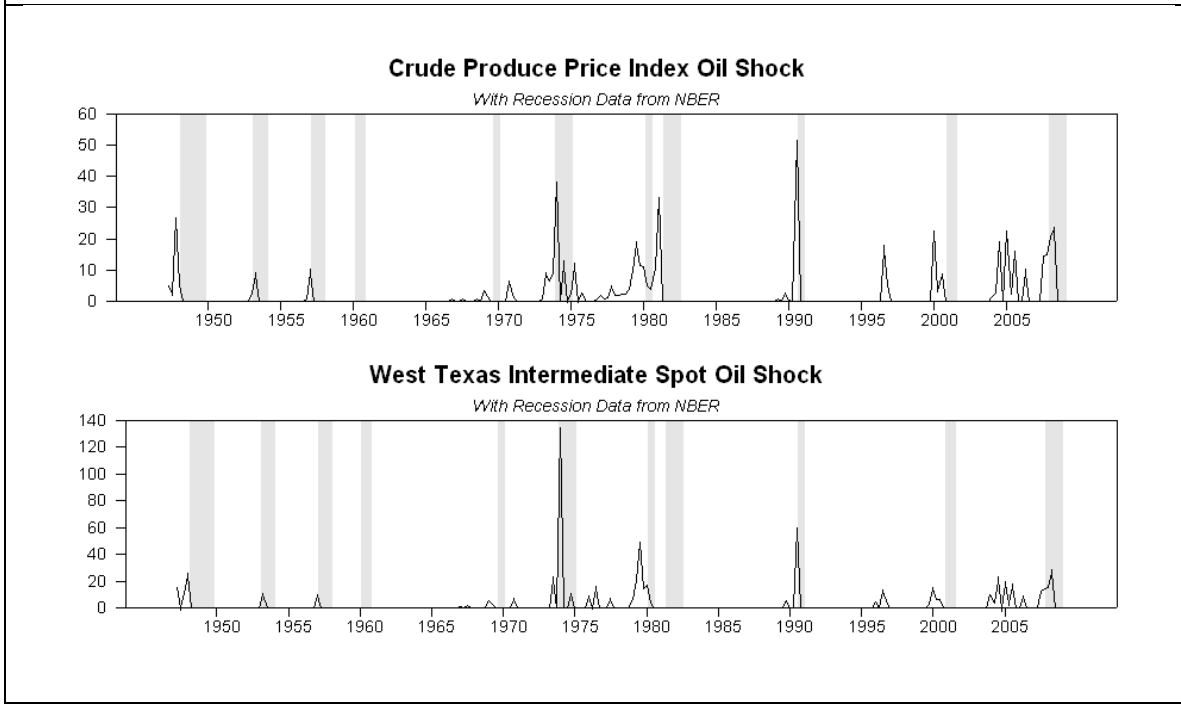


Figure 2



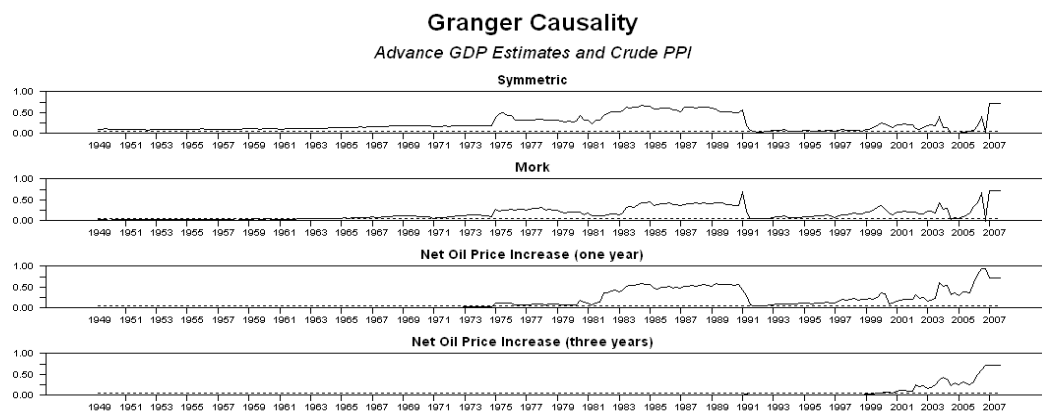
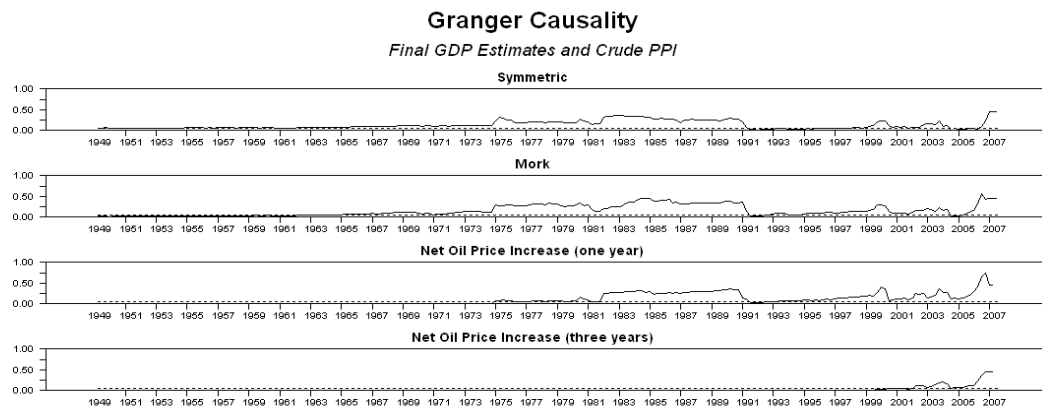
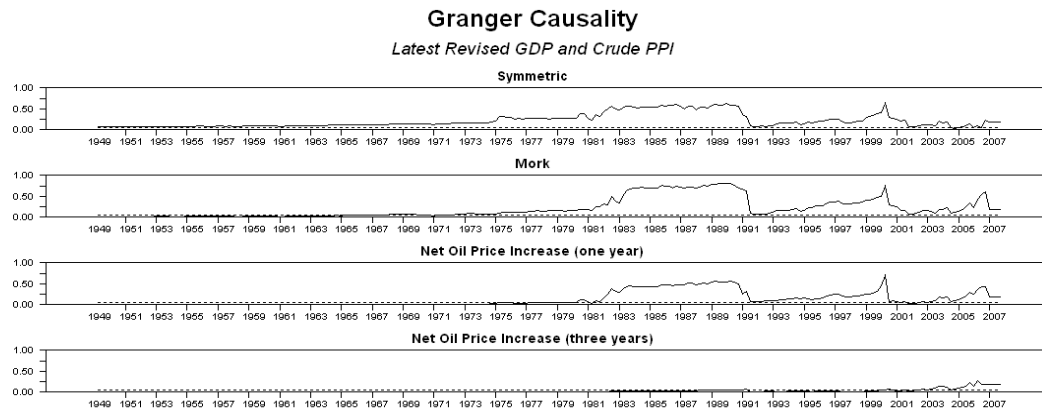
Annualized quarterly percent changes of Real-Time GDP , 1949:Q2 – 2009:Q1

Figure 3



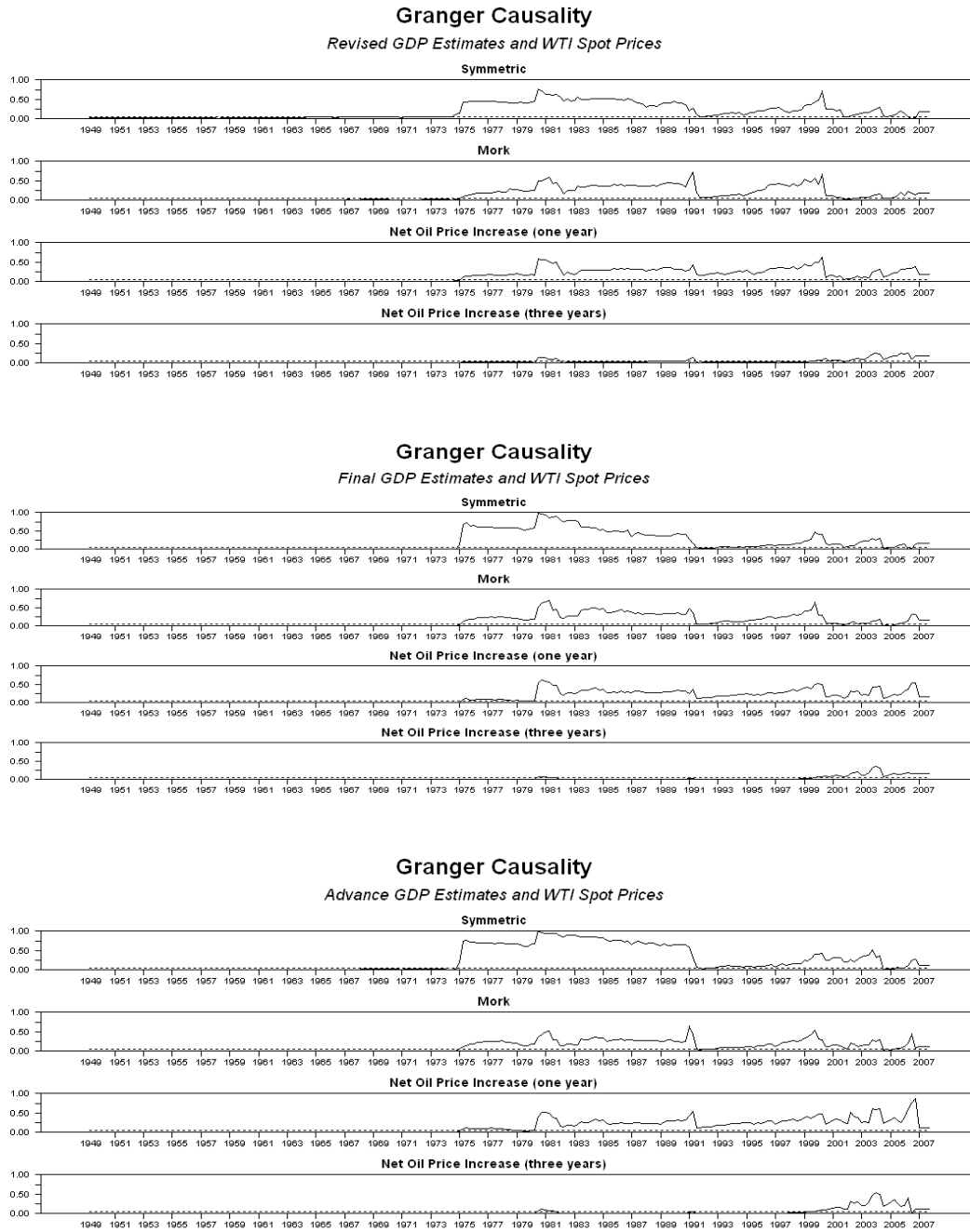
Measures of the 3-year net oil increase using the nominal crude price index and nominal West Texas Intermediate Spot Price, 1949:Q2 – 2009:Q1

Figure 4



Evidence of Granger causality. Each figure plots the p-value for a test of the null hypothesis that coefficients on the oil price measure are zero in a regression of real-time GDP growth on a constant, four of its own lags, and four lags of the oil price measure from CRUDE PPI, where the first date in the regression is plotted on the horizontal axis. Dashed lines denote $p=0.05$.

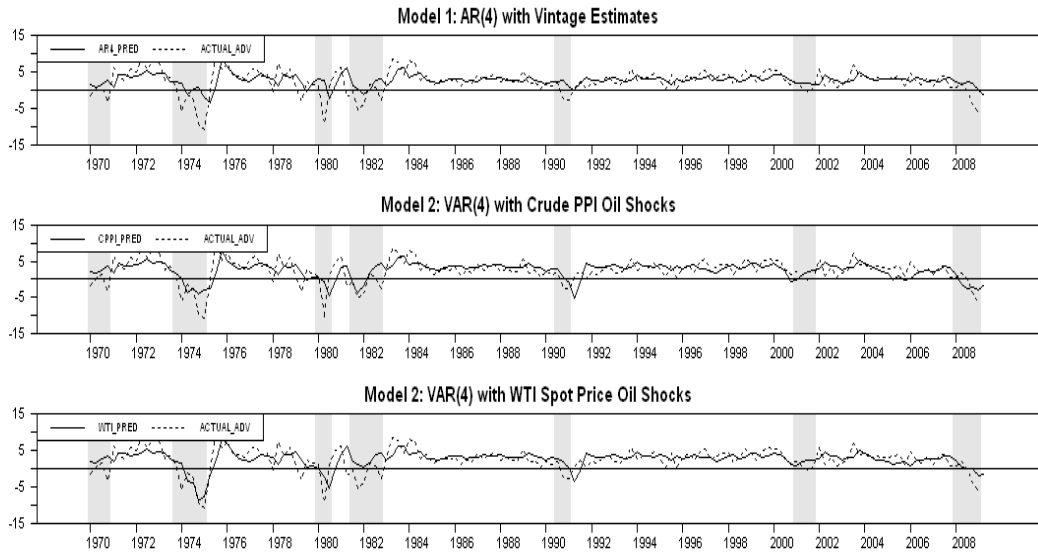
Figure 5



Evidence of Granger causality. Each figure plots the p-value for a test of the null hypothesis that coefficients on the oil price measure are zero in a regression of real-time GDP growth on a constant, four of its own lags, and four lags of the oil price measure from WTI Spot Prices, where the first date in the regression is plotted on the horizontal axis. Dashed lines denote $p=0.05$.

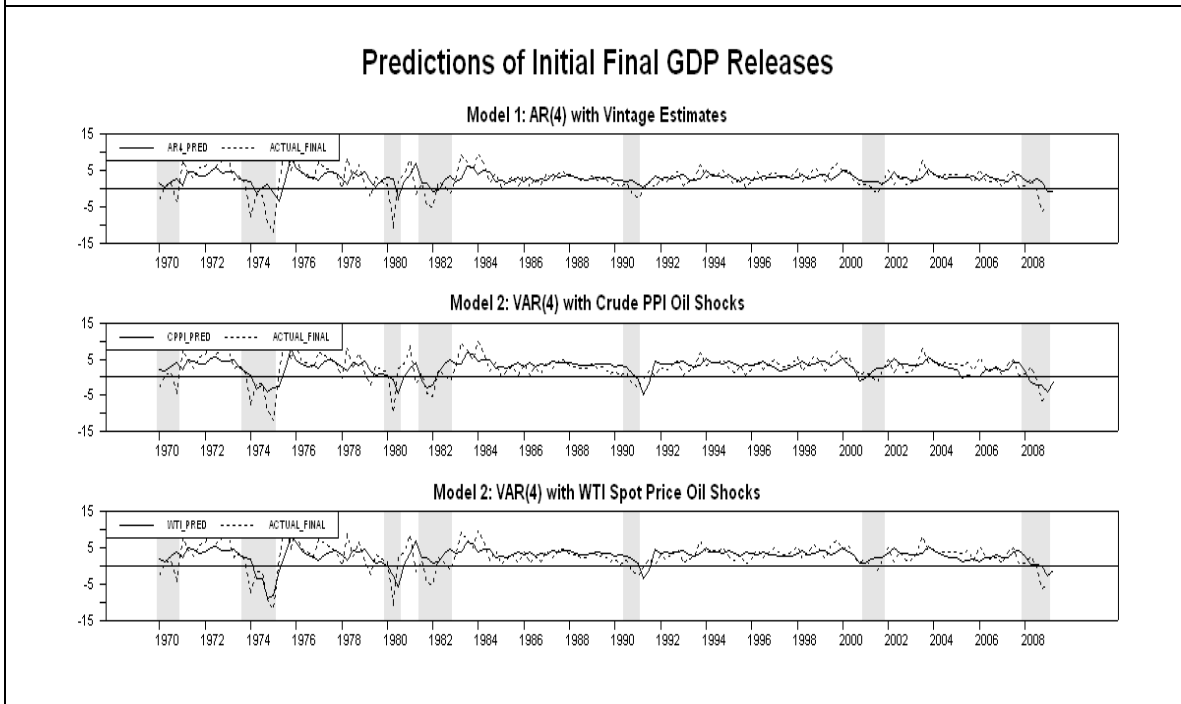
Figure 6

Predictions of Initial Advance GDP Releases



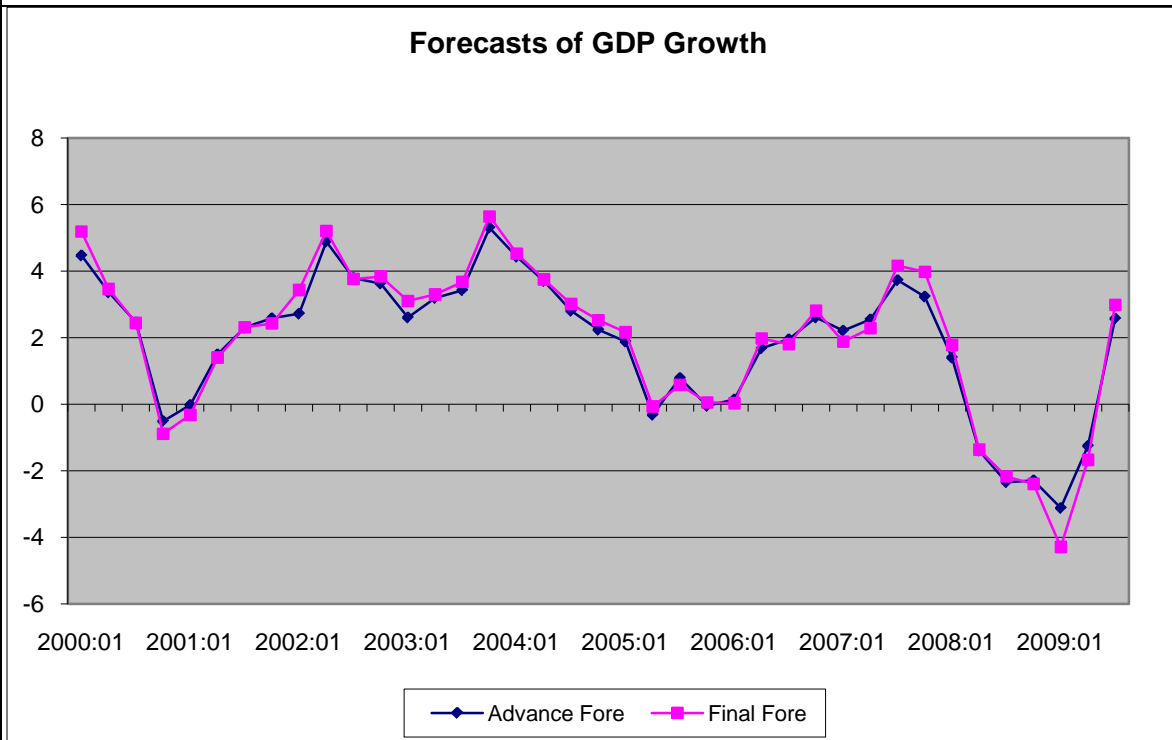
Each figure plots the forecast one step ahead using Model 1 or Model 2. Model 1 is a regression of real-time GDP growth on a constant and four lags of the vintage GDP available at that time. Model 2 is a regression of real-time GDP growth on a constant, four lags of the vintage GDP available at that time and four lags of the 3-year net oil price increase measure, where the first date in the regression is 1949:Q2.

Figure 7



Each figure plots the forecast one step ahead using Model 1 or Model 2. Model 1 is a regression of real-time GDP growth on a constant and four lags of the vintage GDP available at that time. Model 2 is a regression of real-time GDP growth on a constant, four lags of the vintage GDP available at that time and four lags of the 3-year net oil price increase measure, where the first date in the regression is 1949:Q2.

Figure 8



Each figure plots the forecast one step ahead using Model 2. Model 2 is a regression of real-time GDP growth on a constant, four lags of the vintage GDP available at that time and four lags of the 3-year net oil price increase measure from Crude PPI, where the first date in the regression is 1949:Q2. The regression is updated with 2009:Q2 estimates to forecast 2009:Q3 GDP.