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# The Effects of Oil Price Shocks on Output

NEAL GHOSH, CHRIS VARVARES and JAMES MORLEY*

*This analysis explores the effects of oil price shocks on U.S. economic growth. We begin with a well-known model developed by James Hamilton, consider refinements to his definition of an oil price "shock," and then explore alternatives to his basic reduced-form model. We find that a structurally inspired error-correction model for non-farm business output, which allows for oil price changes to have both long-run and short-run effects, performs better than the basic reduced-form model and also shows significantly smaller adverse effects of rising oil prices. Our preferred model suggests that oil prices reduced GDP growth by about 0.4 percentage point on average through the first three quarters of 2008, before contributing 1.7 percentage points in the fourth quarter as prices plummeted.*
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The period since 2003 witnessed a dramatic increase in crude oil prices, culminating in 2008's meteoric rise of crude oil prices to near $150/bbl as of mid year, as shown in Figure 1 for the price of West Texas Intermediate crude. The bulk of this rise was quite quickly reversed, as prices fell to roughly $45 by the end of December. The run-up both impinged on business operating margins and squeezed the real disposable incomes of households. This no doubt restrained the growth of aggregate demand in a U.S. economy already reeling from the transition from housing boom to housing bust and the rapid unraveling of key components of our financial infrastructure. As such, the surge in oil prices may well have been instrumental in tipping the U.S. and global economy into recession and brought into sharp focus the importance of the question of what effect do oil price movements have on output?

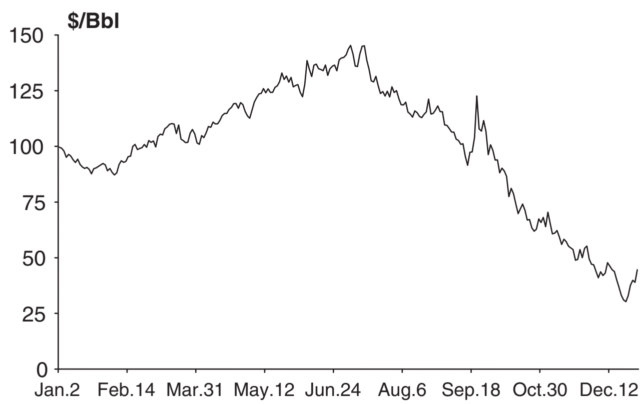
This analysis explores the effects that oil price shocks have on U.S. economic growth. We begin with a well-known model developed by James Hamilton, consider refinements to his definition of an oil price "shock," and then explore alternatives to the basic reduced-form model employed by Hamilton. We find that a structurally inspired error-correction model (ECM) for non-farm business output, which allows for oil price changes to have both long-run and short-run effects, performs better than the reduced-form model and also shows significantly smaller adverse effects of rising oil prices. Our preferred model suggests that oil prices reduced GDP growth by about 0.4 percentage points on average through the first three quarters of 2008, before contributing 1.7 percentage points in the fourth quarter as prices plummeted.

*Neal Ghosh is an economic analyst at Macroeconomic Advisers where he works across a range of research tasks including model estimation and simulation support, data collection and analysis in support of special projects, and current macroeconomic analysis. He received a B.A in Economics in December 2007 and an M.S. in Finance in May 2009, both from Washington University.

Chris Varvares is the president of Macroeconomic Advisers, LLC, a company he co-founded in 1982. Mr. Varvares is also the current president (October 2008 – September 2009) of the National Association for Business Economics (NABE). Prior to founding Macroeconomic advisers, he was a member of the staff of the President's Council of Economic Advisers. Mr. Varvares is a former director of NABE, past president of the St. Louis chapter, and is a member of the American Economic Association. He is a member of the New York State Economic and Revenue Advisory Board, serves on the Bureau of the Census Advisory Committee, and has been a panelist for the World Economic Forum. Mr. Varvares holds a B.A. in Economics from the George Washington University and an M.A. in Economics from Washington University in St. Louis.

James Morley is an associate professor of Economics at Washington University in St. Louis, where he teaches macroeconomics, finance, and econometrics. His research focuses on the development of time series models and techniques to examine the nature and sources of business cycle fluctuations. His other professional activities include being a visiting researcher at the Bank of Canada and a research fellow at the Federal Reserve Bank of St. Louis. He has also been a "time series" consultant for Macroeconomic Advisers, LLC since 2005.

Figure 1. Daily Price of West Texas Intermediate Crude in 2008




## 1. What Is an Oil Price Shock?

There is a broad literature on the topic of oil price shocks. Mostly, the literature focuses on two critical questions. First, what is the true "shock" in price movements? Most of the major fluctuations in oil prices during the 1970s and 1980s were caused by exogenous political events [Hamilton 1985], such as the OPEC oil embargo, but subsequent movements were mostly the result of demand shocks [Barsky and Kilian 2004]. Kilian [2009] provides a thorough discussion of the different categories of shocks, noting that the source of the shock is critical in determining its effect on macroeconomic aggregates. Others have focused on the responses in output to oil price movements. Structural models have been developed that explain output responses pre-1980 [Wen and Aguiar-Conraria 2005], but do not perform well thereafter. These results are consistent with Hooker [1996], who found a break in the oil price—macroeconomy relationship in 1986. There is structural evidence as to why oil price increases would negatively impact both consumption [Kliesen 2008] as well as investment [Wen and Aguiar-Conraria 2005]. Moreover, Bernanke, Gertler, and Watson [1997] suggested that endogenous monetary responses are responsible for most of the output response rather than the oil price shock itself, although Hamilton and Herrera [2004] have provided some evidence to refute this claim.

Perhaps the most commonly used definition of an oil price shock is a concept that Hamilton labels the net oil price increase (NOPI) [Hamilton, 2003]. Underlying this definition are two hypotheses: first, that price movements are not considered shocks unless they pass a relative threshold, and second, that only positive price movements matter. The relative threshold was meant to eliminate small movements that would not be expected to trigger an adjustment in production, as well as eliminate any endogenous movements in prices. Hamilton considered only positive price movements to address the observed asymmetry in output responses. This asymmetry, he argues, arises because output "costs" are associated with re-organizing production to economize on higher relative energy costs when energy prices rise above the prior peak but are not subsequently undone when energy prices subsequently fall.

NOPI is defined as one hundred times the logarithmic difference between the current oil price and the maximum price within the previous 12 quarters, if positive. Mathematically it can be defined as:

$$o_t^{\#} = 100 * \log\left(\frac{P_t}{\max(P_{t-1}, \ldots, P_{t-12})}\right)^{+} \qquad (1)$$

In equation (1), $o^{\#}$ is Hamilton's shock (where # on the left-hand side and $+$ on the right-hand side denote the inclusion of nonnegative values only) and $P$ is the price level of West Texas Intermediate Crude (WTI). In his analysis, Hamilton estimates the effects of these shocks in an autoregressive distributed lag (ADL) framework, with four quarters of lags.

$$\Delta\log(y_t) = c + \sum_{i=1}^{4} \alpha_i \cdot \Delta\log(y_{t-i}) + \sum_{j=1}^{4} \delta_j \cdot o_{t-j}^{\#} + \varepsilon_t \qquad (2)$$

In equation (2), $y$ is U.S. real GDP. Notably, Hamilton was able to reject that the oil shock terms were jointly insignificant.

For the purposes of this analysis, we have re-estimated Hamilton's model, short fitting the sample to begin in 1970, but extending it through 2008, and the results can be found in Table 1, column 1. Our results are very similar to what Hamilton found: all four lags have negative coefficients, and although they are not individually significant, jointly they are very significant. Most importantly, the results trounce an alternative model that defines oil price shocks as the simple one-quarter logarithmic change (column 2). This suggests that Hamilton's non-linear transformation captures the true "shock" in oil prices better than the simple measure.

**Table 1. Hamilton's Model**

Dependent Variable $\Delta\ln(y)$

Sample: 1970q1—2008q4

| | Column 1 | Column 2 |
|---|---|---|
| | $o = o^{\#}$ | $o = \Delta\ln(P)$ |
| $c$ | 0.0075 | 0.0051 |
| *t-stat* | *5.6* | *4.4* |
| $\Delta\ln(y_{t-1})$ | 0.1435 | 0.1926 |
| *t-stat* | *1.7* | *2.3* |
| $\Delta\ln(y_{t-2})$ | 0.0766 | 0.1339 |
| *t-stat* | *0.9* | *1.6* |
| $\Delta\ln(y_{t-3})$ | −0.0290 | −0.0082 |
| *t-stat* | *−0.4* | *−0.1* |
| $\Delta\ln(y_{t-4})$ | −0.0121 | 0.0160 |
| *t-stat* | *−0.1* | *0.2* |
| $o_{t-1}$ | −0.0109 | −0.0074 |
| *t-stat* | *−1.4* | *−1.5* |
| $o_{t-2}$ | −0.0160 | −0.0062 |
| *t-stat* | *−2.1* | *−1.2* |
| $o_{t-3}$ | −0.0080 | −0.0045 |
| *t-stat* | *−1.0* | *−0.9* |
| $o_{t-4}$ | −0.0198 | −0.0084 |
| *t-stat* | *−2.5* | *−1.7* |
| $R^2$ adjusted | 0.155 | 0.104 |
| LL | 540.797 | 536.241 |

## 2. An Alternative Definition of an Oil Price Shock

Hamilton uses a non-parametric approach to derive the non-linear transformation of oil prices that best fits the data in equation (2). However, we feel his definition is still not complete. First, the relative threshold is meant to wash out endogenous movements; however, we have observed in 2008 a large increase in the oil price that was not caused by any known exogenous event. Second, he attempts to address potential asymmetries by assuming no positive output responses for negative shocks; we think this is too restrictive and prefer to test whether negative shocks have no effect, the same effect, or a different effect compared with positive shocks. Third, this transformation is based solely on the observed oil price level and fails to account for the potentially important feedback from the economy to oil prices. Hence, we explore whether parsing oil price movements into the unobservable endogenous and exogenous components makes a difference to the results. In doing so, we are motivated by Barsky and Kilian [2004], who found reverse causality from macroeconomic variables to oil prices. This approach is based on the notion that oil prices are endogenous to the global economy, and that movements that correspond to this endogeneity would not constitute a "shock." Addressing this endogeneity would help differentiate movements caused by political events, which would be seemingly uncorrelated with economic performance, from movements caused by endogenous change. Indeed, being able to determine which portions of fluctuations are endogenous and which are exogenous is a critical step toward unveiling the responses in output.

There are several sources of endogeneity in oil prices, including domestic economic activity, foreign economic activity, interest rates, core inflation, and persistence. Rising global demand for oil tied to rapid growth abroad, against the backdrop of tight supplies, is widely viewed as the primary source of the rise in oil prices in 2008; meanwhile, the development and deepening of oil futures markets has transformed oil into a financial instrument for many agents. To discern the true disturbances in oil price movements, we would like to remove any effects of these drivers of oil prices. Therefore, we define the oil price shock in terms of movements that are orthogonal to the above set of factors.

To define our oil price shock, we first estimate what effect the economy has on oil prices. To do so, we regress oil prices on the listed factors above in an ADL framework with one lag:

$$\begin{aligned}\Delta\log(P_t) = c &+ \beta_1 \cdot \Delta\log(y_{t-1}) \\ &+ \beta_2 \cdot \Delta\log(w_{t-1}) \\ &+ \beta_3 \cdot \Delta i_{t-1} + \beta_4 \cdot \Delta\log(\pi_{t-1}) \\ &+ \beta_5 \cdot \Delta\log(P_{t-1}) + \varepsilon_t \qquad (3)\end{aligned}$$

In equation (3), $y$ is once again U.S. GDP, $w$ is foreign GDP, $i$ is the federal funds rate, and $\pi$ is the core PCE price level. We would expect all these variables to have positive coefficients, as they all exert upward pressure on oil prices in some manner. Furthermore, because we will later test the contemporaneous effects of oil prices on output, we impose that oil prices do not respond

**Table 2. Oil Price Equation Estimates**

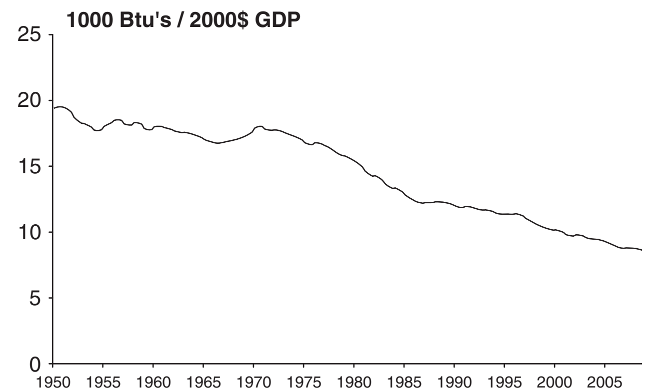
Dependent Variable $\Delta\ln(P)$

Sample: 1979q1—2008q4

| | Column 1 | Column 2 |
|---|---|---|
| $c$ | −0.0742 | −0.0715 |
| *t-stat* | *−1.9* | *−1.9* |
| $\Delta\ln(y_{t-1})$ | 0.4838 | — |
| *t-stat* | *0.2* | — |
| $\Delta\ln(e_{t-1} \times y_{t-1})$ | — | 2.6532 |
| *t-stat* | — | *1.3* |
| $\Delta\ln(w_{t-1})$ | 8.3769 | 6.4287 |
| *t-stat* | *2.4* | *1.8* |
| $\Delta(i_{t-1})$ | 0.0198 | 0.0123 |
| *t-stat* | *0.8* | *0.5* |
| $\Delta\ln(\pi_{t-1})$ | 1.3129 | 2.6509 |
| *t-stat* | *0.5* | *0.9* |
| $\Delta\ln(P_{t-1})$ | 0.1621 | 0.1731 |
| *t-stat* | *1.6* | *1.7* |
| $R^2$ adjusted | 0.091 | 0.103 |
| LL | 70.158 | 71.012 |

contemporaneously to the other factors. The results of this estimation are in column 1 of Table 2. All coefficients have the expected sign; however, the coefficient on domestic output is quite low and very insignificant, a surprising result. This specification, however, ignores the time-varying relationship between the U.S. economy and energy consumption. This point was also raised by Kilian [2008]. Figure 2 shows the energy intensity of the U.S. economy, defined as 1,000s of Btu's per GDP in 2000 dollars. One can see that this intensity has declined steadily over time, making domestic output less dependent and less sensitive to oil prices. To judge the true response of oil prices to output, one must normalize output by its energy intensity. Column 2 of Table 2 shows the results of (3) with the energy intensity parameter, $e$, premultiplying domestic output. The variable $e$ is the energy intensity defined in Figure 2. One can see now that the coefficient on domestic output growth is much larger and more significant. The realized

**Figure 2. Energy Intensity of the U.S. Economy**




errors $\varepsilon$ then become our estimate of exogenous oil price shocks.

These MA-defined ("MA" for Macroeconomic Advisers) oil price shocks, $\varepsilon$, represent the exogenous components of oil price movements over time. However, as we previously argued, the effects of oil price changes on output should be importantly influenced by the energy intensity of output. So, we normalize the shocks by the energy intensity parameter ($e$), scaled by its sample mean, leading to an adjusted measure of energy shock, $\tilde{\varepsilon}$. This represents the exogenous movements in oil prices (to a first approximation)—that is, the movements in energy prices that cannot be explained by past economic performance—adjusted to reflect the secular decline in the energy intensity of the U.S. economy.

## 3. The Reduced-Form Horse Race

To test the relative effectiveness of these newly defined MA shocks, we run a horse race between our shocks ($\varepsilon$ and $\tilde{\varepsilon}$) and Hamilton's shocks ($o^{\#}$) in the same reduced-form framework proposed by Hamilton, except we include the contemporaneous shock term along with the four lags. Table 3 shows the results of this race.

Column 1 shows the regression using Hamilton's shocks, while column 2 is for the realized errors $\varepsilon$ from equation (3); and column 3 shows the results of using the errors of equation (3) multiplied by the energy intensity parameter scaled by its sample mean, $\tilde{\varepsilon}$. The results of this horse race suggest that Hamilton's shocks are best at fitting the data in the reduced-form framework. Furthermore, adjusting Hamilton's shocks by the energy intensity did not improve their fit, nor did parsing the MA shocks into positive and negative components.

**Table 3. Horse Race**

Dependent Variable $\Delta\ln(y)$

Sample: 1971q2—2008q4

| | Column 1 | Column 2 | Column 3 |
|---|---|---|---|
| | $o = o^{\#}$ | $o = \varepsilon$ | $o = \tilde{\varepsilon}$ |
| $c$ | 0.0077 | 0.0051 | 0.0054 |
| *t-stat* | *5.8* | *4.2* | *4.3* |
| $\Delta\ln(y_{t-1})$ | 0.1856 | 0.2477 | 0.2325 |
| *t-stat* | *2.3* | *3.0* | *2.8* |
| $\Delta\ln(y_{t-2})$ | 0.0297 | 0.0916 | 0.0720 |
| *t-stat* | *0.4* | *1.1* | *0.8* |
| $\Delta\ln(y_{t-3})$ | −0.0230 | −0.0424 | −0.0505 |
| *t-stat* | *−0.3* | *−0.5* | *−0.6* |
| $\Delta\ln(y_{t-4})$ | 0.0268 | −0.0054 | −0.0068 |
| *t-stat* | *0.3* | *−0.1* | *−0.1* |
| $o_t$ | −0.0196 | −0.0029 | −0.0065 |
| *t-stat* | *−2.7* | *−0.6* | *−1.2* |
| $o_{t-1}$ | −0.0078 | −0.0061 | −0.0065 |
| *t-stat* | *−1.1* | *−1.2* | *−1.2* |
| $o_{t-2}$ | −0.0134 | −0.0070 | −0.0092 |
| *t-stat* | *−1.8* | *−1.3* | *−1.6* |
| $o_{t-3}$ | −0.0065 | −0.0043 | −0.0048 |
| *t-stat* | *−0.9* | *−0.8* | *−0.9* |
| $o_{t-4}$ | −0.0212 | −0.0076 | −0.0096 |
| *t-stat* | *−2.8* | *−1.5* | *−1.7* |
| $R^2$ adjusted | 0.214 | 0.099 | 0.112 |
| LL | 533.028 | 522.729 | 523.795 |

## 4. An ECM Approach

One reason that the MA-defined shocks underperformed in the horse race could be because the model may be incomplete, omitting too many variables. Indeed, many other factors affect output growth [Bernanke, Gertler, and Watson, 1997], and it could be that Hamilton's shock is capturing that variation better than the MA shocks. More importantly, by modeling output as a reduced-form equation for differences in log output, Hamilton is ignoring the possibility of co-integration between oil prices and output. The existence of co-integration would provide valuable information to understanding the effects of price shocks. It could be the case that oil prices movements have non-linear effects because of firms' inability to adjust to price swings in the short run. However, in the long run, one would expect firms to make the full adjustment, and for the level of oil prices to have a linear relationship with the level of output. So, we would like to model output by capturing both the short-run effects of oil price movements as well as the long-run relationship between the level of output and oil prices, which is why we proceed with an ECM approach.

We define the target level of non-farm business output as determined by an underlying production function, depending on the level of hours and total factor productivity. We then augment the production function with the real price of oil, normalized by the energy-intensity parameter, $e$, scaled by its sample mean. By including the oil price level in the long-run relationship, we allow for oil prices to linearly affect the desired level of output. This is consistent with economic theory, which defines the oil price as a capacity constraint in the production function. This long-run relationship is estimated to be:

$$\begin{aligned}\log(Q) = &- 1.146 + 0.867 \cdot \log(hours) \\ &+ 1.057 \cdot \log(prod) - 0.008 \\ &\cdot \frac{e}{\ddot{e}} \cdot \log\left(\frac{P}{\pi}\right)\end{aligned} \tag{4}$$

In this regression, $Q$ is the level of non-farm business output; *hours* is hours worked in the non-farm business sector; *prod* is an estimate of the level of structural productivity in the non-farm business sector, derived in the Macroeconomic Advisers model of the U.S. economy. The coefficient on the oil price term is very small but, with a $t$-statistic of $-3.5$, significant. Note that we use dynamic OLS in our estimate of the coefficients to address bias. Furthermore, a Phillips-Ouliaris test of the residuals at the 5 percent level implies that these variables are in fact co-integrated.

## 5. The ECM and Horse Race Part II

Next, we specify a dynamic ECM for the change in non-farm business output. This will be the equation we will use to conduct our horse race. We regress the logarithmic change of output onto the lagged deviation between the long-run and actual levels of output, growth of hours, growth of productivity, growth of government output, growth of foreign output, a dummy variable for the dock strike of

**Table 4. Horse Race II**

Dependent Variable $\Delta\ln(Q)$

Sample: 1971q2–2008q4

| | Column 1 | Column 2 | Column 3 | Column 4 |
|---|---|---|---|---|
| | | $o = o^{\#}$ | $o = \varepsilon$ | $o = \tilde{\varepsilon}$ |
| $\ln(Q_{t-1}/Q^*_{t-1})$ | −0.2206 | −0.1910 | −0.2266 | −0.2250 |
| *t-stat* | *−5.7* | *−4.5* | *−5.7* | *−5.6* |
| $\Delta\ln(hours_t)$ | 1.4358 | 1.3771 | 1.4812 | 1.4655 |
| *t-stat* | *10.6* | *9.3* | *10.9* | *10.5* |
| $\Delta\ln(prod_t)$ | 1.7166 | 1.7119 | 1.9133 | 1.8896 |
| *t-stat* | *5.4* | *5.3* | *5.9* | *5.9* |
| $\Delta\ln(w_t)$ | 0.4390 | 0.4511 | 0.4252 | 0.4171 |
| *t-stat* | *3.3* | *3.3* | *3.1* | *3.0* |
| $\Delta\ln(g_t)$ | 0.1569 | 0.1738 | 0.1760 | 0.1800 |
| *t-stat* | *2.7* | *2.9* | *2.9* | *2.9* |
| $i10-\pi^e$ | −0.1225 | −0.1236 | −0.1478 | −0.1440 |
| *t-stat* | *−2.9* | *−2.9* | *−3.4* | *−3.4* |
| $1_{dock\ strike}$ | 0.0159 | 0.0154 | 0.0149 | 0.0149 |
| *t-stat* | *5.8* | *5.0* | *5.0* | *4.9* |
| $o_t$ | — | −0.0072 | −0.0073 | −0.0085 |
| *t-stat* | — | *−1.8* | *−2.8* | *−2.7* |
| $o_{t-1}$ | — | −0.0100 | −0.0100 | −0.0100 |
| *t-stat* | — | *−2.4* | *−2.7* | *−2.6* |
| $o_{t-2}$ | — | −0.0095 | −0.0031 | −0.0049 |
| *t-stat* | — | *−1.5* | *−0.6* | *−0.8* |
| $o_{t-3}$ | — | 0.0064 | −0.0009 | −0.0009 |
| *t-stat* | — | *1.4* | *−0.3* | *−0.2* |
| $o_{t-4}$ | — | −0.0026 | 0.0014 | 0.0012 |
| *t-stat* | — | *−0.5* | *0.3* | *0.0* |
| $R^2$ adjusted | 0.660 | 0.666 | 0.671 | 0.671 |
| LL | 550.935 | 555.132 | 556.128 | 556.226 |

1978, and the real 10-year note yield. The results are in column 1 of Table 4. This equation already has an $R$-squared of 0.66, suggesting that oil prices are unlikely to gain power from omitted variables when added to the specification.

Table 4 also shows the results of conducting the same horse race as before within the new, more structurally oriented equation. Column 2 contains the results of using Hamilton's shocks, column 3 show the results of using our un-scaled shocks, and column 4 employs $\tilde{\varepsilon}$ as the shock term. The horse race shows that the MA shock, adjusted for energy intensity, provides the best fit of the data within this more structurally oriented framework, although the distinction is quite small. Still, we consider it formidable that we can achieve marginally better explanatory power with a shock that has a more intuitive economic rationale and that allows both positive and negative oil price changes to impact output.

## 6. Are the Effects Symmetric?

Next, we return to the question of potential asymmetries in the effects of oil price shocks on output. Hamilton hypothesized that only positive shocks mattered. We would like to see

- if negative shocks matter, and
- if they have a different effect than positive shocks.

The horse race described in section 5 suggested that the MA energy-adjusted shock works best in the ECM, so we will use this definition of the shock in this exercise.

First, let us separate the shock into its positive and negative components, defined as:

$$\tilde{\varepsilon}^{+} = \max(\tilde{\varepsilon}, 0) \tag{5}$$

$$\tilde{\varepsilon}^{-} = \min(\tilde{\varepsilon}, 0), \tag{6}$$

where "+" in equation (5) and "−" in equation (6) indicate nonnegativity and nonpositivity, respectively. In the prior horse race using our preferred shock, the third and fourth lags were highly insignificant, so we remove them. Table 5 shows the results of three additional regression estimates of the ECM shown in Table 4. For brevity, we omit reporting all the terms except the oil price shock terms, although all coefficients remain of the correct sign and significant. Column 1 of Table 5 shows the results of this estimation, yielding three oil shock terms: the contemporaneous and two lags. Note that we can now substitute for the total shock with the positive (5) and negative (6) shocks, as defined above. This will allow the data to tell us if output has a different sensitivity to negative shocks than positive shocks. The results of this estimation are in column 2 of Table 5.

Table 5. Estimating Asymmetric Effects

| | Column1 | Column 2 | Column 3 |
|---|---|---|---|
| $\tilde{\varepsilon}_t$ | −0.0086 | — | — |
| *t-stat* | *−2.7* | — | — |
| $\tilde{\varepsilon}_{t-1}$ | −0.0099 | — | — |
| *t-stat* | *−2.7* | — | — |
| $\tilde{\varepsilon}_{t-2}$ | −0.0050 | — | — |
| *t-stat* | *−0.9* | — | — |
| $\tilde{\varepsilon}_t^+$ | — | −0.0028 | — |
| *t-stat* | — | *−0.8* | — |
| $\tilde{\varepsilon}_{t-1}^+$ | — | −0.0101 | −0.0117 |
| *t-stat* | — | *−2.5* | *−2.6* |
| $\tilde{\varepsilon}_{t-2}^+$ | — | −0.0105 | −0.0097 |
| *t-stat* | — | *−1.8* | *−1.8* |
| $\tilde{\varepsilon}_t^-$ | — | −0.0178 | −0.0191 |
| *t-stat* | — | *−3.3* | *−3.7* |
| $\tilde{\varepsilon}_{t-1}^-$ | — | −0.0104 | — |
| *t-stat* | — | *−1.1* | — |
| $\tilde{\varepsilon}_{t-1}^-$ | — | 0.0032 | — |
| *t-stat* | — | *0.5* | — |
| $R^2$ adjusted | 0.676 | 0.676 | 0.679 |
| LL | 556.162 | 557.957 | 557.015 |

One can see now that the lags of the oil shock term in column 1 gained their statistical power from different components of the shock. Specifically, the contemporaneous negative shock is significant, but the contemporaneous positive shock is not. Moreover, the two lags of the positive shock are significant while the two lags of the negative shock are not. Column 3 shows the result of a condensed model that eliminates the insignificant shock terms, leaving the contemporaneous negative shock and the two lags of the positive shock. This model has a slightly better fit than that of column 1, where the positive and negative shocks were combined. Furthermore, one can see that the negative coefficient is less than the sum of the two positive coefficients. This would suggest that effects of oil price shocks on output are indeed asymmetric. However, one cannot reject the null hypothesis that the two are equal, using a Wald coefficient test. Thus, the magnitude of the effects may be symmetric, but this equation suggests that certainly the timing of the shocks are different. Because the model that allows the positive and negative shocks to enter differentially fits slightly better, we are inclined to make this our preferred model.

## 7. 2008 and the Forecast

Now that we have settled upon our preferred model, we can run some simulations to estimate the partial effect of oil prices on output. Our focus here is for 2008, but we will extend the simulations into the forecast period to compute future expected shocks and effects. The first forecast period at the time this article was written was the 2009:Q3, and forecasted values of inputs are consistent with MA's base forecast published August 10, 2009. Figure 3 shows the different shocks we have identified—$o^{\#}$, $\varepsilon$, and $\tilde{\varepsilon}$—for 2008 through 2011, based on current readings from oil price futures.

Hamilton's shock, aside from being only positive by definition, is quite small, and is equal to zero from 2008:Q3 onward. This is because the quarterly average price of WTI reached its peak in 2008:Q2, and thus all price movements afterwards are irrelevant due to the relative maximum established in the denominator. Moreover, it completely ignores any effects of the huge decline in oil prices in 2008:Q4 ($118 to $60), something that is picked up by the MA shocks. Finally, one can see that the energy-adjusted shock is somewhat subdued because of the declining energy intensity parameter.

Figure 4 shows the static contributions to the annualized growth of non-farm business output

Figure 3. Different Definitions of Oil Price Shocks

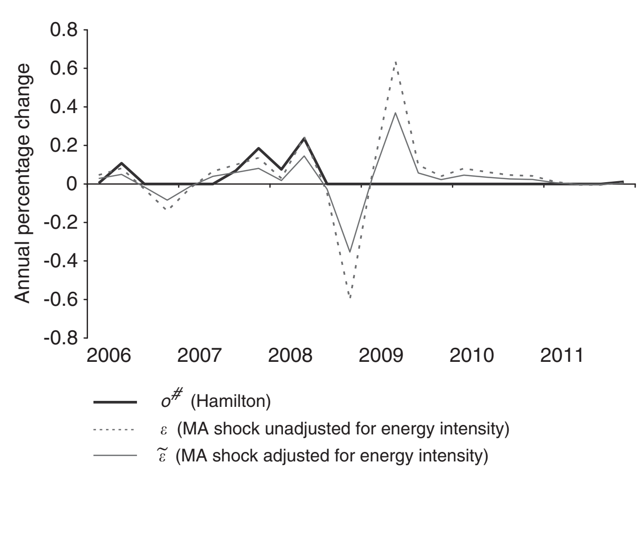


**Figure 4. Decomposition of Oil Price Contribution to Growth of Non-Farm Business Output**

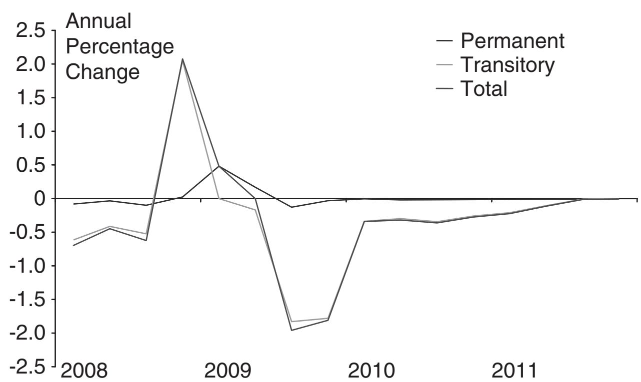
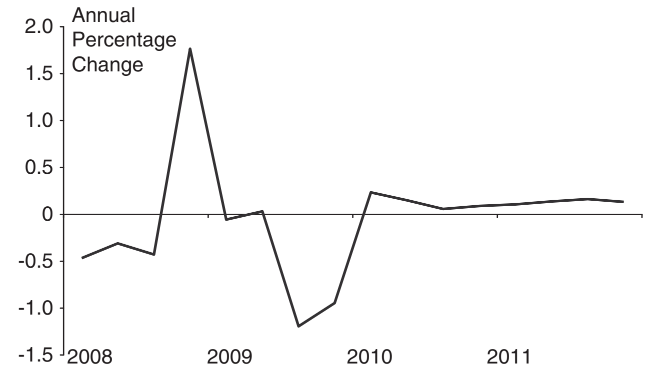



**Figure 5. Oil Price Contribution to GDP Growth**




from recent oil price shocks in our preferred model. It also separates the shocks into the non-linear effects of the shock terms in the difference equation (the transitory effects), as well as the linear effects of the price level in the long-run equation (the permanent effects). Because the error-correction term comes in with one lag, the large decline in oil prices during 2008:Q4 makes a significant positive contribution in the long-run equation to growth in 2009:Q1. In addition, the shock terms contribute about 0.6 percentage point of drag on average in the first three quarters of 2008, before adding over 2 percentage points in the fourth. Additionally, the increase in oil prices in 2009:Q2 (38 percent simple rate) alongside a contracting economy resulted in a large positive price shock, according to our definition, and will result in large negative contributions in the second half of 2009. Finally, the steady increase in oil price futures going forward would imply smaller but still positive oil price shocks, becoming a source of modest drag on growth in 2010 and 2011.

If one assumes that government output is exogenous to oil prices, then the partial effects on GDP tell the same story but are smaller in magnitude. Figure 5 shows the contributions of our preferred model to annualized GDP growth. These contributions were calculated by simulating our preferred ECM, first assuming the historical/forecast oil prices and corresponding shock transformations, and then simulating once again assuming no oil price shocks. The contribution in Figure 5 is the difference in growth rates between the two simulations, multiplied by the lagged nominal share of non-farm business output in GDP. According to our model, oil prices contributed about $-0.4$ percentage point on average in the first three quarters of 2008, and plus 1.7 percentage points in the fourth quarter.



## 8. Conclusion

Although Hamilton defines an oil shock as a positive movement above a relative threshold, we prefer to think of it as a positive or negative price movement relative to an endogenous response to the economy. This makes more economic sense to us than specifying a data-driven threshold that is uninformed by what is going on in the economy. Hamilton's shocks tend to perform better in a reduced-form ADL framework for modeling GDP, while our shocks work better in a more structurally oriented error-correction equation for non-farm business output, where relative oil prices are allowed to linearly affect the long-run output level. Furthermore, our definition of an oil shock is enhanced by adjusting it for the secular decline in energy intensity of U.S. economy, as well as by separating the positive and negative shocks, and allowing each component to have differential effects in the error-correction specification. Our preferred model shows that oil prices (both the linear and non-linear effects) reduced GDP growth by 0.4 percentage point on average through the first three quarters of 2008, while the steep fall in prices added about 1.7 percentage points in the fourth quarter. Moreover, price increases earlier this year are set to negatively impact growth in the second half, and according to futures prices, a steady increase in oil prices through 2011 will provide some modest drag over the next couple of years.

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