ARTICLES

INTRODUCTION TO *OIL PRICE SHOCKS*

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1. OVERVIEW

The relationship between the price of oil and the level of economic activity is a fundamental empirical issue in macroeconomics. Hamilton (1983) showed that oil prices had significant predictive content for real economic activity in the United States prior to 1972, whereas Hooker (1996) argued that the estimated linear relations between oil prices and economic activity appear much weaker after 1973. In the debate that followed, several authors suggested that the apparent weakening of the relationship between oil prices and economic activity is illusory, arguing that the true relationship between oil prices and real economic activity is asymmetric, with the correlation between oil price decreases and output significantly different from the correlation between oil price increases and output—see, for example, Mork (1989) and Hamilton (2003).

Although the relationship between the price of oil and the level of economic activity has attracted considerable attention in the literature [see also Hamilton (2009), Kilian (2008), Kilian and Vigfusson (2009), and Lee and Ni (2002)], there are relatively few studies that investigate the effects of uncertainty about the price of oil on the level of economic activity. This special issue of *Macroeconomic Dynamics* is devoted to papers that use recent advances in macroeconometrics and financial econometrics to investigate the effects of oil price shocks and uncertainty about the price of oil on the level of economic activity.

The areas that are the focus of the articles in this special issue are as follows:

- Is the oil price–output forecast equation nonlinear?
- Is the oil price–output response function nonlinear?
- What are the macroeconomic effects of oil price uncertainty?
- Do oil price shocks drive business cycles?

We will discuss each of these areas in turn in the following sections.

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2. NONLINEARITY IN THE OIL PRICE–OUTPUT PREDICTIVE REGRESSION

Let y_t be the growth rate of real output ($y_t = \Delta \ln \text{Output}_t$) and x_t that of the real or nominal price of oil ($x_t = \Delta \ln \text{Oil}_t$). Testing the null hypothesis that the optimal one–period ahead forecast of y_t is linear in past values of x_t involves estimating (by ordinary least squares) the predictive regression

$$y_t = \alpha_0 + \sum_{j=1}^{p} \alpha_j y_{t-j} + \sum_{j=1}^{p} \beta_j x_{t-j} + \sum_{j=1}^{p} \gamma_j \tilde{x}_{t-j} + \varepsilon_t, \tag{1}$$

where α_0, α_j, β_j, and γ_j are all parameters, ε_t is white noise, and $\tilde{x}_t$ is a known nonlinear function of oil prices. In equation (1), testing for nonlinearity is equivalent to testing the null hypothesis that the coefficients on the nonlinear measure, $\tilde{x}_t$, are all equal to zero—that is, $\gamma_1 = \gamma_2 = \cdots = \gamma_p = 0$. If the joint null of linearity and symmetry in the coefficients can be rejected, then the conclusion is that the relationship is nonlinear.

In the context of (1), Mork (1989) censored the oil price change to exclude all oil price decreases and proposed the following nonlinear transformation of the real price of oil:

$$\tilde{x}_t = \max\{0, o_t - o_{t-1}\},$$

where o_t is the logarithm of the real price of oil. Hamilton (1996, 2003) refined this approach and captured nonlinearities in the nominal price of oil by the "net oil price increase" over the previous three years (to filter out increases in the price of oil that represent corrections for recent declines),

$$\tilde{x}_t = \max\{0, o_t - \max\{o_{t-1}, \ldots, o_{t-12}\}\},$$

with o_t in this case denoting the logarithm of the nominal price of oil ($o_t = \ln \text{Oil}_t$). A large number of papers have tested the joint null of linearity and symmetry in the slope coefficients of the predictive regression (1) and rejected it. The present special issue contains three papers that look directly at aspects of nonlinearity in the predictive relationship between the price of oil and U.S. real output. The first paper, by James D. Hamilton, builds on Hamilton's (1996, 2003) analysis of the postwar period. After extending the sample period to include the recent Great Recession, Hamilton concludes that the evidence is convincing that the predictive relation between GDP growth and nominal oil prices is nonlinear.

The second paper is by Lutz Kilian and Robert J. Vigfusson. It shows that substantively identical test results are obtained for the real price of oil in the sample period since 1973. That finding holds even using an alternative slope-based test recently developed in Kilian and Vigfusson (2009) that includes additional contemporaneous regressors in model (1). This modified test is based on the

structural equation

$$y_t = \alpha_0 + \sum_{j=1}^{p} \alpha_j y_{t-j} + \sum_{j=0}^{p} \beta_j x_{t-j} + \sum_{j=0}^{p} \gamma_j \tilde{x}_{t-j} + \varepsilon_t, \qquad (2)$$

and testing the joint null hypothesis of linearity and symmetry involves testing the null that the coefficients on Hamilton's (2003) nonlinear measure, $\tilde{x}_t$, are all equal to zero—in this case, $\gamma_0 = \gamma_1 = \cdots = \gamma_p = 0$. Kilian and Vigfusson reject the null hypothesis, although with slightly larger p-values than Hamilton does.

The third paper that investigates whether the oil price–output relationship is nonlinear is by Ana María Herrera, Latika Gupta Lagalo, and Tatsuma Wada. They test this hypothesis in the context of the reduced form (1), using monthly U.S. data on oil prices and 37 industrial production indices (of which 5 represent aggregates). In doing so, they use Mork's oil price increase, Hamilton's (1996) net oil price increase over the previous 12 months, and Hamilton's (2003) net oil price increase over the previous 36 months. They reject the null hypothesis of linearity (and symmetry) for a large number of industrial production indices, with the evidence against the null appearing stronger when the net oil price increase over the previous 36 months is used (for example, in this case the null is rejected for 25 out of the 37 indices). They also report results based on the structural equation (2) that are very similar to their results based on the reduced form (1).

Thus, there is a consensus that slope-based tests generally support the view that the predictive relationship between the price of oil and U.S. real output is nonlinear.

3. NONLINEARITY IN THE OIL PRICE–OUTPUT RESPONSE FUNCTION

The evidence of nonlinearity based on slope-based tests has so far been taken as being in support of an asymmetric relation between the price of oil and output. Recently, however, Kilian and Vigfusson (2009) questioned the methodology used in the past to test for nonlinearities and asymmetries in the response of real output to positive and negative oil price shocks. They argue that slope-based tests focus on the wrong null hypothesis and propose a direct test of the null hypothesis of symmetric impulse responses to positive and negative oil price shocks based on impulse-response functions (rather than slopes), observing that this is the hypothesis of interest to economists. The idea is that asymmetric slopes are neither necessary nor sufficient for asymmetric responses of real output to positive and negative oil price shocks. As Kilian and Vigfusson (2009, p. 27) put it, "what is at issue in conducting this impulse-response-based test is not the existence of asymmetries in the reduced form parameters, but the question of whether possible asymmetries in the reduced form imply significant asymmetries in the impulse response function."

In particular, slope-based tests (either the traditional or the modified ones) are not informative with respect to whether the asymmetry in the impulse responses is

economically or statistically significant. This is because impulse-response functions are nonlinear functions of the slope parameters and innovation variances, and it is possible for small and statistically nonsignificant departures from symmetry in the slopes to cause large and statistically significant departures from symmetry in the implied impulse-response functions. Similarly, it is possible for large and statistically significant departures from symmetry in the slopes to cause small and statistically nonsignificant departures from symmetry in the implied impulse-response functions. In addition, Kilian and Vigfusson observed that slope-based tests of symmetry cannot allow for the fact that the degree of asymmetry of the response function by construction depends on the magnitude of the shock. In other words, the degree of asymmetry may differ greatly for an oil price innovation of typical magnitude (say, one standard deviation) and a large oil price innovation (say, two standard deviations).

Kilian and Vigfusson (2009) use the estimated parameters of an unrestricted encompassing structural model and condition on a history Ω^i (a block of p consecutive values of y_t and x_t) to simulate conditional impulse responses at horizon $h\ (= 0, 1, \ldots, H)$ that take into account the (prespecified) size of the shock, δ. They denote these conditional structural impulse responses as $I_y(h, \delta, \Omega^i)$. Then they average over all the histories to get the unconditional impulse response $I_y(h, \delta)$. Finally, they compute a Wald test of the null hypothesis of symmetric impulse responses,

$$I_y(h, \delta) = -I_y(h, \delta),$$

for $h = 0, 1, \ldots, H$. It should be noted that the method employed by Kilian and Vigfusson (2009) for calculating nonlinear impulse-response functions focuses on average responses. In addition, researchers might be interested in examining the effects of an oil shock at a particular point in time, rather than averaged across all histories. This question could be investigated, building on Kilian and Vigfusson's (2009) proposal for a conditional response function.

Kilian and Vigfusson (2009) investigate whether the responses of U.S. real GDP over the post-1973 period are asymmetric to oil price increases and decreases and find no evidence against the null hypothesis of symmetry. In this issue, the paper by Kilian and Vigfusson extends the sample period to include the Great Recession and find no evidence against the null hypothesis of symmetry in the case of shocks of typical magnitude. However, they find statistically significant evidence of nonlinearity when they examine the effects of large (two–standard deviation) shocks. They discuss the possibility that this evidence could be an artifact of the simultaneous occurrence of the financial crisis and rising oil prices.

Herrera et al. (this issue) also use the Kilian and Vigfusson (2009) impulse response–based test and reject the null hypothesis of symmetric impulse responses with both aggregate and disaggregate monthly industrial production series, for both typical and large shocks, in samples that include pre-1970s data. However, for the post-1973 period they find no evidence against the null of symmetry at the aggregate level, consistent with the results by Kilian and Vigfusson (2009) for

aggregate real GDP, but continue to find some evidence at the disaggregate level in response to large shocks.

Thus, based on the Kilian and Vigfusson (2009) impulse response-function tests, it appears that for shocks of typical magnitude the nonlinearities in the impulse-response functions are immaterial.

Elder and Serletis (2010 and this issue) and Rahman and Serletis (this issue) present additional evidence, based on multivariate GARCH-in-mean VARs (to be discussed in more detail in Section 4), that the relationship between real output and the price of oil is nonlinear and asymmetric. The nonlinearity and asymmetry in these multivariate GARCH-in-mean VARs, which are designed to provide a better description of the data than homoskedastic VARs, are a consequence of both increases and decreases in oil prices tending to increase oil price uncertainty, which has a significant and negative effect on output.

Finally, the paper by Miller and Ni (this issue) examines how future real GDP growth relates to changes in the forecast long-term average of discounted real oil prices and to changes in unanticipated fluctuations of real oil prices around the forecasts. In the context of a state-space oil-market model, in which global real economic activity and real oil prices share a common stochastic trend, they find that positive and negative changes in the unanticipated fluctuations of real oil prices correlate with asymmetric responses of future real GDP growth. They also find that changes in the forecast long-term average of discounted real oil prices are smaller in magnitude than the unanticipated fluctuations, but are more influential on real GDP and more symmetric. Their findings support those of Kilian and Vigfusson (2009), in the sense that asymmetry in output responses is more evident as a result of large oil price movements than of smaller ones. Miller and Ni identify the latter using oil price forecasts based on global real economic activity. According to their estimates, persistent upward revisions of forecasts in the 2000s had a substantial negative impact on real GDP growth.

4. WHAT ARE THE EFFECTS OF OIL PRICE UNCERTAINTY?

The theoretical foundations for uncertainty (about, for example, input prices) affecting investment decisions are well established. The foundations are provided by Bernanke (1983), Brennan and Schwartz (1985), Majd and Pindyck (1987), and Brennan (1990), among others. In the finance literature, such concepts are often grouped under the heading of "real options."

These ideas are now well established. There are numerous consulting groups that assist firms in implementing these valuation methodologies (see for example, the Real Options Group at http://rogroup.com) and numerous firms, particularly in the oil and gas industries, that claim to implement them. Moreover, policy makers seem to believe that uncertainty about oil prices is relevant to macroeconomic performance. For example, Lawrence H. Summers, as director of the National Economic Council, stated that "if energy prices will trend higher, you invest one way; if energy prices will be lower, you invest a different way. But if you don't

know what prices will do, often you do not invest at all." Moreover, Gordon Brown, the former prime minister of the United Kingdom, and Nicolas Sarkozy, the current president of France, jointly published a statement entitled "We Must Address Oil-Market Volatility" (*Wall Street Journal*, July 8, 2009).

Given this, we might be surprised if we were unable to empirically confirm a relationship that firms claim to implement and policy makers believe to exist.

The present special issue has three papers that look at aspects of uncertainty about the price of oil and its effects on the level of economic activity. The first paper, by Kiseok Lee, Wensheng Kang, and Ronald Ratti focuses on investment decisions by firms, instead of using aggregate economic and financial data. It follows a strand in the literature advanced by Leahy and Whited (1996) and Bloom et al. (2007) according to which uncertainty faced by the individual firm can be represented by its own stock market volatility, and examines the effects of real oil price shocks on firm level investment, both directly and in interaction with firm stock market volatility. Using data on over 3,000 manufacturing firms in the United States, the authors find that oil price shocks depress investment decisions by firms, and do so differentially by depressing investment more for more uncertain firms.

The second paper, by Elder and Serletis, and the third one, by Rahman and Serletis use aggregate data and state-of-the-art advances in ARCH modeling, originally introduced by Engle (1982), to model uncertainty about the price of oil and investigate its effects on the level of economic activity. In this regard, it should be noted that one of the early papers to use financial econometrics to model oil price uncertainty was Lee et al. (1995). In particular, they used the following univariate GARCH process (abstracting from nonessential variables) for the rate of change in the price of oil, x_t:

$$x_t = \alpha_0 + \sum_{i=1}^{r} \alpha_i x_{t-i} + e_t,$$

where $e_t \mid \Omega_{t-1} \sim N(0, h_t)$, Ω_{t-1} is the information set, and

$$h_t = \gamma_0 + \sum_{i=1}^{q} \gamma_i e_{t-i}^2 + \sum_{j=1}^{p} \gamma_{q+j} h_{t-j}.$$

The conditional expectation of the rate of change in the price of oil is $\hat{x}_t = E(x_t \mid \Omega_{t-1})$ and the forecast error is $e_t = x_t - \hat{x}_t$. Because the forecast error, e_t, does not reflect changes in conditional volatility over time, Lee et al. (1995) calculated the following measure of an unexpected oil price shock that reflects both the magnitude and the variability of the forecast error:

$$e_t^* = \frac{e_t}{\sqrt{h_t}}.$$

Lee et al. (1995) then introduced e_t^* in various VAR systems, and found that oil price volatility is highly significant in explaining economic growth. They also found evidence of asymmetry, in the sense that positive shocks have a strong effect on growth whereas negative shocks do not. The Lee et al. (1995) approach, however, is subject to the generated regressor problem described by Pagan (1984).

In a recent paper, Elder and Serletis (2010) used a bivariate GARCH-in-mean structural VAR to reinvestigate the relationship between the price of oil and the level of economic activity, focusing on the role of uncertainty about oil prices. They utilized an internally consistent simultaneous-equations empirical model that accommodates an independent role for the effects of oil price volatility, and estimate their model by full-information maximum likelihood, thereby avoiding Pagan's (1984) generated regressor problems associated with estimating the variance-function parameters separately from the conditional mean parameters, as in Lee et al. (1995). They find that volatility in oil prices has had a negative and statistically significant effect on several measures of investment, durables consumption, and aggregate output. They also find that accounting for the effects of oil price volatility tends to exacerbate the negative dynamic response of economic activity to a negative oil price shock, whereas it dampens the response to a positive oil price shock.

Elder and Serletis, in their paper in this volume, continue that investigation by analyzing the effect of oil price uncertainty on monthly measures of U.S. firm production related to mining, manufacturing, and utilities industries. They use a more general specification, an updated sample that includes the increased oil price volatility since 2008, and control for other nonlinear measures of oil prices.

In particular, they use the following structural VAR modified for conditional heteroskedasticity in the parametric form of a multivariate GARCH-in-mean model:

$$\boldsymbol{B}\boldsymbol{z_t} = \boldsymbol{C} + \sum_{i=1}^{p} \boldsymbol{\Gamma}_i \boldsymbol{z_{t-i}} + \boldsymbol{\Lambda}\sqrt{\boldsymbol{h_t}} + \boldsymbol{e_t},$$

with $\boldsymbol{z_t} = [\pi_t, y_t, x_t, R_t]'$, where π_t is the inflation rate and R_t the federal funds rate. $\boldsymbol{C}$ is a 4×1 parameter vector, $\dim(\boldsymbol{B}) = \dim(\boldsymbol{\Gamma}) = \dim(\boldsymbol{\Lambda}) = (n \times n)$, $\boldsymbol{e_t} \mid \Omega_{t-1} \sim N(\boldsymbol{0}, \boldsymbol{H_t})$, where $\boldsymbol{0}$ is the null vector, Ω_{t-1} denotes the available information set in period $t-1$, and $\boldsymbol{H_t}$ is the conditional covariance matrix.

To deal with identification issues, they assume that the structural disturbances are contemporaneously (and conditionally) uncorrelated, which implies that $\boldsymbol{H}$ is diagonal. Under these assumptions, the multivariate GARCH variance function they use is

$$\boldsymbol{h_t} = \text{diag}(\boldsymbol{H_t}) = \boldsymbol{C_v} + \sum_{i=1}^{r} \boldsymbol{F}_i \text{diag}(\boldsymbol{e_{t-i}}\boldsymbol{e'_{t-i}}) + \sum_{j=1}^{s} \boldsymbol{G}_j \text{diag}(\boldsymbol{H_{t-j}}),$$

where diag is the operator that extracts the diagonal from a square matrix, $\boldsymbol{C_v}$ is a 4×1 parameter vector, and $\boldsymbol{F}$ and $\boldsymbol{G}$ are 4×4 parameter matrices.

Elder and Serletis estimate their multivariate GACRH-in-mean VAR by full-information maximum likelihood and find additional empirical evidence in support of the predictions of the real options theory. Their results indicate that the extreme volatility in oil prices observed in 2008 and 2009 contributed to the severity of the decline in manufacturing activity, consistent with the observations of policy makers. By splitting their sample, they also find no support for the Edelstein and Kilian (2009) hypothesis that the Tax Reform Act of 1986 accounts for the observed asymmetry.

In the spirit of the Elder and Serletis paper, Rahman and Serletis use a bivariate reduced-form VAR modified to accommodate GARCH-in-mean errors as in Grier et al. (2004). Their model is

$$z_t = a + \sum_{i=1}^{p} \Gamma_i z_{t-i} + \sum_{j=0}^{q} \Psi_j \sqrt{h_{t-j}} + e_t,$$

where $z = [y_t, x_t]'$, $e_t \mid \Omega_{t-1} \sim N(\mathbf{0}, H_t)$, where $\mathbf{0}$ is the null vector, Ω_{t-1} denotes the available information set in period $t-1$, H_t is the conditional covariance matrix, and $h_t = \mathrm{diag}(H_t)$.

Rahman and Serletis use an asymmetric version of the BEKK model, introduced by Grier et al. (2004), as follows:

$$H_t = C'C + \sum_{j=1}^{f} B'_j H_{t-j} B_j + \sum_{k=1}^{g} A'_k e_{t-k} e'_{t-k} A_k + D' u_{t-1} u'_{t-1} D,$$

where C, B_j, A_k, and D are 2×2 matrices (for all values of j and k), with C being a triangular matrix to ensure positive definiteness of H. This-variance function specification allows past volatilities, H_{t-j}, as well as lagged values of ee' and uu', to show up in estimating current volatilities of y_t and x_t. Moreover, the introduction of the uu' term extends the BEKK model by relaxing the assumption of symmetry, thereby allowing different relative responses to positive and negative shocks in the conditional variance–covariance matrix, H.

The model used by Rahman and Serletis is extremely general and allows for the possibilities of spillovers and asymmetries in the variance–covariance structure for real output growth and the change in the real price of oil. Their measure of oil price uncertainty is the conditional variance of the oil price change forecast error. They isolate the effects of volatility in the change in the price of oil and its asymmetry on output growth and, following Koop et al. (1996) and Hafner and Herwartz (2006), employ simulation methods to calculate generalized impulse-response functions (GIRFs) and volatility impulse-response functions (VIRFs) to trace the effects of shocks on the conditional means and the conditional variances, respectively, of the variables. They find that oil price uncertainty has a negative effect on output, and that shocks to the price of oil and its uncertainty have asymmetric effects on output, consistent with the evidence of Elder and Serletis.

5. DO OIL PRICE SHOCKS DRIVE BUSINESS CYCLES?

As Hamilton (1983) noted, at that time seven out of eight postwar recessions in the United States had been preceded by sharp increases in the price of oil. In the first paragraph of his paper in this special issue, Hamilton continues this line of argument, saying that

> Iraq's invasion of Kuwait in August 1990 led to a doubling in the price of oil in the fall of 1990 and was followed by the ninth postwar recession in 1990–91. The price of oil more than doubled again in 1990–2000, with the tenth postwar recession coming in 2001. Yet another doubling in the price of oil in 2007–2008 accompanied the beginning of recession number 11, the most recent and frightening of the postwar economic downturns. So the count stands at 10 out of 11, the sole exception being the mild recession of 1960–61 for which there was no preceding rise in oil prices.

Motivated by these considerations, the paper by Kristie Engemann, Kevin Kliesen, and Michael Owyang considers whether oil price shocks significantly increase the probability of recessions in the United States and a number of other countries. In doing so, the authors combine two strands of the literature, one that focuses on forecasting recessions using oil price movements and one that forecasts business cycles using term structure data. In the context of a Markov-switching model with time-varying transition probabilities, they find that for most countries, oil price shocks do affect the likelihood of entering a recession. In particular, an average-sized shock to WTI oil prices increases the probability of recession in the United States by nearly 50 percentage points after one year and nearly 90 percentage points after two years.

The Engemann et al. paper could also be viewed as contributing to the non-linearity issues discussed in Sections 2 and 3. In particular, the paper defines a business cycle in terms of certain nonlinear properties of optimal forecasts, and its main result is that oil prices do help make such a nonlinear contribution to predicting GDP.

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