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Article

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Ryan Kellogg is a Research Associate in the NBER Programs on Energy and Environmental Economics and Industrial Organization. An associate professor of economics at the University of Michigan, he received a B.A. in economics and a B.S. in chemical engineering at Rice University in 1999, and completed his Ph.D. in agricultural and resource economics at the University of California, Berkeley in 2008. He worked for BP from 1999–2003.

Kellogg's research bridges industrial organization, energy economics, and environmental policy. Many of his projects examine the behavior of U.S. oil and gas producers, addressing questions such as how production companies interact with drilling companies to improve productivity, how drilling decisions react to price volatility in crude oil markets, and why oil production is unresponsive to oil price shocks in the short run. He also has studied the effectiveness of U.S. reformulated gasoline programs, household vehicle demand and future fuel price expectations, the economics of interstate oil and gas transmission, and potential impacts of climate change.

He lives in Ann Arbor, Michigan, with his fiancée, Kim, and their collie, Sophie.

How Oil-Price Shocks Affect Producers and Consumers

Ryan Kellogg

Markets for crude oil have been characterized by multiple episodes of volatility over the past 20 years. The price of Brent crude oil, an international “light” crude oil benchmark priced in the North Sea, varied from a low of about \$10 per barrel (bbl) in 1999 to a peak of more than \$140/bbl in 2008, before falling again during the Great Recession. While the Brent price stabilized around \$110/bbl during 2010–13, it recently and suddenly collapsed to around \$50/bbl. The majority of these oil price swings have been attributed to global demand shocks such as the Great Recession, though the price drop this past autumn has not yet been extensively studied.¹

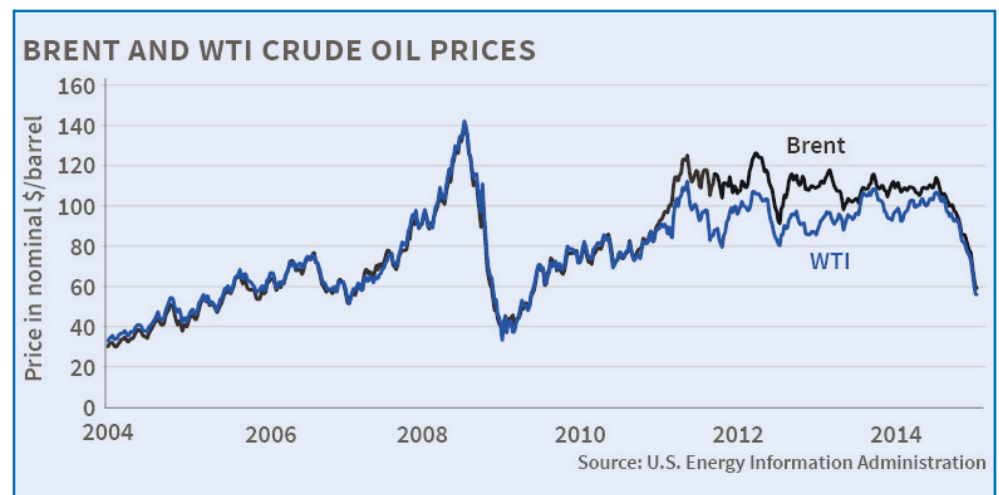
The accompanying figure shows the price both of Brent light and West Texas Intermediate (WTI) crude oil, which is priced in Cushing, Oklahoma. Historically, the WTI and Brent crude oil prices tracked each other extremely closely. However, beginning in 2011 these two price series diverged substantially, with WTI sometimes falling more than

\$20/bbl below Brent. This gap has recently closed substantially, but not entirely.

In a series of papers, my co-authors and I have studied how shocks to crude oil markets affect oil producers and consumers. We have addressed questions such as “How do oil drilling and production respond to oil price shocks?”, “Is oil price volatility itself important?”, and “How do consumers forecast future price changes?” This research summary briefly describes these papers and notes issues where future research is needed.

The Cushing Oil Glut

In a recent project, Severin Borenstein and I studied the divergence between WTI and Brent oil prices that began in 2011.² This divergence arose from the confluence of a dramatic increase in unconventional crude oil production in Alberta, North Dakota, and West Texas and a lack of sufficient pipeline capacity to transport this new crude oil to Gulf Coast refineries. These factors led to a “glut” of oil



at Cushing, Oklahoma, depressing the WTI price relative to the price of international crude oil. Our paper focuses on whether this decrease in the WTI price passed through to regional gasoline and diesel prices.

Using data from the Energy Information Administration (EIA) on wholesale refined product markets, we find that gasoline and diesel prices in the Midwest, including Oklahoma, did not decrease at all in response to the glut of crude oil at Cushing. This lack of response is explained by the fact that, even though crude oil pipeline capacity was constrained after 2011, refined-product pipeline capacity was not. Thus, the marginal barrels of gasoline and diesel in the Midwest were, and still are, imported from the Gulf Coast, where they are refined using high-cost internationally-procured crude oil. These results imply that increases in crude oil production in the central U.S. did not lead to benefits for local consumers in the form of lower gasoline prices. Instead, Midwest refiners profited from the large spread between Midwest prices for crude oil and refined products.

Since the publication of our paper, a series of significant pipeline investments has substantially decreased the spread between WTI and Brent oil prices. As our paper predicted, the relative increase in the WTI price has not passed through to Midwest refined product prices. Still, the WTI-Brent price wedge has not completely closed, owing to the U.S. ban on crude oil exports and to the fact that shale oil from North Dakota and West Texas is “light” relative to imported “heavy” crude. Because most U.S. Gulf Coast refineries are designed to handle heavy crude oil, they only purchase light crude oil at a discount, creating a differential relative to the international price. This situation presents a clear need for research into the economics of lifting the U.S. crude oil export ban, including a detailed analysis of how changes in light vs. heavy crude oil use by refineries would affect U.S. and

global prices for refined products.

Consumers’ Future Gasoline Price Expectations

How do U.S. consumers respond to gasoline price shocks? A complete answer to this question requires information on what consumers believe about how future gasoline prices are affected by shocks to today’s price. For example, if consumers believe that a gasoline price shock is only temporary, then their preferences for fuel-efficient versus fuel-inefficient vehicles should not be significantly affected by the shock, since vehicles typically last many years. Soren T. Anderson, James M. Sallee, and I provide the first evidence on consumers’ gasoline-price forecasts by examining two decades of data from the Michigan Survey of Consumers.³ We show that, on average, consumers expect that the real price of gasoline five years in the future will be equal to the current real price. That is, consumers on average have a “no-change” forecast for gasoline prices, and moreover believe that shocks to gasoline prices today will be persistent into the future.

Our result accords well with studies of optimal crude oil price forecasts, which show that it is very difficult to identify a forecast that reliably “beats” a no-change forecast in terms of predictive power, especially for multi-year time horizons.⁴ It therefore appears that consumers on average have reasonable beliefs about future prices, though we also find considerable cross-consumer heterogeneity. An important implication of this finding is that consumers should, to the extent that they care about future vehicle operating costs, substantially adjust their valuation of fuel economy in response to gasoline price shocks.

Realistic Modeling of Oil Drilling and Production

How have U.S. oil producers responded to the large swings in oil prices observed over the past 20 years? Looking ahead, should we expect new shale oil producers to reduce their production

rates following this year’s drop in crude oil prices? Addressing these questions requires a model of oil supply. The workhorse model dates back to 1931, when Harold Hotelling’s classic paper studied a framework in which exhaustible resource owners can freely allocate the production of the resource across time.⁵

In a recent paper, Anderson, Stephen Salant, and I observe that Hotelling’s framework does not apply to oil extraction.⁶ Instead, the maximum production rate from any well is physically constrained by the pressure available in the underground oil reservoir, and this pressure declines toward zero as more and more oil is extracted. Using detailed data on well-level production and drilling from Texas, we show that oil production from existing wells exhibits essentially zero response to price shocks, contradicting a basic prediction of Hotelling’s standard model. Instead, production declines steadily toward zero, consistent with a model in which firms always produce their wells at their maximum flow rate. In contrast, we show that the rate of drilling of new wells responds substantially to oil price shocks, as does the cost of renting drilling rigs.

Thus, oil price shocks do not affect oil supply immediately, but rather over the medium run as changes in drilling gradually affect the stock of producing wells and ultimately the total rate of production. More broadly, our results indicate that oil supply modeling should focus not on firms’ production decisions—since production from drilled wells is essentially price-inelastic—but on firms’ drilling investment decisions. With regard to the recent drop in oil prices, our results suggest that we should look to the market for drilling rigs, not to changes in production, for signs that the recent growth in U.S. oil supply is being curtailed.

Oil Price Volatility and Option Value

It has not been just the level of oil prices that has changed substantially over time: oil price volatility has varied substantially as well. For instance, oil prices

were quite stable during 1992–97, then experienced substantial swings in both directions in subsequent years. How might changes in expected price volatility affect firms' drilling behavior? In a paper titled "The Effect of Uncertainty on Investment: Evidence from Texas Oil Drilling," I study this question using drilling data from Texas and data from options markets on expected oil price volatility.⁷ The logic behind the use of options markets is that the price of an option to buy oil at some future date implicitly incorporates information on the expected volatility of the oil price: The greater the volatility, the higher the price of the option. The options price data therefore provide me with a time series of data on the expected future volatility of the price of oil.

I find that, controlling for the oil price level, periods of expected high price volatility are associated with low levels of investment in new wells. This result accords with predictions from real options theory.⁸ From the perspective of a firm, an undrilled well is an option in the sense that it can be drilled either today or at some future date or never. The value of drilling in the future increases with uncertainty about the future price of oil. Why? If the oil price increases substantially, the future value of drilling will also substantially increase, but if the oil price decreases, the loss in the well's value is limited by the fact that it cannot fall below zero (since the firm won't drill a well that is expected to lose money).

Thus, increases in expected price volatility increase the upside gain more than they decrease the downside loss, yielding an increase in the value of waiting.

In my paper, I construct a real option model of firms' drilling decisions and then estimate this model using the Texas drilling data. I find that the magnitude with which the rate of drilling in Texas responds empirically to volatility shocks closely matches the predictions from the model. In other words, the investment behavior of oil producers in Texas corresponds remarkably well to that of dynamically optimizing firms in a textbook real options model. An implication of this result is that, when trying to predict the impact of an oil price shock on drilling activity, it is important to consider not just the magnitude of the shock but also whether firms expect additional shocks in the near future. In particular, if firms believe that the recent gyrations in oil prices are likely to continue, forecasts of changes in oil supply that use only changes in price levels may underestimate the extent to which drilling activity will fall.

¹ L. Kilian, "Oil Price Shocks: Causes and Consequences," *Annual Review of Resource Economics*, 6(1), 2014, pp. 133–54. [Return to text.](#)

² S. Borenstein and R. Kellogg, "The Incidence of an Oil Glut: Who Benefits from Cheap Crude Oil in the Midwest?"

NBER Working Paper No. 18127, June 2012, and *Energy Journal*, 35(1), 2014, pp. 15–33. [Return to text.](#)

³ S. T. Anderson, R. Kellogg, and J. M. Sallee, "What Do Consumers Believe About Future Gasoline Prices?" *NBER Working Paper No. 16974*, September 2012, and *Journal of Environmental Economics and Management*, 66(3), 2013, pp. 383–403. [Return to text.](#)

⁴ R. Alquist, L. Kilian, and R. J. Vigfusson, "Forecasting the Price of Oil," in G. Elliot, A. Timmerman, eds., *Handbook of Economic Forecasting*, Vol. 2, Amsterdam, The Netherlands: Elsevier, North-Holland Press, 2013. [Return to text.](#)

⁵ H. Hotelling, "The Economics of Exhaustible Resources," *Journal of Political Economy*, 39(2), 1931, pp. 137–75. [Return to text.](#)

⁶ S. T. Anderson, R. Kellogg, and S. W. Salant, "Hotelling Under Pressure," *NBER Working Paper No. 20280*, July 2014. [Return to text.](#)

⁷ R. Kellogg, "The Effect of Uncertainty on Investment: Evidence from Texas Oil Drilling," *NBER Working Paper No. 16541*, November 2010, and *American Economic Review*, 104(6), 2014, pp. 1698–1734. [Return to text.](#)

⁸ For an extensive intuitive and mathematical discussion, see A. K. Dixit and R. S. Pindyck, *Investment Under Uncertainty*, Princeton, New Jersey: Princeton University Press, 1994. [Return to text.](#)