

Uncertainty and Investment: Evidence from Domestic Oil Rigs

Asad Dossani and John Elder
Colorado State Univ
john.elder@colostate.edu

- "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."
  – Lawrence H. Summers, 2009.

- "Uncertainty is seen to retard investment independently of considerations of risk or expected return. Introduction of uncertainty can be associated with slack investment, resolution of uncertainty with an investment boom.'
  – Ben Bernanke, 1979 PhD thesis

Theory and Existing Evidence

- Macro-level – extensive theoretical and empirical literature
  - Fernández-Villaverde and Guerrón-Quintana (2020) surveys literature on equilibrium business cycle models of uncertainty shocks, suggesting focus on two sources - financial and macroeconomic.
  - Equilibrium macro-finance models show energy uncertainty generates contractions (Gao et al. (2021)).
  - Proxies for uncertainty include newspaper counts (Bloom, 2009) and composites (Jurardo et al 2015).

- Firm level – Theory suggests several channels, but we think about capital budgeting with real options
  - Firms jointly decide which investment projects and when to invest.
  - Uncertainty increases value of waiting (Henry (1974), Pindyck (1991), Dixit and Pindyck (1994)).
  - Requires some level of irreversibility, but not restrictive, and may include investment/consumption, manufacturing facilities, equipment with impaired secondary market, goods costly to store, labor.

- Firm level empirical evidence is limited
  - Difficult to link micro-investment decisions with uncertainty due to data constraints
  - Behavior of mine closings in Brazil (Moel and Tufano (2002)).
  - Conventional drilling in Texas declines with oil volatility, prior to 2003 (Kellog (2014)).

Our approach

- Data
  - We use data on weekly number of onshore rotary rigs exploring for oil.
  - Oil prices measured by spot WTI (Alquist and Kilian (2010)).
  - Uncertainty measured by 6-month implied volatility from options on oil futures.
  - Baseline sample 2012 to 2020 to capture tightest link between prices and drilling.
  - Robustness
    - longer samples
    - Model oil supply/demand VAR Kilian (2009), with BDI transformed as suggested by Hamilton (2021).
    - measure uncertainty by MGARCH, return on delta-neutral straddles.

- Identifying restrictions
  - Weekly data permits simple VAR identifying restrictions.

- Sample (2012-) corresponds to rise in hydraulic fracturing and rapid increases in technology and efficiency.
  - Gilje, Ready, and Roussanov (2016)
  - Surge in production not forecasted by EIA or markets – EIA see Annual Energy Outlook.
  - Oil field services firms experienced abnormal returns.

Results

- We find that drilling is tightly linked to both the level of oil prices and oil price uncertainty.
  - We describe institutional features which permit drilling activity to respond quickly to oil prices.
  - We show that oil production responds relatively quickly to oil price shocks.
  - One std dev increase in oil price causes drilling rigs to increase by about 1% after just 3 weeks; and about 5% after 12 weeks; and we do not measure intensity
  - This matters for a large literature on the propagation of oil shocks.
  - The number of onshore rotary rigs declines in response to rising uncertainty about oil prices
  - One std dev increase in uncertainty reduces drilling rigs by up to 4%, controlling for level of oil price.

Domestic Energy Extraction

- Domestic (U.S.) employment in oil and gas extraction.
  - Operating and developing oil and gas field properties, such as exploration for crude oil and natural gas from conventional vertical wells, oil shale and oil sands (eastern Utah).
  - Bakken, Eagle Ford, Macellus and Permian fields.

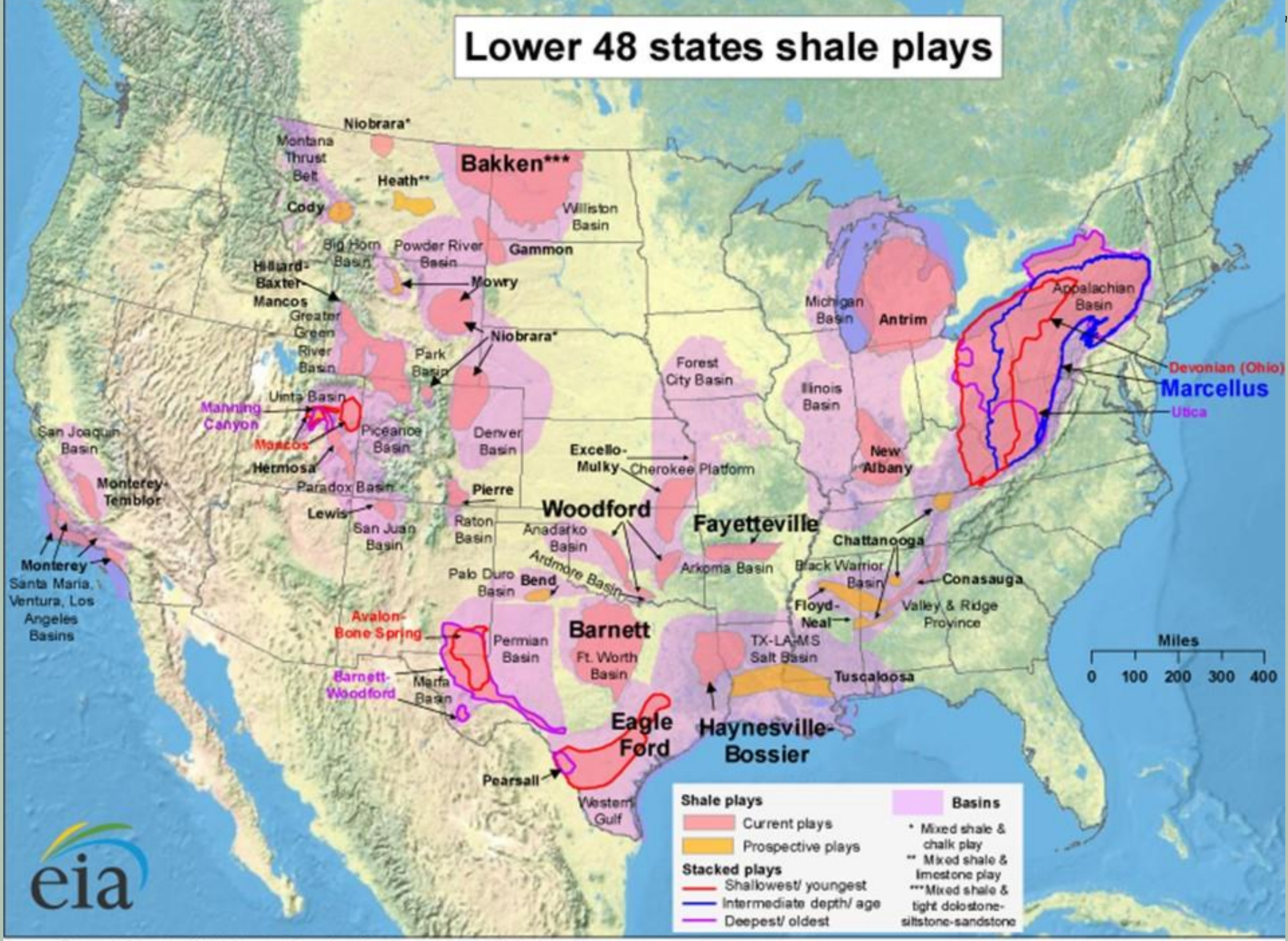
- Site preparation (~6% of costs onshore), such as road construction and surface equipment
  - storage tanks, separators and hook-up to gathering systems.

- Drilling (~31% costs) to total depth with a rig.
  - Casing, liner, drill bits, rig hire fees, cement, mud and drilling fluids and fuel costs.

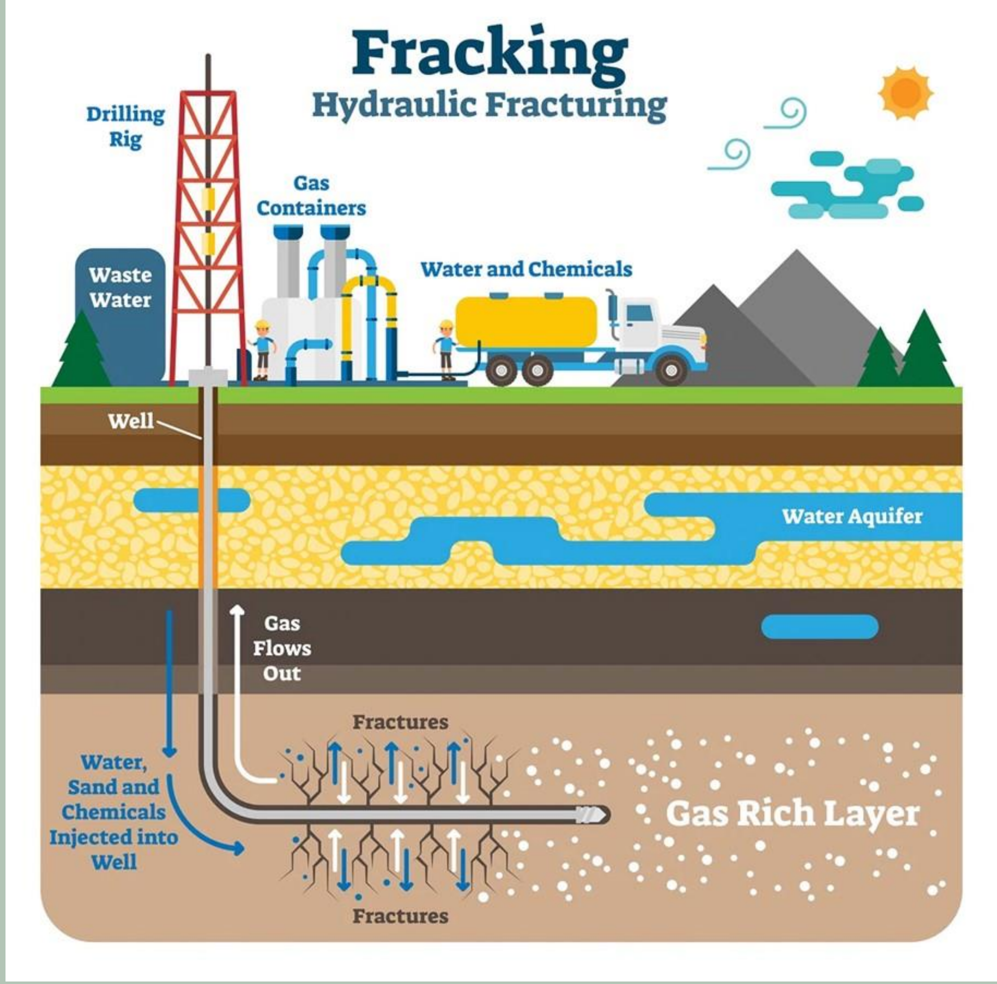
  - Firms hold inventory of Drilled but Uncompleted Wells (another paper).

- Completion (~63% costs) by frack crews and a workover rig.
  - Well perforations, fracking and fluid supply and disposal.

- Operating activities consist of well maintenance and occasional workover activities and other costs up to the point of shipment from the producing property.



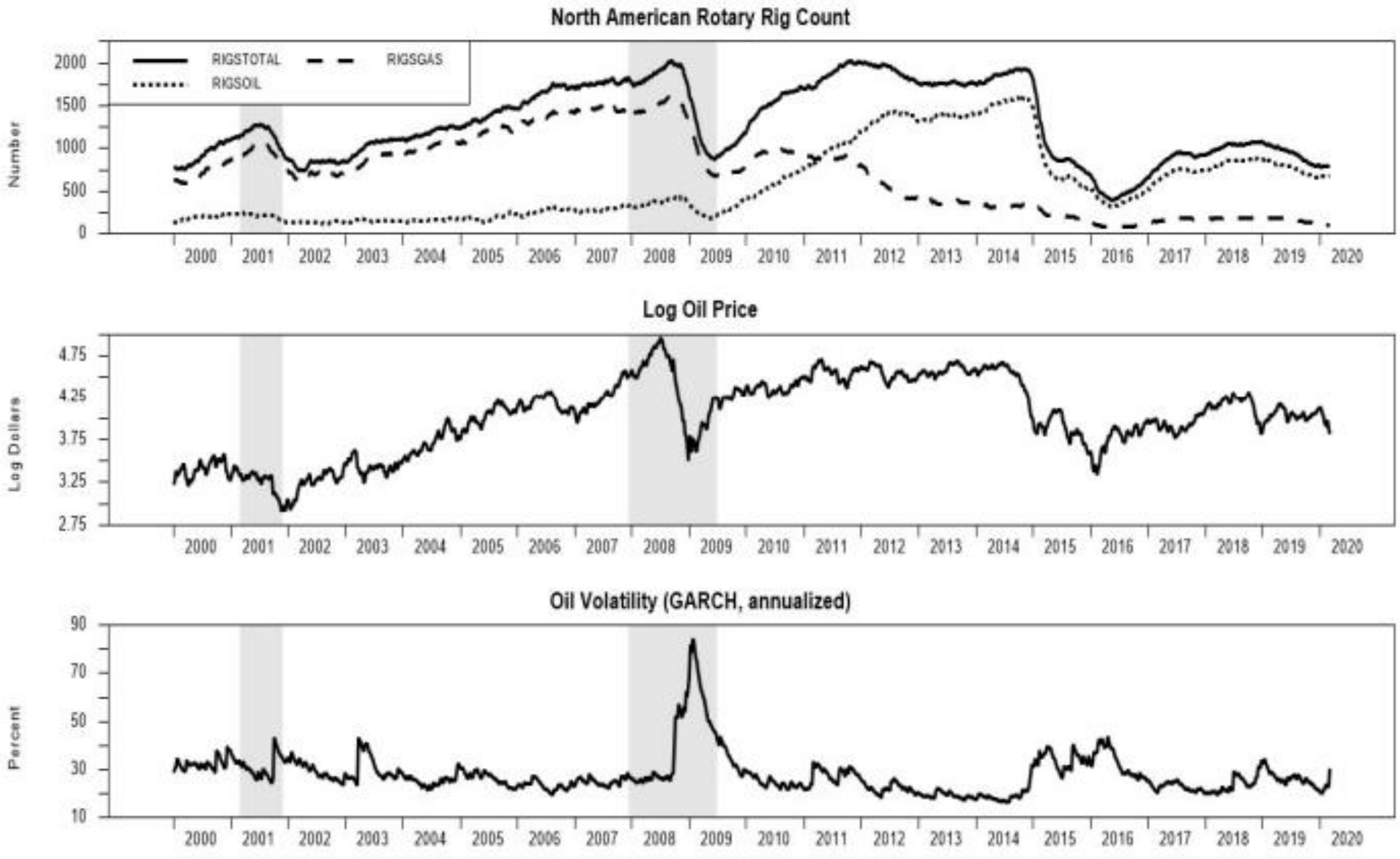
Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011


Fracking
Hydraulic Fracturing
Drilling Rig
Gas Containers
Waste Water
Water and Chemicals
Well
Water Aquifer
Gas Flows Out
Fractures
Water, Sand and Chemicals Injected into Well
Gas Rich Layer
Fractures


LIBERTY


FLEX RIG
MULTIPLE LATERAL KICK-OFFS FROM ADJACENT WELLS
ES =
IN
NTS
MULTI-WELL DRILLING
MOBILE HYDRAULIC LEGS

Figure 1. Rig Count, Oil and Oil Volatlity



APPENDIX 1. DATA

Identifier	Description
IV1M	Implied volatility of options on crude oil futures expiring in one month
IV3M	Implied volatility of options on crude oil futures expiring in three months
IV6M	Implied volatility of options on crude oil futures expiring in six months
Oil	West Texas Intermediate Oil Price from FRED
BDI	Baltic Dry Index from https://www.balticexchange.com/en/index.html
Rigs	The number of active rotary rigs exploring for oil from https://rigcount.bakerhughes.com/na-rig-count

Figure 2. Oil Volatility

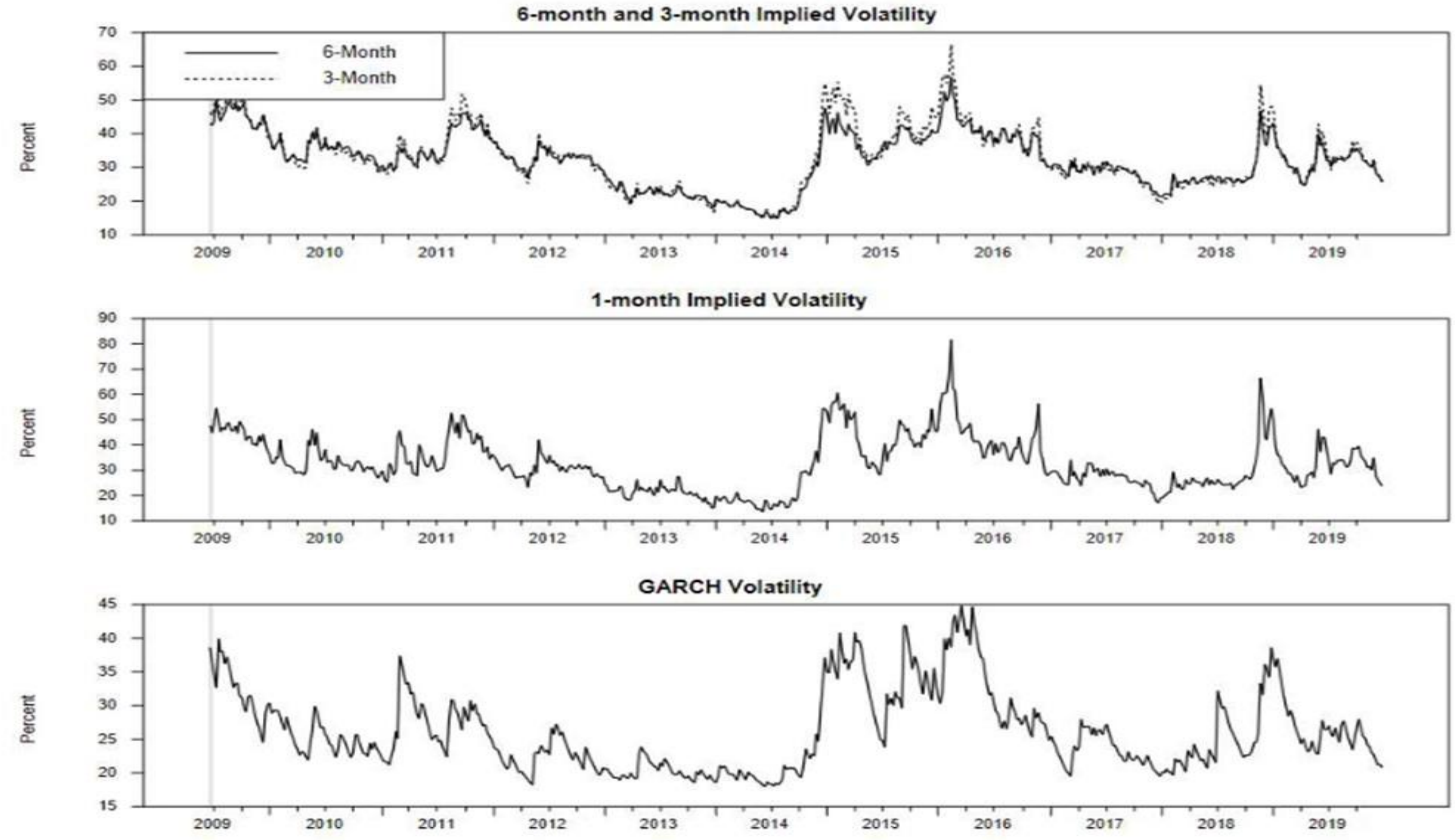
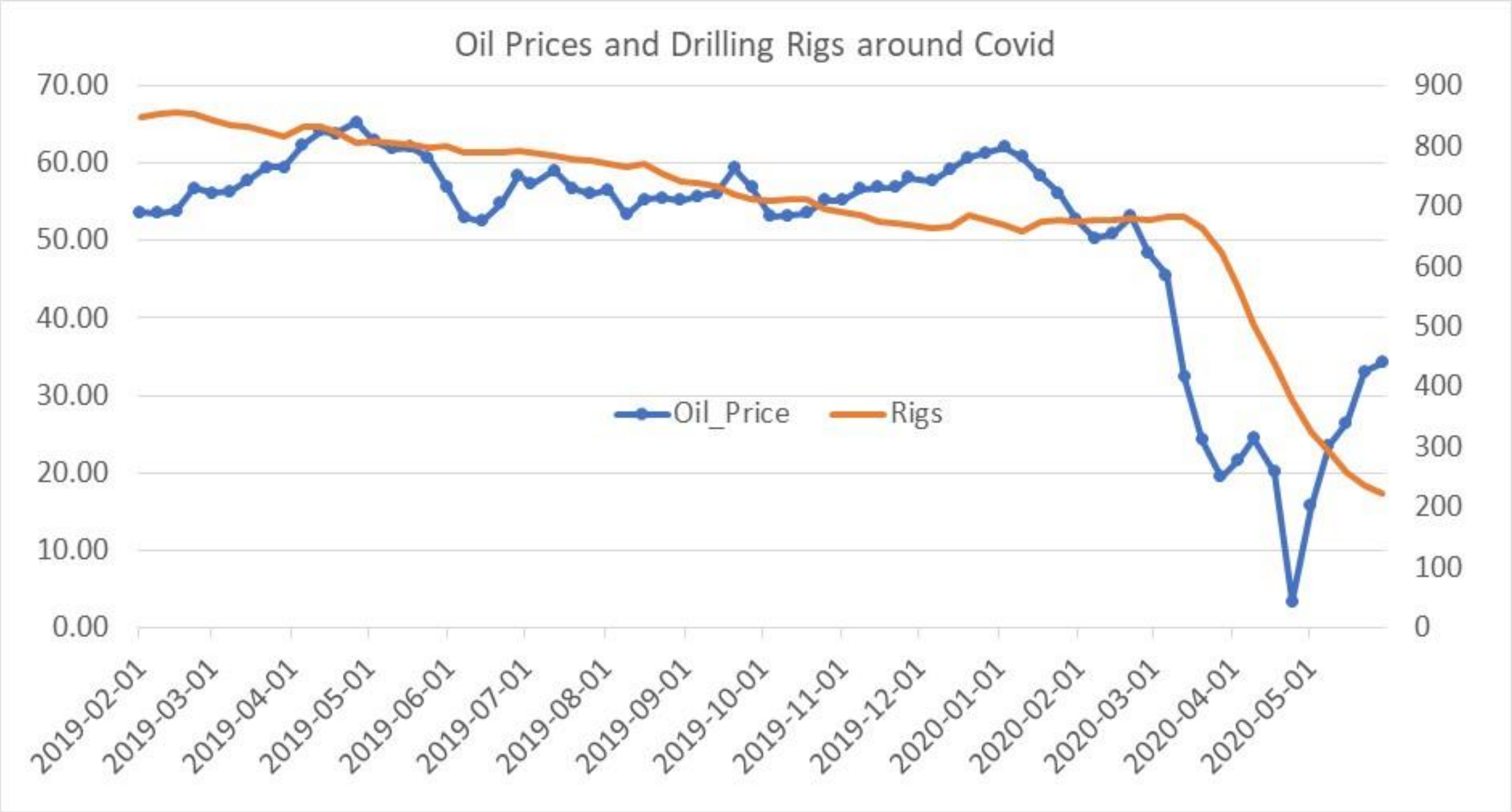


Table 4. Correlation of Volatility Measures

	1-M IV	3-M IV	6-M IV	GARCH
1-M IV	1	-	-	-
3-M IV	0.982	1	-	-
6-M IV	0.937	0.980	1	-
GARCH	0.773	0.802	0.813	1

This table reports the correlation matrix for each measure of oil volatility, where 1-M IV refers to 1-month implied volatility, for example. The sample is 2012:01:06-2020:03:06.

Oil Prices and Drilling Rigs during Covid



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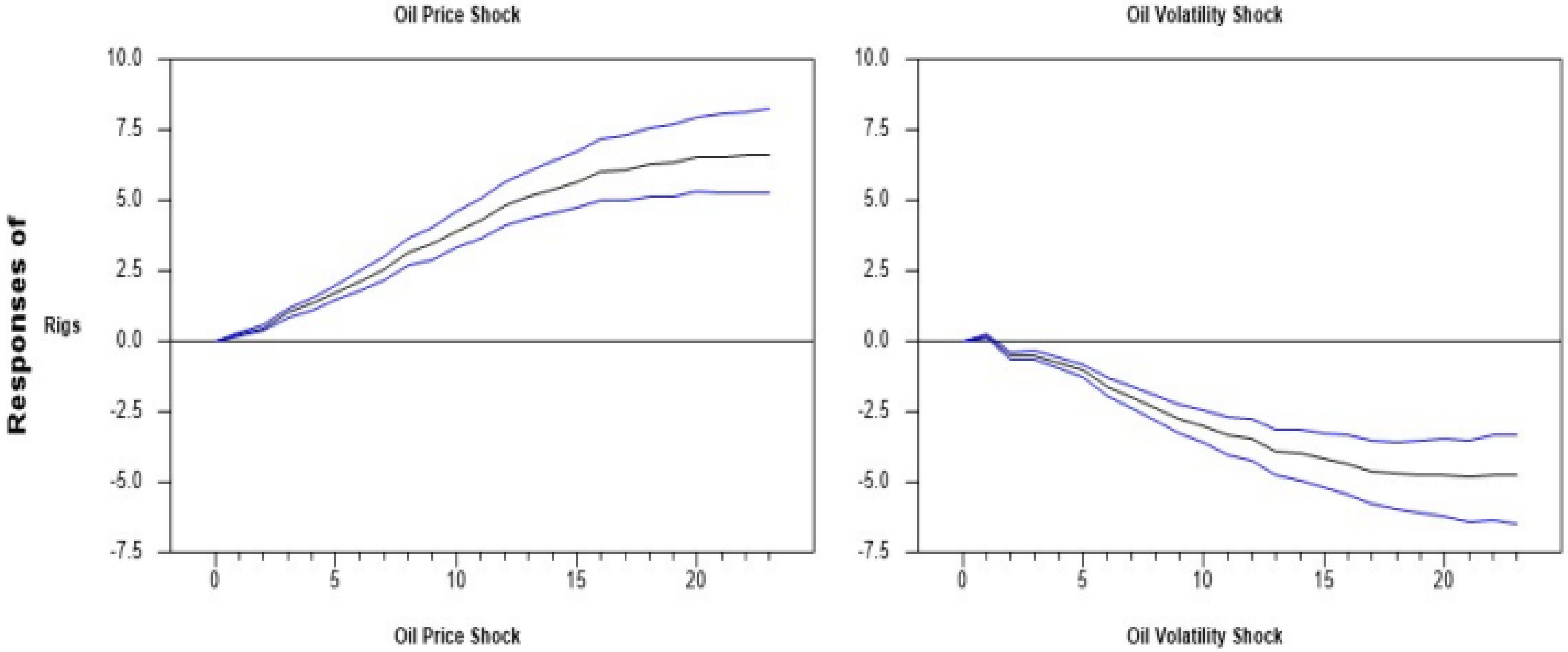
Empirical Model

- Vector Autoregession with and without MGARCH-in-Mean
  - Measure oil volatility by implied volatility from options on oil futures, GARCH, zero-cost straddle.
  - Flexible empirical model that summarizes relevant dynamics and captures uncertainty effect.
  - Goal is to identify an uncertainty shock, orthogonal to contemporaneous information set.
  - Oil volatility is variance of the forecast error, conditional on contemporaneous information set.
  - Simple identifying restrictions.

  - $\mathbf{B}\mathbf{y}_t = \mathbf{C} + \mathbf{\Gamma}_1\mathbf{y}_{t-1} + \mathbf{\Gamma}_2\mathbf{y}_{t-2} + \cdots + \mathbf{\Gamma}_p\mathbf{y}_{t-p} + \mathbf{\Lambda}\, diag(\boldsymbol{H_t}^{1/2}) + \boldsymbol{\varepsilon}_t,$
  -
  - $$diag(\boldsymbol{H_t}) = C + diag(\boldsymbol{\varepsilon_{t-1}}\boldsymbol{\varepsilon_{t-1}}') + diag(\boldsymbol{H_{t-1}})$$
  - $$y_t = \begin{bmatrix} Rigs_t \\ Oil_t \\ Vol_t \end{bmatrix}$$ for homoscedastic VAR
  - $$y_t = \begin{bmatrix} Rigs_t \\ Oil_t \\ \end{bmatrix}$$ for SVAR with MGARCH

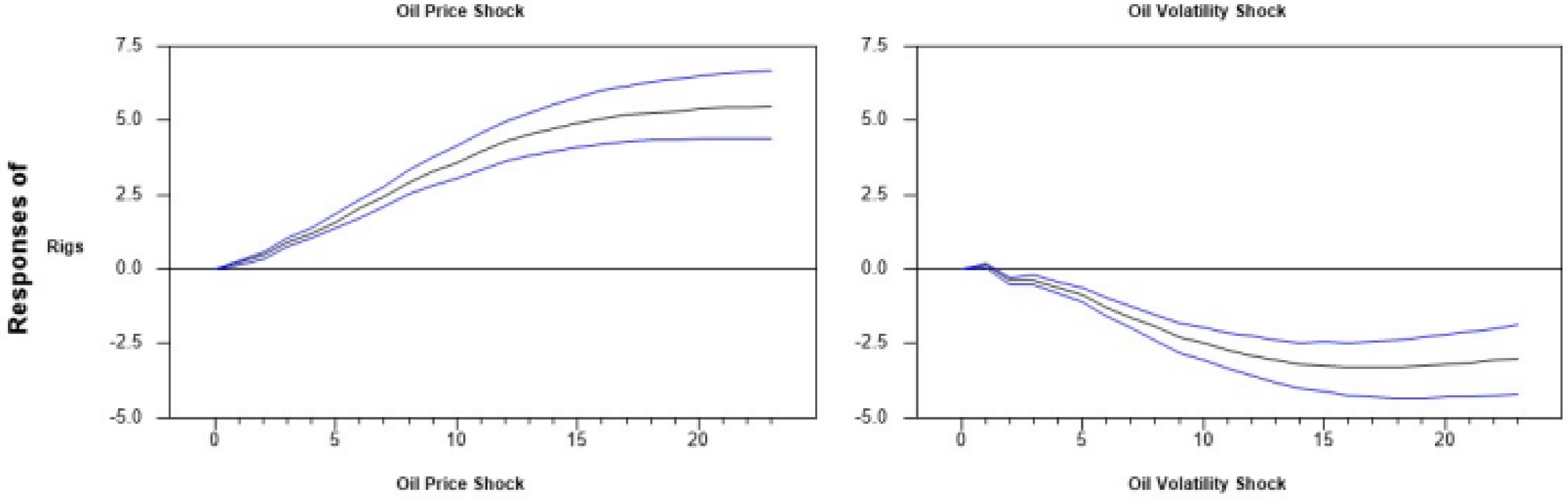
Figure 4. Response of Rigs to Oil Price and Volatility Shocks - Pre-COVID



Pointwise 68% Posterior Bands; Sample 01/06/2012-03/06/2020

Note: These impulse responses are the weekly cumulative percent increase in rigs in response to a shock to oil prices and implied oil volatility for the VAR given by equation (2) over the sample 01/06/2012-03/06/2020, orthogonalized with the triangular with ordering $y_t = \begin{bmatrix} Rigs_t \\ Oil_t \\ Vol_t \end{bmatrix}$.

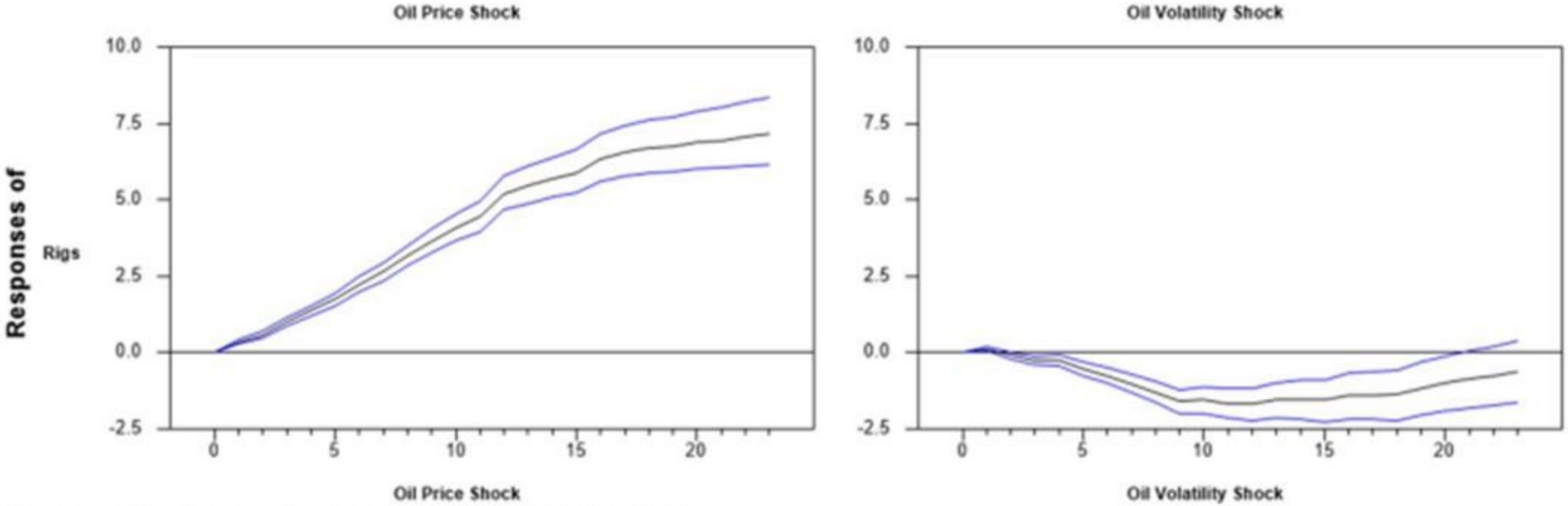
Figure 5. Response of Rigs to Oil Price and Volatility Shocks - Current



Pointwise 68% Posterior Bands; Sample 01/06/2012-04/08/2022

Note: These impulse responses are the weekly cumulative percent increase in rigs in response to a shock to oil prices and implied oil volatility for the VAR given by equation (2) over the sample 01/06/2012-04/08/2022, orthogonalized with the triangular with ordering $y_t = \begin{bmatrix} Rigs_t \\ Oil_t \\ Vol_t \end{bmatrix}$.

Figure 6. Response of Rigs to Oil Price and Volatility Shocks - 2007-Current



Pointwise 68% Posterior Bands; Sample 06/01/2007-04/08/2022

Note: These impulse responses are the weekly cumulative percent increase in rigs in response to a shock to oil prices and implied oil volatility for the VAR given by equation (2) over the sample 06/01/2007-04/08/2022, orthogonalized with the triangular with ordering $y_t = \begin{bmatrix} Rigs_t \\ Oil_t \\ Vol_t \end{bmatrix}$.

Table 5. Rigs, Oil Prices and Oil Volatility

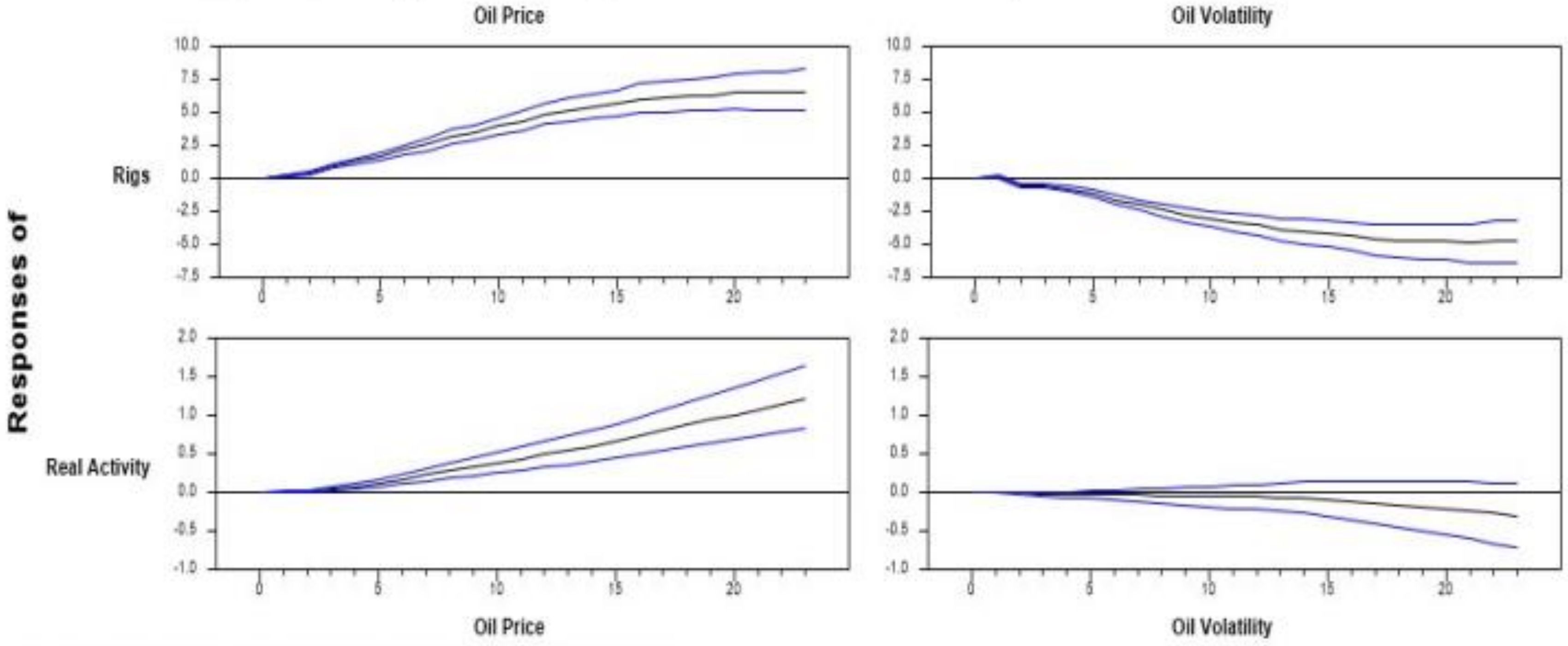
Sample / Parameter	β_{Vol}
2012:01:06 - 2020:03:06	–0.18** (2.22)
2012:01:06 - 2022:04:28	–0.011 (0.88)
2005:01:01 - 2020:03:06	–0.093* (1.66)
2000:01:07 - 2020:03:06	–0.117*** (2.61)
1995:01:06 - 2020:03:06	–0.182*** (2.84)

Estimates from MGARCH-VAR given by equations (3) and (4), where β_{Vol} is the coefficient relating weekly oil volatility to the weekly growth rate of drilling rigs

$$e_t \equiv \begin{bmatrix} e_t^{\Delta\, rigs} \\ e_t^{real\ global} \\ e_t^{oil\ price} \\ e_t^{oil\ vol} \end{bmatrix} = \begin{bmatrix} b_{1,1} & 0 & 0 & 0 \\ b_{2,1} & b_{2,2} & 0 & 0 \\ b_{3,1} & b_{3,2} & b_{3,3} & 0 \\ b_{4,1} & b_{4,2} & b_{4,3} & b_{4,4} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{domestic\ oil\ supply} \\ \varepsilon_t^{industria\ \ demand\ shoc} \\ \varepsilon_t^{oil\ specific\ demand\ shock} \\ \varepsilon_t^{oil\ volatility\ shock} \end{bmatrix} \quad (5).$$

The first equation postulates a vertical weekly short-run supply curve of domestic crude oil, in which the number of active rigs does not respond to global economic activity, oil prices or oil volatility at the weekly frequency. At the monthly frequency, this assumption may be restrictive, as discussed in Kilian and Murphy (2014), Baumeister and Hamilton (2019), Bjørnland, Nordvik, and Rohrer (2021). Since our data are weekly, this assumption may be less controversial.

Figure 7. Response of Rigs to Oil Price and Volatility Shocks - Kilian Model



Pointwise 68% Posterior Bands; Sample 01/06/2012-03/06/2020

Note: These impulse responses are the weekly cumulative percent increase in Rigs and Real Activity in response to a shock to oil prices and implied oil volatility for the VAR given by equation (5) over the sample 01/06/2012-03/06/2020, orthogonalized based on the model of Kilian (2009).

Conclusions

- We find that drilling is tightly linked to both the level of oil prices and oil price uncertainty.

- We describe institutional features which permit drilling activity to respond quickly to oil prices.

- We show that oil production responds relatively quickly to oil price shocks.
  - One std dev increase in oil price causes drilling rigs to increase by about 1% after just 3 weeks; and about 5% after 12 weeks; and we do not measure intensity
  - This matters for a large literature on the propagation of oil shocks.

- The number of onshore rotary rigs declines in response to rising uncertainty about oil prices
  - One std dev increase in uncertainty reduces drilling rigs by up to 4%, controlling for level of oil price.

Fully-assembled rig moving between pads