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Panel Analysis of Well Production History in the Barnett Shale

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for the study

"The Role of Shale Gas in the U.S. Energy Transition: Recoverable Resources, Production Rates, and Implications"

presentation by

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Purpose

- The primary purpose of the empirical analysis is to test the statistical validity of the proposed methodology (REI) for modeling well production.
- The REI method proposes production, denoted $q_{t,i}$, can be modeled as

$$q_{t,i} = \frac{k \cdot REI_i}{t_i^{0.5}}$$

- The above equation can be transformed into

$$\ln q_{t,i} = \ln\left(k \cdot REI_i\right) + \rho \ln t_i$$

- where the term $\ln\left(k \cdot REI_i\right)$ is well-specific. Moreover, we can test whether or not $\rho = -0.5$.

Estimation

- Estimation is done using longitudinal monthly production data for over 16,500 wells drilled in the Barnett shale covering 1990 through 2011.
- We include the well's production history, as well as a set of variables to indicate the geological characteristics of the shale at the well's location. We also include variable to indicate the size of the operator, the year of first production, whether or not the well has been refractured, and the average price of the 12 month strip of futures.
- We estimate the following equation

$$\ln q_{t,i} = u_i + \alpha \ln t_i + \delta \ln q_{t-1,i} + \beta \ln p_{NYMEX,t}$$
$$+ a_1 poros_i + a_2 top_i + a_3 TM_i + a_4 TOC_i + a_5 thick_i + a_6 \theta h_i + a_7 press_i + a_8 bg_i$$
$$+ b_1 oper_{sm,i} + b_2 oper_{med,i} + b_3 refrac_i + b_4 length_i + b_5 vintage_i$$

- where u_i is a well-specific term that can be modeled as either fixed or random. It turns out that u_i is treated as random, meaning the other included variables capture the systematic variation between wells.

Variable Definitions

- for well i
  - t_i denotes the time period since initial production
  - $p_{NYMEX,t}$ is the average of the 12 month strip of NYMEX futures prices,
  - $poros_i$ denotes the effective porosity of the reservoir,
  - top_i denotes the depth to the top of the shale,
  - TM_i denotes thermal maturity of the shale resource,
  - TOC_i denotes total organic carbon,
  - $thick_i$ denotes the shale thickness after accounting for the limestone intrusion,
  - Φh_i denotes effective porosity multiplied by thickness,
  - $press_i$ is the reservoir pressure,
  - $length_i$ is the length of the lateral in horizontal wells
  - bg_i denotes the gas formation volume factor,
  - $oper_{sm,i}$ and $oper_{med,i}$ are indicator variables denoting operator size,
  - $refrac_i$ is an indicator variable denoting a refracture has occurred, and
  - $vintage_i$ denotes the first year of production.

Estimation Results

Variable	Parm	Vertical	Horizontal
lnt	α	-0.1570***	-0.1798***
		(0.00137)	(0.00191)
lnq_{t-i}	δ	0.6862***	0.6407***
		(0.00128)	(0.00129)
$lnp_{NYMEX,t}$	β	0.1082***	0.0305***
		(0.00266)	(0.00469)
$poros$	a_1	13.4287***	7.6875***
		(0.9352)	(0.6723)
top	a_2	-7.1e-05***	-0.00018***
		(2.1e-05)	(1.4e-05)
TM	a_3	0.5715***	0.3225***
		(0.0254)	(0.0164)
TOC	a_4	0.0581***	0.0150***
		(0.0051)	(0.00411)
$thick$	a_5	0.0005***	0.00144***
		(0.0002)	(0.00012)
Φh	a_6	-0.00378	-0.00502**
		(0.00269)	(0.00219)

Variable	Parm	Vertical	Horizontal
$press$	a_7	-0.00018***	-0.00041***
		(3.9e-05)	(2.6e-05)
bg	a_8	-32.9624**	-115.093***
		(16.4667)	(14.8089)
$oper_{sm,i}$	b_1	-0.2182***	-0.0837***
		(0.0062)	(0.0064)
$oper_{med,i}$	b_2	-0.1447***	-0.0546***
		(0.0067)	(0.00444)
$refrac_i$	b_3	0.1532***	0.0426***
		(0.0066)	(0.0099)
$length_i$	b_4	9.6e-05***	8.6e-05***
		(2.0e-05)	(1.96e-06)
$vintage_i$	b_5	-0.0079***	0.00292**
		(0.0009)	(0.00133)
R^2		0.807	0.693
Observations		360,039	405,326
Sample Size		3,839	11,645

Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Implications

- The equation estimated represents a state-transition equation and, accordingly, the term is interpreted as a "short run" effect. Thus, the production profile of any well is path dependent, and by definition, depends on production in the previous period. Because of this, we should expect autocorrelation in the residuals if we impose the restriction $\delta = 0$. By specifying the model as such, we want to test the hypothesis that $\rho = -0.5$, where $\rho = \alpha/(1 - \delta)$.
- It turns out that we cannot reject the hypothesis that $\rho = -0.5$ in either vertical or horizontal wells. In fact, we have

  Horizontal: $\rho = -0.5014$

  Vertical: $\rho = -0.5000$
- So, the data supports using the *REI* measure as a valid description of well performance in the Barnett shale.
- Note that the decline profile so modeled is approximated by a hyperbolic decline model where "*b*" can be fit or numerically approximated.

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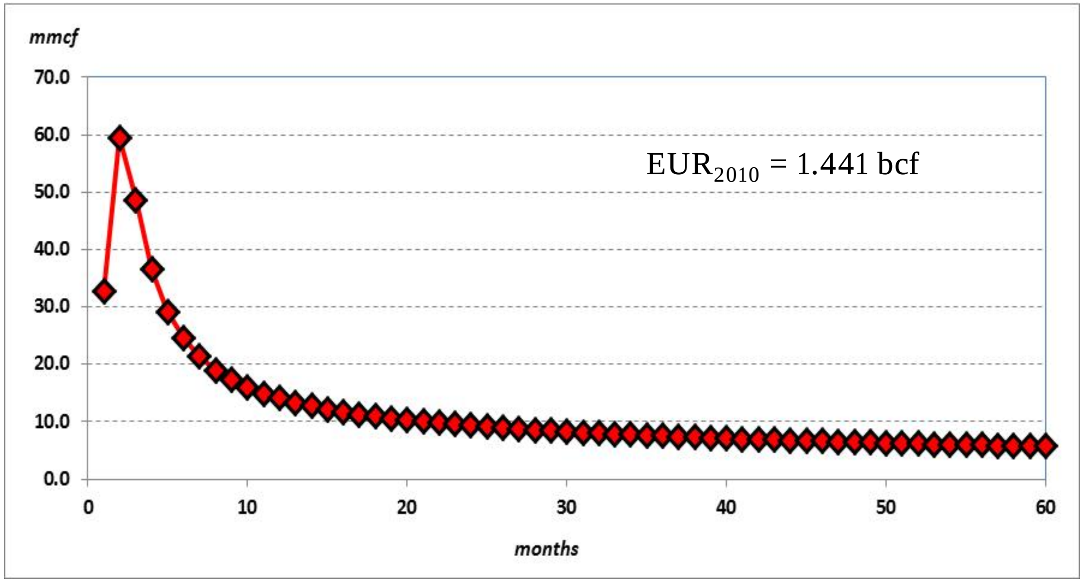
Simulation

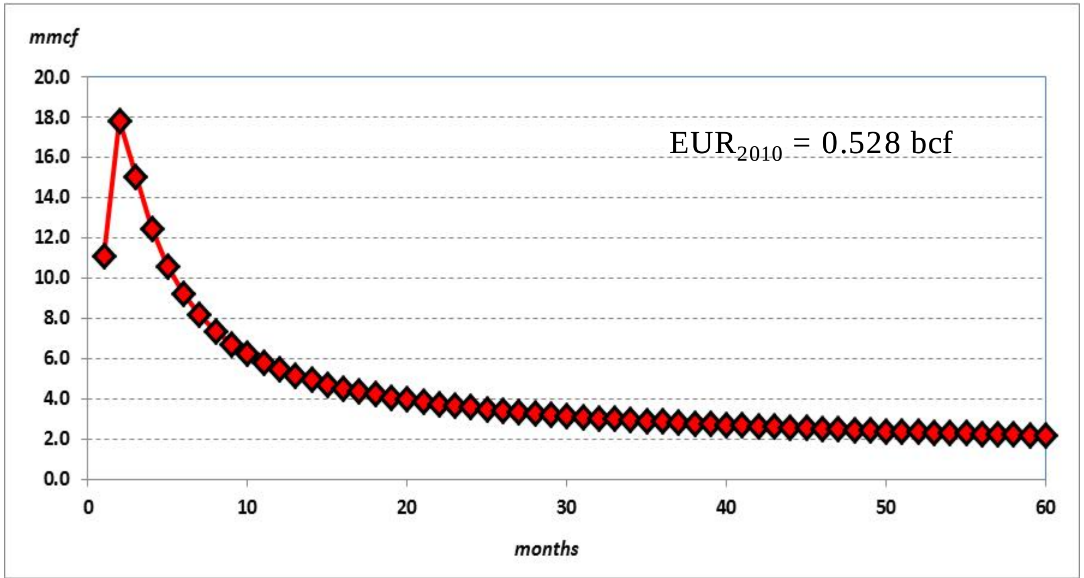
Sample Average Values

Variables	Vertical	Horizontal
top	-6365.55	-5921.97
TM	1.2835	1.3079
TOC	3.3685	2.9627
thick	291.394	285.121
perfzon	462.73	2293.47
phih	18.6864	17.0353
bg	0.0045	0.0049
press	3662.24	3376.41
poros	0.0641	0.0589
length	427.09	2876.64
price	4.00	4.00

Fitted Horizontal "Type" Well



Fitted Vertical "Type" Well



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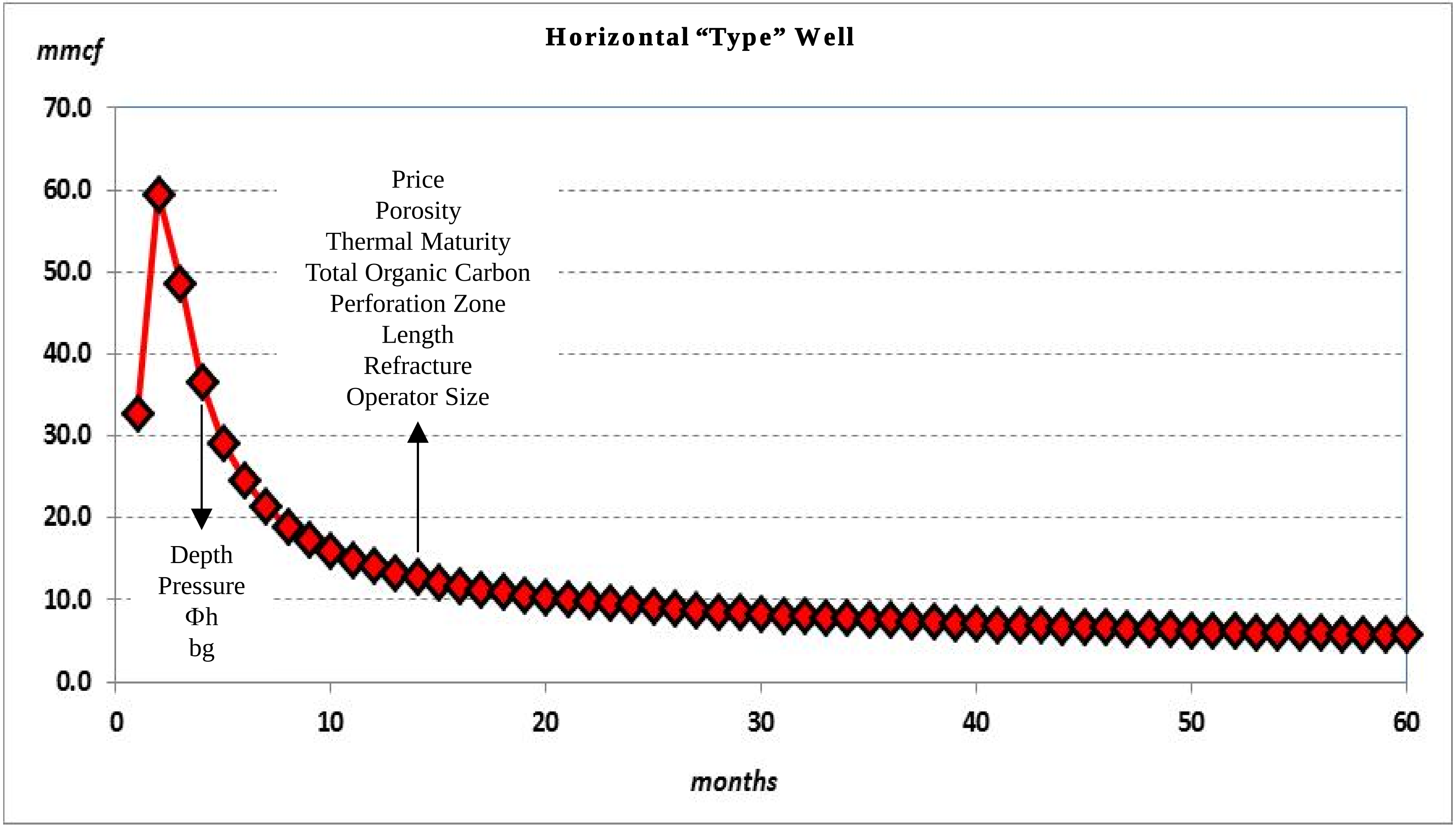
Marginal Effects of Geology and Other Parameters on Production



A Note on Refracs

- The value of the estimated parameter b_3 indicates that refractures improve well production, in particular because $b_3 > 0$, meaning production will on average be higher after a refracture. Moreover, the degree to which production increases will depend on when in the well's life the refracture occurs, and whether or not the refracture is in a vertical or horizontal well.
- If a refrac occurs in month 12, the effect on production is given as:

$$\ln \frac{q_{post-refrac}}{q_{pre-refrac}} = \frac{b_3}{1-\delta} + \rho \ln \frac{12}{11}$$

where the calculated values for horizontal and vertical wells are given as:

horizontal: 1.176 vertical: 1.703

- The baseline type curve is 0.502 MMcf/d in a horizontal well and 0.190 MMcf/d in a vertical well, meaning the production increase so estimated is not large…

Questions/Comments